Authenticity in Biology Education

Benefits and Challenges

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This volume consists of 31 original papers presented at the 8th Conference of European Researchers in Didactics of Biology (ERIDOB) held in July 2010 and hosted by the Research Centre CIEC of the Institute of Education, University of Minho, Portugal.
The theme of the conference was Authenticity in Biology Education: Benefits and Challenges. This theme emerged from discussions that took place at the ERIDOB 2008 meeting in Utrecht. During those discussions it became apparent that various ERIDOB members relate differently to the meaning of the term authenticity. Some expressed views that activities that are carried outside the classroom are authentic, while others thought that authentic activities should engage students in posing questions and designing their own paths to solve them. During the conference we re-explored the meaning of the concept of authenticity and discussed possible means to implement it in schools. The outcomes of those discussions can be appreciated in the ERIDOB 2010 special issue of the Journal of Biological Education that is devoted to the conference theme (Vol. 45 (3), September 2011) as well as in one of the sections of this volume (Section 1). The theme of authenticity blends wonderfully with many other topics that are of outmost interest to researchers in biology didactics, such as various teaching strategies for the teaching of biology (Section 2), teaching and learning biology in primary schools (Section 3), reasoning and argumentation: the use of controversial socio-scientific issues (Section 4), students' conceptions and conceptual change: focus on evolution (Section 5), and environmental education: field work (Section 6). Altogether, we hope that this volume represents the current state of the art of research in the field of biology education.

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Authenticity in Biology Education: Benefits and Challenges

Anat Yarden, Graça S. Carvalho

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Universidade do Minho
Instituto de Educação
Centro de Investigação em Estudos da Criança

Authenticity in Biology Education

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Edited by
Anat Yarden
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A selection of papers presented at the VIIIth Conference of European Researchers in Didactics of Biology (ERIDOB), Braga, Portugal

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Contents

Preface

This volume consists of 31 original papers presented at the 8th Conference of European Researchers in Didactics of Biology (ERIDOB) held in July 2010 and hosted by the Research Centre CIEC of the Institute of Education, University of Minho, Portugal.

The theme of the conference was *Authenticity in Biology Education: Benefits and Challenges*. This theme emerged from discussions that took place at the ERIDOB 2008 meeting in Utrecht. During those discussions it became apparent that various ERIDOB members relate differently to the meaning of the term authenticity. Some expressed views that activities that are carried outside the classroom are authentic, while others thought that authentic activities should engage students in posing questions and designing their own paths to solve them. During the conference we re-explored the meaning of the concept of authenticity and discussed possible means to implement it in schools. The outcomes of those discussions can be appreciated in the ERIDOB 2010 special issue of the Journal of Biological Education that is devoted to the conference theme (Vol. 45 (3), September 2011) as well as in one of the sections of this volume (Section 1). The theme of authenticity blends wonderfully with many other topics that are of outmost interest to researchers in biology didactics, such as various teaching strategies for the teaching of biology (Section 2), teaching and learning biology in primary schools (Section 3), reasoning and argumentation: the use of controversial socio-scientific issues (Section 4), students' conceptions and conceptual change: focus on evolution (Section 5), and environmental education: field work (Section 6). Altogether, we hope that this volume represents the current state of the art of research in the field of biology education.

Approximately 55 papers were submitted for consideration of publication in this volume, from amongst approximately 200 presentations at the ERIDOB 2010 conference. The ERIDOB Academic Committee, together with other members of the ERIDOB community, peer-reviewed all the papers and helped us put together the selected articles that appear in this volume. We are thankful to all the reviewers who invested significant time and effort in the review process. Our thanks go also to Camille Vainstein for improving the English and for copy-editing the papers, and to Antonio Carlos Jesus for his excellent work in type-setting this volume.

Anat Yarden Graça S. Carvalho

Section 1 Teaching biology using authentic learning environments

1 RESEARCH-BASED DESIGN OF A TEACHING SEQUENCE ON MARINE RESOURCE MANAGEMENT: HOW TO MANAGE CLASSROOM RESOURCES?

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Abstract

This paper discusses the design of a teaching sequence on marine resource management, intended to engage students in argumentation. The objectives of the paper are to analyse 1) the research-based process of constructing a teaching sequence, and 2) how it was enacted in the classroom. The sequence is organized around an authentic problem: how to manage scarce fish resources in a bay in order to feed more people.

The design was informed, on the one hand, by the didactical transposition approach, and on the other by preliminary empirical data generated by research. Taking both into account, a sequence for the 10th grade was designed, involving students in constructing concept maps, modelling and writing a report about how to manage fish resources to feed a population. In the second step of the didactical transposition, the teacher adapted the sequence to the available number of sessions and made other changes. We analysed the process of transformation of the reference knowledge, first into the designed curriculum and then into taught knowledge. The findings reveal changes introduced by the teacher towards devoting less time to students' active participation and more to explanations. Educational implications are discussed.

Keywords: argumentation; use of evidence; ecology; didactical transposition; authentic problem

1. Research-based design of a teaching sequence: rationale and objectives of the study

The objectives of this paper are: 1) to analyse the research-based design of a teaching sequence on marine resource management that seeks to engage students in the scientific practices of argumentation and modelling, and 2) to examine how the teaching sequence was enacted in the classroom, particularly in terms of communicative approach. The design process was informed by the didactical transposition approach and by empirical research-generated data.

This work is part of a research project exploring students' use of evidence and scientific models in the context of authentic problems. The paper is framed by the notion of didactical transposition and by argumentation about socio-scientific issues (SSI).

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1.1 Didactical transposition

The process of designing a teaching sequence involves a transformation, termed *didactical transposition* (Chevallard, 1991), from *reference knowledge*, or knowledge of the scientific community, to school knowledge. Although, according to Chevallard, knowledge can only stay alive if it is used, its meaning is different in each group. For instance, the meaning of energy is quite different in a physics research group and in a secondary school biology classroom. Tiberghien, Vince, and Gaidioz (2009) characterize this transposition process as a migration of knowledge from the community of reference to live knowledge in the classroom or *taught knowledge*. They distinguish two steps in the process: 1) from the reference knowledge to the knowledge to be taught, and 2) from the knowledge to be taught to the taught knowledge.

The knowledge to be taught consists, for instance, of official curricula, textbooks or other resources, usually written for people who are familiar with these contents. In contrast, the taught knowledge is related to the context in a particular class. Figure 1, adapted from Puig and Jiménez-Aleixandre (2011) summarizes different elements, both theoretical and empirical, shaping the design of the teaching sequence.

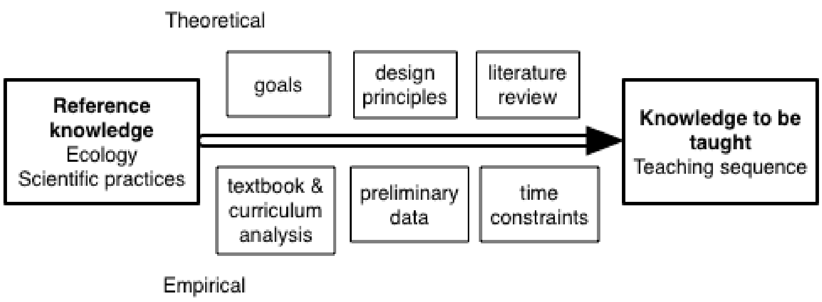

Figure 1
First step in the didactical transposition: from reference knowledge to knowledge to be taught
(adapted from Puig & Jiménez-Aleixandre, 2011)

These elements are analysed in Section 3, with the aim of rendering the decisions made during the design process explicit. Next we turn to a review of the reference knowledge.

1.2 Argumentation about socio-scientific issues and ecology learning

Authentic tasks and SSI, or problems for which science is involved in a social debate, share features such as having social significance or being relevant to the students' lives (Sadler, 2009). They provide an appropriate environment for engaging students in scientific practices, such as argumentation and modelling (Berland & Reiser, 2009), because they involve ill-structured problems, with open questions, where students have to exchange arguments in order to obtain solutions. Note that these problems involve not only social or ethical issues, but also scientific concepts and skills, in our case the model of energy flow and the trophic pyramid.

To deal with this sort of problem, students need, first, to be able to evaluate claims in light of the evidence (Jiménez-Aleixandre, 2008). Constructing good explanations implies recognising what is evidence, selecting evidence that is relevant to the claim and relating it to the model. But students often have difficulties in, for instance, identifying the meaning of a piece of evidence, i.e. whether it supports or rebuts a claim, citing enough evidence or explaining how the evidence supports the claim (Sandoval & Millwood, 2005).

Second, they need to be able to use the conceptual knowledge to identify the issue in question. In the teaching sequence, this means understanding complex ecological models such as energy flow and trophic pyramids, which require a comprehension of the relationships among concepts. From the literature, we know that students experience difficulties in using these models in terms of recognizing the role of energy in the ecosystem (Carlsson, 2002), or connecting the biological processes with the organisms. For instance, they do not appreciate the role of photosynthesis in transforming the sun's energy into chemical energy (Leach et al., 1996); they also construct trophic chains based on predator-prey relationships, rather than on energy transfer (Gallegos, Jerezano, & Flores, 1994). In this sequence, they need to understand that eating fish or any organisms from higher trophic levels implies less ecological efficiency than eating fish from lower levels.

2. Methodology

2.1 Methods

The study was framed in the developmental research approach (Brown, 1992; Linjse, 1995) and designed as a four-year cycle in which theory and empirical data interact.

In year 1, a review of the literature was undertaken, and data were collected on university biology students’ competence in using evidence and models in the context of version 1 of one task. The examination of university students' performance in the application of ecology concepts to resource management provided valuable indications of the students' difficulties and how to address them from secondary school onwards.

In year 2, these data were used to design a small-scale intervention, and the use of energy flow by 12th-grade students was analysed in a representative sample. This provided a perspective on students' knowledge about energy flow and its implications.

In year 3, the data from years 1 and 2 were used to further develop version 1 of the sequence, and to test it in three classrooms.

In year 4, data from this testing were used to refine the sequence and a second cycle of classroom testing was run.

This paper focuses on the design process in year 3.

2.2 School context and data collection

In year 3, participants were three classes of 10th-grade students (N=52), 15 to 17 years of age, in a school in Galicia (Spain) and their teacher, who holds degrees in biology and primary education, and has 10 years of teaching experience. The ecology sequence consisted of five 50-minute sessions in each class. Data collection included video and audio recordings of all sessions and the researcher’s (first author) field notes.

2.3 Analysis

For research question 1, analysis of the first step of the didactical transposition focused on the contribution of each theoretical and empirical element to the resulting teaching sequence.

For research question 2, analysis of the second step of the didactical transposition focused on the teacher's communicative approach and how it influenced the taught knowledge. The communicative approach was analysed by means of Mortimer and Scott's (2003) categorisation, which distinguishes four classes of communicative approaches resulting from combining two dimensions: interactive/non-interactive with dialogic/authoritative.

3. Which fishing option is better? From reference knowledge to knowledge to be taught

In this section, we discuss research question 1–the process of designing the sequence–through the didactical transposition approach, which helps render the decisions made during the process explicit. This process constitutes the first step of the didactical transposition: the transformation of reference knowledge into knowledge to be taught. As summarized in Figure 1, we distinguish two types of elements influencing this transformation: theoretical and empirical.

3.1 Reference knowledge

The reference knowledge is drawn from 1) concepts and models of ecology, in particular the model of energy flow, and 2) scientific practices, including modelling, argumentation and the use of evidence. The sequence focuses on an issue that has social relevance–marine resource management. Fishing, aquaculture, and related activities such as canning are of economic importance in Galicia, which contributes 86% of Spain's cannery production, although overexploitation is threatening the viability of this sector. The issue is socially relevant as fish farms are the subject of heated controversy.

3.2 Goals

The goals for the teaching sequence are related, on the one hand, to the policy recommendations issued by the educational authorities, and on the other to the two sources in the reference knowledge. A learning goal set in the Biology curriculum for the 10^{th} grade (MEC, 2007) is that "*the students will be able to relate the energy losses in each (trophic) level with a sustainable management of world food resources*". To draw these relationships, we believe that the students need to understand trophic relationships, energy flows and cycles of matter.

Taking this into account, three goals were set for the sequence, two related to ecology and the curriculum, and the third to the use of evidence: 1) to be able to apply the model of energy flow to real-life contexts; 2) to be able to relate the loss of energy along the trophic chain to food resource management, and 3) to develop competence in using evidence to support an argument.

3.3 Design principles

The goals and design principles are closely related. The decisions made in the design are informed by Jiménez-Aleixandre's (2008) proposal of design principles for argumentation-learning environments. We will focus on how three of them, the curriculum approach, the role of students and the role of teachers, shape the task design.

– *A curriculum approach* based on cognitive apprenticeship leads to organizing learning tasks around authentic activities, set in everyday-life contexts. For instance, task 5 'Fishing resource management', summarized below, requires students to select data supporting their decision, and to build justifications based on the energy flow model.

– *A role for students* as active knowledge producers means engaging them in the scientific practices of using evidence and modelling. For instance, in task 4, the students, working in small groups, take on the role of farmers seeking to gain higher yield from a piece of land, and support their decisions with evidence.

– *A role for teachers* providing the scaffolding for inquiry, is assumed in the design. The transformations made by the teacher in the sequence lead to the second step in the didactical transposition: the taught knowledge.

3.4 Literature review

The literature on ecology learning was reviewed to identify and consider students' learning problems, such as: 1) failing to understand that energy is contained in food; 2) trophic relationships conceived only as predator-prey relationships, rather than as a transfer of energy among organisms, or 3) failing to connect energy flow with biological processes such as photosynthesis or respiration.

3.5 Analysis of textbooks and the curriculum

The official curriculum was examined, as discussed in the learning goals. Then the chapter on ecosystem dynamics in four textbooks–the one used by the students and another three among the most widely used in Spain–was analysed. As the curriculum requires students to apply the energy lost in each level to resource management, we checked the tasks set for students on this issue. The most salient finding was that two books included one task related to this issue, while the other two did not. The implication for design was a need for tasks engaging students in application of the energy flow model.

3.6 Results of preliminary studies

Empirical data were collected in two preliminary studies carried out with biology undergraduates, with the aim of examining how these students, who have a high level of biology, apply the energy flow model to real-life problems. The sample for the third study was from the 12th grade.

Study 1: 93 university biology students solved a problem about the sustainability of aquaculture of carnivorous fish. Only 16% of them used the notion of energy flow; 66% justified their option, to feed on herbivorous fish although only 5 % were able to coordinate empirical and theoretical evidence (Bravo-Torija & Jiménez-Aleixandre, 2010).

Study 2: an intervention with a learning task about ecological efficiency was used to compare the results with those from study 1. The students improved in the use of both the model of energy flow and evidence (Bravo-Torija & Jiménez-Aleixandre, 2009a).

Study 3: the focus was on use of the notion of energy flow, and how this notion is articulated with evidence at different epistemic levels. A representative sample of 254 responses from 12th-grade students was drawn from the university entrance examinations. Only 29% used the most complex model of energy, and with respect to evidence, only 33% used it at three or more epistemic levels (Bravo-Torija & Jiménez-Aleixandre, 2009b).

To sum up, these results indicated the difficulties that students (even those with higher biology knowledge) have in relating the model of energy flow to its consequences in ecosystems. In other words, they experienced problems in transferring theoretical knowledge to different contexts and in connecting it to pieces of evidence. To overcome these problems, we decided that the learning tasks in the sequence needed to 1) explicitly address energy transfer among trophic levels; 2) create situations in which the students would be required to apply the model to ecosystem management, and 3) engage students in selecting and using evidence to build explanations.

3.7 Time constraints

Another empirical element influencing the transformation of reference knowledge is the time constraint limiting the developed sequence. Although the sequence was initially designed for six sessions over two weeks, negotiations with the teacher led to a reduced version with five sessions.

3.8 The knowledge to be taught: the teaching sequence about marine resources

In terms of structure of the sequence, taking into account the theoretical and empirical elements, we decided to use session 1 to explore students' previous knowledge, sessions 2 to 4 (originally 2 to 5, reduced to three sessions) for learning tasks in small groups, and session 5 (initially 6) for a written evaluation. Table 1 summarizes the tasks and concepts in the designed sequence.

Table 1

Concepts, tasks and foci in each session of the designed sequence

Session	Ecology concepts	Type of task/activity	Focus
1	Ecosystem, energy, trophic chains	Students construct a concept map about ecology	Exploration of students' ideas
2	Energy flow, trophic levels	What flows in a trophic chain? Students model the energy flow	Decrease of energy in each trophic level
3	Biomass, energy, trophic pyramids, trophic levels	Students construct two models of trophic pyramids	Decrease in energy and biomass along trophic levels
4	Trophic chain, energy flow, trophic pyramids	Students are asked to select a strategy to manage a marine ecosystem, and to use evidence to support their choice	Authentic problem: food resource management
5	Energy flow, trophic relationships, trophic pyramids, ecological efficiency	Students are asked: to identify a claim and support it with evidence; to apply the model of energy flow to a problem	Evaluation: problem about the sustainability of aquaculture

Task 1. *Exploration of students' ideas*: Students construct a concept map with ecology terms studied in previous years. The objectives are to examine: 1) which relationships they establish among trophic levels; 2) their ability to connect elements in the trophic chain to biological processes.

Task 2. *What flows in a trophic chain?* Small groups of students model energy flow through analogical modeling using water and five plastic bottles with holes in the bottom, representing energy loss. Then the groups are asked to 1) discuss what happens in the model and why; 2) connect the analogy and the target, and draw conclusions for the ecosystems.

Task 3. *Building a trophic pyramid*: Students construct two models of trophic pyramids (with pasta pieces of different sizes from data tables about two ecosystems, terrestrial and marine. To do so, they need to relate each organism with its trophic level and with the data on biomass, production and numbers. They are then asked to explain why the resulting figures have the shape of a pyramid and not another geometrical shape.

Note that the design included a task (omitted in the taught sequence) about resource management in a terrestrial ecosystem.

Task 4. *How should scarce fish resources be managed in order to feed more people?* Students play the role of a non-governmental organization (NGO) with the responsibility of managing a bay to feed a population for as long as possible. They need to choose among fishing in different trophic levels. The available data include the diet of each fish, and production and biomass of the trophic chain. The objectives are to 1) relate energy transfer among trophic levels with resource management; 2) select pieces of evidence and connect them with the energy flow model to justify their choice.

Task 5. *Evaluation*: A task was designed based on the PISA scheme (OECD, 2006). It was introduced by a text questioning the sustainability of aquaculture, and asked students to: 1) identify the claim; 2) support it with evidence from the text; 3) apply the model of energy flow to a problem about ecological efficiency. The objectives were to assess students' ability to identify and draw conclusions, select supporting evidence and apply the model of energy flow to harnessing food resources.

Tasks 1 and 5 were individual, and in tasks 2, 3 and 4, students worked in small groups.

4. Shifting the responsibility for learning: from knowledge to be taught to taught knowledge

In this section, we discuss research question 2, the process of transformation of knowledge to be taught into taught knowledge, and how the teacher's communicative approach influences it. In fact, the main element influencing this transformation is the teaching approach, as it is the teacher who manages how knowledge is enacted in the classroom. The results of the analysis show that the approach is predominantly interactive/authoritative. It is interactive because there is a great deal of participation from the students. For instance in class 1, during sessions 1 and 2 devoted mostly to the teacher's explanations, out of 689 utterances, 57% (390) were uttered by students and 43% (299) by the teacher.

It is authoritative because, in most episodes, the focus was on school science rather than students' views. Although the students talked on many occasions, they did so mostly in answer to the teacher's questions. When they initiated an episode, the teacher usually reacted but quickly returned to her explanation without changing her discourse. For instance, in the whole sequence in class 1, out of the 39 episodes, only 4 were initiated by the students and they took only 6 minutes in all.

Another dimension in the transformation are the changes introduced by the teacher in the design of the tasks, in particular for tasks 1, 2 and 5.

– Task 1, Exploration of students' ideas. *From eliciting students' ideas to teacher lecture*: the initial task required students to construct a concept map, retrieving previous knowledge. The teacher decided to use session 1 to introduce the most relevant ecology concepts. In that way, what was designed with the purpose of eliciting and mobilizing students' ideas, was taught as an explanation, and the teacher decided which concepts to cover and how much time to devote to each of them.

–Task 2, What flows in a trophic chain? *From students modelling in small groups to teacher lecture plus illustration experiment*: in the original design, students were asked to work in small groups, modelling energy flow with the analogical water bottle model. The teacher deemed it necessary to further explain the concepts of energy flow and matter cycles, which she thought would facilitate students' understanding. This took about 40 minutes, so only 10 minutes were left for the analogy, which the teacher carried out in front of the class, without enough time to unravel its meaning.

–Task 5, Evaluation. *From a common evaluation task to split items*: we had not considered that in some cases, teachers would place great emphasis on using different evaluation items with different classes (in order to avoid their memorizing the answers). So the teacher created three versions of the task, splitting the original one in two and developing a new one, using the activity designed for the original task 4, which had been omitted. We will discuss the significance of this change in Section 5.

In summary, we interpret the transformations of the knowledge to be taught, particularly in sessions 1 and 2, as a substantial shift in the responsibility for learning from the students to the teacher. In the designed tasks, students were assumed to take an active role, retrieving their previous ideas, modelling, and discussing the meaning of the tasks with their peers. However, in the taught sequence, the teacher devoted the full session 1, and most of the time in session 2 to explanations.

Moreover in session 2, the analogical model was demonstrated by the teacher and the discussion about its meaning was omitted. Only in session 4 were students made to take responsibility for the task, applying their knowledge to a new problem. Although the communicative approach may be described as interactive, it was authoritative, with a focus on school science. In our opinion, these decisions, shaping the taught knowledge, reveal assumptions about teaching and learning that are addressed in Section 5.

5. Discussion and educational implications

This paper analyses the research-based design of a teaching sequence on marine resource management. Traditionally, fishing, canning and related activities hold considerable economic weight in Galicia. Thus the overexploitation of marine resources and the depletion of fish stocks are not only scientific problems. They also have social relevance, both because fishermen are reluctant to accept their responsibility in exploitative practices, and because of the controversies surrounding the plans for (carnivorous) fish farms. As with other SSI, these are complex problems, with citizens being subjected to contradictory messages from interested parties, making it difficult to decide on the 'best' solution.

The goal of the teaching sequence is for students to be able to apply their knowledge to real-life problems, such as managing fishing resources in a given area. They need to take responsibility about what to fish and to justify their choice, supporting it with evidence backed by the relevant scientific models, such as energy flow.

The analysis is framed in the didactical transposition (Chevallard, 1991), charting the transformation from reference knowledge–including ecology and scientific practices–to taught knowledge. The first step in this transformation, resulting in the knowledge to be taught, is influenced by both theoretical and empirical elements: goals, design principles and a literature review on the one hand, and textbook analyses, data from preliminary studies and time constraints on the other.

We discussed how these elements were integrated in the teaching sequence, with a focus on involving students in the scientific practices of modelling and using evidence. Research has suggested that students do not develop these skills from practicing them only once, so it was considered that the minimum number of sessions should be six, and that students needed to devote four of them to building models, selecting evidence and (simulating) decision-making, with a justification of their choices.

Note that the final state of any designed sequence is its enactment in the classroom, with changes constituting the second step of didactical transposition, from knowledge to be taught into taught knowledge. Analysis of the sequence's development showed how the teacher transformed it, in particular how she shifted a great deal of the responsibility for learning onto herself. In terms of communicative approach, this means that the students listened to explanations for a substantial portion of the time, instead of building models or discussing their meaning, as originally designed. These changes were the same in the three classrooms.

We believe that these decisions and changes, shaping the taught knowledge, reveal assumptions about teaching and learning, which are probably shared by many science teachers in Spain. To use most of the time for lectures assumes that most or all of the students learn better from listening to a well-structured explanation than from being engaged in learning tasks, where they will take tentative paths, and eventually make mistakes. Teachers are concerned about time, as the curriculum in Spain is long and extensive, and they seem to think that this scarce resource is better managed through teacher explanations. These decisions may also be related to the teacher's pedagogical content knowledge, in particular to a lack of confidence as to how to support students in the tasks focusing on modelling and use of evidence.

Another interesting change relates to the splitting of evaluation tasks. Our interpretation is that the concern with different items for the three classes is framed by a notion of assessment related to memorization rather than to application of knowledge. While the use of the same definition items in consecutive evaluation sessions in different classes may lead to students in the last session (class) looking up the answer in a textbook, we contend that the proposed problem-solving item requires knowledge transfer, and that knowing something about its wording would not substantially change the outcome in the different classes.

It should be remembered that the overall goal of secondary education in Spain, according to the new curriculum, is the development of competencies. In other words, the students should be able to put what they have learned into practice in different contexts. To achieve this, we suggest that they need to have opportunities to practice the application of knowledge, to use it in different situations, rather that in only one context. Engaging students in real-life problems, in SSI, is time consuming, but it is necessary for the development of these competencies.

Another type of implication is the usefulness of the didactical transposition as an analytical tool for examining knowledge transformation in classroom contexts. It helps to render the decisions made during the process explicit. We suggest that it can also be used as an evaluation instrument, to identify strengths and weaknesses in the sequence, thus enabling changes for the next version, and the subsequent classroom study. We are currently involved in this process.

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2 NEW OPPORTUNITIES FOR AUTHENTICITY IN A WORLD OF CHANGING BIOLOGY

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Abstract

Biology now produces massive data, genomic and other types. New ways of building knowledge are thus increasingly reliant on data processing. Biological data and analytical tools, widely accessible via the internet, offer new authentic opportunities to explore, test and validate hypotheses in numerous fields of biology and allow students to engage in the same cognitive processes associated with hands-on biology. New authentic text resources are also freely available, enabling students to practice the authentic scientific process of knowledge validation. Indeed science is a process of building knowledge by confronting ideas, and discussing their certainty, the links to the data that they are built on and their source. Framing authenticity in terms of resources and student activities, we have spent 7 years refining designs for building scientific knowledge within wiki-supported learning environments that confront students with an overabundance of resources of differing authenticity.

We will discuss the influence of resource authenticity, and of the students being progressively given responsibility for validation, on the development of scientific knowledge and learning strategies. Results include an increase in the epistemic complexity of student-produced texts, a shift towards using increasingly authentic resources, and autonomy in validating information. Some authenticity-linked design features, and generalisability, will be discussed.

Keywords: knowledge building; didactics; design; inquiry; authenticity

1. Introduction

The importance of authenticity in education has long been recognized (Dewey, 1911; Freinet, 1960), but is intrinsically limited by didactic transposition (Chevallard, 1991). Our goal was to develop and analyse designs that would involve students in the authentic scientific process of validating their own knowledge.

1.1 Authentic science?

In its most general sense, "authenticity" represents the search for some similarity between educational processes and those practiced by "real people". In general, "doing biology" implicitly refers to scientists and their activities, questions and methods: the "social practice of reference" (Martinand, 1989). Here we discuss authenticity in terms of the resources or tools provided and authenticity of the learner's processes, activities and productions.

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We identify three authenticity levels, modified from The Cognition and Technology Group at Vanderbilt (1990): (1) true research data, considered more authentic than carefully selected, educationally polished data; (2) tools and methods: involving students in similar tasks, with the same tools and methods used by professionals; (3) "doing real research": creating new–or at least locally new–scientific knowledge. “Doing science” in education should help students build the scientific properties of their own knowledge, rather than simply learning facts. The way in which knowledge is validated is one key attribute that will be discussed in this article.

Here we define science as a method for validating knowledge (Sandoval & Morrison, 2000) based on confrontation with data and alternative explanations. Indeed the process of science relies on argumentation and debate to validate knowledge, although these are virtually absent from science education (Osborne, 2010).

The classification of knowledge as scientific does not depend on its subject (about animals, ecosystems or sequences) so much as on its being grounded in sources, in the data on which it is based, and in its justification leading to a given certainty. These are metacognitive characteristics (Bromme, Pieschl, & Stahl, 2008). For example, the “fact” that humans and chimpanzees differ by 1.23% can be called scientific knowledge when it is based on i) the source of this figure (The Chimpanzee Sequencing and Analysis Consortium, 2005), ii) the justification by methods used (differences in terms of nucleotide substitutions), iii) the links to the data (full genome accessible in MapViewer), iv) the comparison with other methods for establishing similarities (DNA hybridization, gene homology, SNP identity, sequence identity, etc.). A person who “knows scientifically” can infer from this structure, guarantee the certainty of this information, and put it in perspective. In contrast, this difference of 1.23% is not scientific when given as “true” by reference to an authority (*Nature*, a textbook or the teacher). When a student states “1.23%”, one cannot distinguish scientific from naive knowledge.

One major difficulty of getting students to “know scientifically” is the tension between developing a scientific way of validating their knowledge and striving for an acceptable understanding of content (Sandoval & Daniszewski, 2004). The issue revolves crucially around validation: if the authority for validation lies with the teacher, students will have little incentive to engage in that demanding scientific process. Striving to place the authority for validation in the most authentic experimental data and literature possible for the students and the teacher in a guiding role is a key issue of this research. Hence the focus is on available resources and validation processes.

1.2 Authentic literature?

Many authors have explored the authentic potential of non-school literature–adapted primary literature (APL) (Falk, Brill, & Yarden, 2008; Yarden et al., 2009) or modified anchored instruction (MAI) (Mueller, Kuhn, Mueller, & Vogt, 2010)–and have shown important effects on motivation and learning outcomes. Even the use of slightly more authentic resources can have educational effects.

We graded the authenticity of resources from school books, popular magazines, and primary literature. Sequences accessible through web portals such as UniProt or Mapviewer, and online books from the NIH database bookshelf are considered more authentic than the same data illustrated in school textbooks.

1.3 Can changing biology's authentic tools engage students in scientific validation of their knowledge?

Biology is deeply changing under the influence of information technology (IT) (NRC, 2003; Pevzner & Shamir, 2009): massive amounts of new data (genomic, botanical, biogeographical, etc.) are available, new tools are being offered (sequence searching and comparisons, phylogenetic tools, etc.), and most scientists spend a large part of their time building biological knowledge by practicing "*in silico biology*".

In fact, data processing alone often qualifies as research in high-impact journals. For example, comparing the human and chimpanzee genomes for evidence of recent change (Pollard et al., 2006) is a legitimate contribution to biological knowledge, even though results were obtained by IT alone, based on freely available genomic data produced by others.

While the whole organism, the cell or the molecule are generally considered the ultimate, authentic reference for biological study, we argue here that biological data such as sequences are often the most authentic data available in schools. This new way of creating knowledge using data from public databases, represents a considerable change in the reference activity of "doing biology". It has been widely adopted by researchers (Strasser, 2006), but appears to have been mostly ignored by education (Lombard, 2007).

Since scientific research is the reference for authenticity in biology education, the fact that it is changing implies that we need to be discussing if and how science teaching should change as well. Elsewhere (Lombard & Blatter, 2009), we discussed a comprehensive teacher-training program in Geneva, for evolution teaching and inquiry in evolution, based on sequence analysis. However, the possibilities for authentic science education are not restricted to the use of scientific data. They include all forms of scientific knowledge contained in scientific publications. Biologists not only analyze data, they also critically discuss the content of scientific publications. Indeed, confrontation of ideas and review are essential parts of the scientific process of validation. Thanks to the development of bibliographic search engines (PubMed), online journals or academic books (NIH_Bookshelf), and open-access policies, students and teachers can now engage in the classroom in the same kind of critical discussions performed by researchers in the laboratory. New learning designs can use these to foster learning, exploring, confronting ideas, testing and validating hypotheses and engage students in some of the cognitive processes of scientists.

Educational technology has added a new twist to the debate by offering opportunities to create environments supporting educational activities. Many contend that these activities can be authentic in terms of the mental processes, even if the environment is virtual (Jonassen, 2003).

Some authors insist that the goal of education should be the production of knowledge, not only its reproduction (Scardamalia & Bereiter, 2006). Conceptual artefacts (Bereiter, 2002) can be effective cognitive tools to support knowledge building and guide students into the scientific building of knowledge.

Research (Britton, 1972; Vygotsky, 1978) supports the idea that writing is not only a medium for communicating pre-existing ideas, it also supports the development of ideas (Keys, 1999).This is in contrast to common practice where writing is mainly used to assess a student's current understanding or as evidence of completion of an activity. When writing is used, it is not often explicitly managed as a process for building knowledge.

Our approach is inspired by Bereiter and Scardamalia (1987). Co-writing in a shared writing space such as wikis can create opportunities for scientific validation via the confrontation of ideas. Numerous writing iterations and feedback tone are critical: "an error-hunting teacher as the sole audience, may do little for the writer, whereas a topic the writer cares about and an audience responsive to what the writer has to say are the essential ingredients for a profitable experience" (Bereiter & Scardamalia, 1987). In addition, educational research highlights the importance of epistemic confrontation in socio-cognitive rather than relational conflicts (Buchs, Butera, Mugny, & Darnon, 2004).

2. Research questions

The general aim of our research is to develop and evaluate learning environments for IT-enhanced biology. This relies on the incremental refinement of learning designs within a design-based research framework (Design Based Research Collective, 2003). The outcomes are therefore links between design features and educational outcomes, rather than a comparison of a given design with a reference as in the classical experimental paradigm.

In this study, we focus on the effects of authenticity of resources and authenticity of the process of scientific validation on the development of scientific knowledge and learning strategies. In particular, we looked for evidence of students being involved in the scientific process of establishing the source and certainty of knowledge, and determined the design features that enhance this development.

Specifically, we discuss i) how confronting students with resources of varying degrees of authenticity influences scientific knowledge building, ii) which design features of wiki-supported iterative writing encourage authentic scientific validation of knowledge, iii) which design features develop autonomy in finding information in infodense environments, iv) what influence the status of the documents produced by the students has on their involvement.

3. Methods

This study was conducted between 2002 and 2009, with seven different classes totalling 83 students, over the course of one full academic year. Nineteen-year-old secondary school students majoring in biology were arbitrarily assigned to these classes. The study covered 100 hours in class, and the curriculum covered molecular biology, immunology and evolution.

The learning design was scaffolded by a wiki in which students wrote their progressive understanding of scientific questions on one sub-theme of a chapter in inquiry cycles lasting 3 to 4 weeks, after which the class addressed a new chapter.

Data were collected from the wiki's history (automatic records of all versions of the text) over 7 years. They were analyzed for progress in writing one theme: "stratigraphic" analysis. Successive wiki documents allowed year-long analysis. Design iterations (2002-2009) allowed longitudinal analysis.

A selection of text was rated for epistemic complexity using a four-point scale adapted from Zhang, Scardamalia, Lamon, Messina and Reeve (2007): each logical text unit was placed into one of four categories: unelaborated facts, elaborated facts, unelaborated explanations, elaborated explanations.
Resource category used was determined by references in the student's text, or by comparing the text with the sources known to be used by students. Coding was done only by the researcher, and interceding is currently being established.

Questionnaires were administered at the beginning and end of each year: they investigated (using Likert scales or a short text) representations of science, resource selection and learning strategies, feelings of autonomy and support, preferences about the efficiency of group work

(50 questions). The results refer to the last year and the final design. Shorter follow-ups were administered by e-mail one year later when the students were at university to explore perceptions of the adequacy of the learning and strategies for academic study.

Descriptive analysis was applied, correlations were sought. Text answers were coded and common answers extracted. Triangulation of data was performed.

As the involved teacher and researcher were one and the same, very radical designs could be explored, but even though the data cover a long period and many iterations of the design offer a good foundation for discussion, conclusions must be seen as exploratory and generalisability of the established design rules has to be carefully evaluated.

4. Basic design

Since in the design-based research paradigm, the design is iteratively refined, its main features are both the results, and the context in which they were elaborated. Here we present the latter.

Each group of students was responsible for a sub-theme, and wrote texts for their peers framed as the main preparation for important exams, in lieu of lectures. The students went through a cyclic succession of activities running 3 to 4 weeks: eliciting questions, gathering preliminary explanations and facts, performing a primary search, deepening the search, co-writing in the wiki, giving an early presentation to peers of the concurrent understanding of questions and answers, refining the questions, deepening the search, restructuring the text, giving a final presentation to peers, performing a final revision of the text, and sharing the exam-preparation brochure. Highly iterative collaborative writing (5-10 revisions per cycle) and repeated presentation of knowledge in construction engaged the students in the authentic process of validating.

A key structuring feature was the requirement that all paragraphs answer an explicit question in their title. This ensured focusing on a single concept, and allowed effective control by the teacher on the direction of the inquiry while leaving the responsibility of finding answers and integrating them into a coherent text with the students. The decision of where to search for the answers was left to the students, but when asked for help or when errors were found, the teacher did not correct the student text, but rather offered links to some of the newer authentic data, tools and experiments where better answers could be found. As students became more knowledgeable, resources of high authenticity were needed and students were not restricted to the usual textbooks, but were encouraged to use academic books for specific questions.

The first iteration (2002) validated the design, proving that it could lead students to appropriate knowledge and success in final exams. Changes in the design were introduced over the years: the 2003 iteration linked the structuring of the inquiry with the guidance and subject's in-depth coverage around the rule that each paragraph should answer one question, and that questions are negotiated; this was formally conceptualized as Inquiry Based Learning (IBL Workshop Collective, 2001). The 2004 iteration introduced oral presentations to peers. The 2005 iteration changed perspective, integrating the teacher as a dependent variable that changes under the influence of the design and adding access to academic textbooks. The 2006 iteration refined the writing to learn features, e.g. introducing editor roles for students. The 2008 iteration introduced cooperative learning features such as authoring records, texts discussed in front of peers early in the learning cycle, creating opportunities for students to discuss partly elaborated ideas and co-writing, organized to encourage confrontation in socio-cognitive conflicts.

5. Selected results and discussion

After giving a few general results, we present a selection of results related to authenticity and scientific knowledge. Each result is immediately discussed.

The design received basic validation in 2002–which has since been repeatedly confirmed–in that it allowed students to produce texts demonstrating sound in-depth biological knowledge. Although Geneva has no standardized exams, convergent anecdotal evidence suggests that student results were as good as, or better than those in other classes. Follow-ups one year later–at university (mostly in medicine)–indicated that the students felt they had acquired efficient learning strategies, and good basic knowledge.

The first iterations established that teacher control of the addressed questions could ensure curriculum coverage, and that student ownership of the questions is crucial and feasible but implies separating the teacher's curricular responsibility from his/her scientific validation role. Further iterations revealed the importance of focusing students on meaningful production (*Matrioshka* model, Lombard, 2007), and on a clear, shared understanding of the document's status. Here, it was framed as a shared exam-preparation brochure.

The frequency and tone of the feedback appeared as critical in the first iterations of the design. Teacher feedback that respects student ownership of the text, suggests modifications and refers to sources for development, rather than involving direct corrections, emerged as decisive in allowing students to experience the process of validation. Furthermore, too much rewriting by the teacher might lead to the student's disengagement. However, this implies that an imperfect text will remain in the final document. The teacher's tolerance of an imperfect text which is seen to be his/her responsibility is also an issue (Horman, 2005), which highlights the importance of clear, visible ownership of the text by students and a common understanding of the status of the document as help for exams.

Our results suggest that to allow the performance of science, the teacher can relinquish text-content ownership to the students, and tolerate minor imperfections, but needs to assert teacher authority on work flow and curriculum through the control of questions, very explicit assignments, and criteria for scientific validation and structuring of the text. Defining a clear framework for the writing assignments left the students with a lot of freedom in finding and selecting content.

As the design removes the teacher from the knowledge-transmission role, one might need to create an opportunity for the teacher to establish scientific authority early in the year.

Analysis of the writing process for knowledge confrontation showed little trace of socio-cognitive conflict. The presentations encouraged confrontation, but little discussion was observed. What might have happened orally outside of class is not available. Altogether, it appears that the students limited confrontation opportunities by adopting strategies to separate the common text into blocks which they managed individually. Modification of the design (each student in turn was "editor" and had the role of ensuring coherence of the texts) produced limited results, as it clashed with last-minute work habits, and possibly stretched the limits of student involvement further than what they could accept. Nevertheless, we believe that this is an important aspect to design for and would consider incorporating design features such as intergroup activities (Meirieu, 1989).

The year-long analysis shows many signs of greater in-depth involvement in knowledge structure–for example a clear increase in epistemic complexity of the texts produced over the course of 6 months. On a typical wiki page, in its final version, the number of facts (elaborated or unelaborated) changed only moderately, but the number of explanations increased greatly (Figure 1).

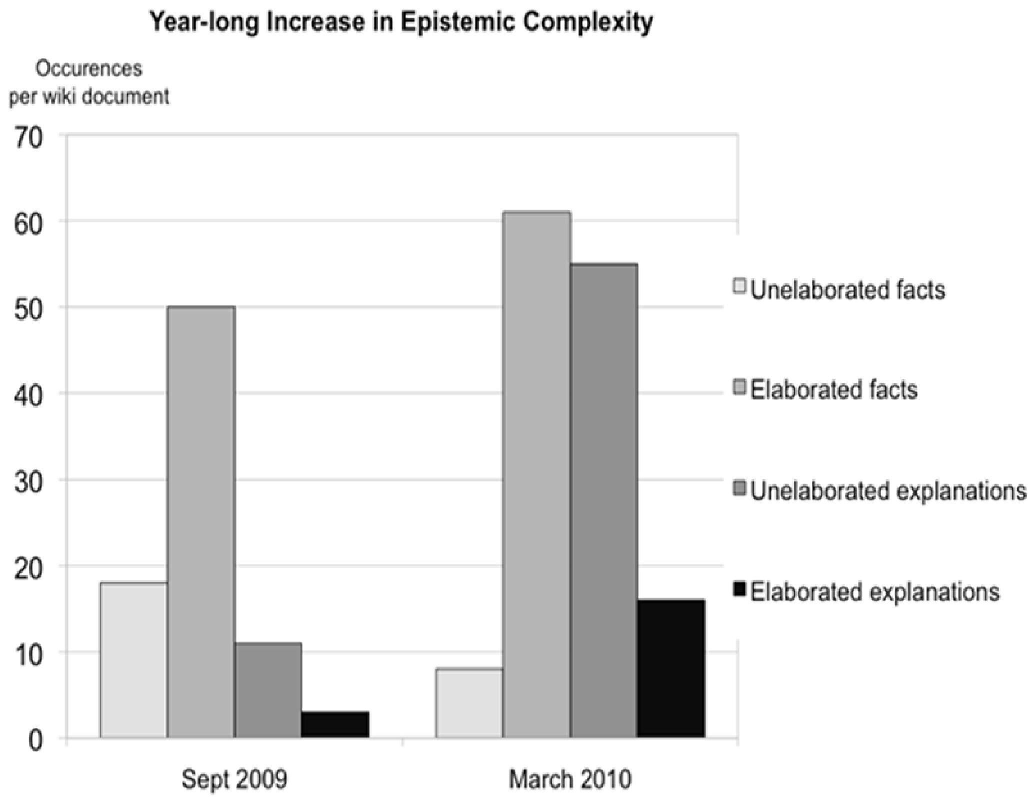

Figure 1
Beginning-end comparison of epistemic complexity, measured as number of occurrences for each category in one typical wiki student group production. See methods for details

Self-validation of knowledge

The design offered students a rich choice of resources from which to choose. The quality of the answers was assessed and feedback was provided, often by referencing on-line resources. In-class resources included a selection of textbooks, a few academic textbooks such as Parham (2002), and access to academic on-line textbooks in English such as Janeway, Travers, Walport and Shlomchik's (2001) on-line version. A large part of the student's work was done from home and most students relied heavily on internet resources and a textbook (Raven, Johnson, Losos, & Singer, 2007).

Observation in class by a teacher and other observers over the course of the year revealed a shift towards resources of increasing authenticity, occasionally even referring to primary literature. For example, one wiki document produced at the end of the year, on humoral immunity, contained 10 explicit references and 7 figures from Janeway on-line.

In the questionnaire, students ranked the sources they would choose for precise questions according to preference, with their textbook being referred to most often (μ=3.1 on a scale from 1 to 4) and Wikipedia much less often. Their comments also suggested that the students had developed strategies for selecting different sources depending on the type of question. They knew more than Wikipedia and chose textbooks or academic books for elaborate questions, and mastered strategies for searching. Many students mentioned that thick books had been daunting, but they now preferred them since they are more likely to contain relevant answers.

Appropriate questions not only directed student activity, but also allowed discarding irrelevant information, moving students from an exhaustive view of learning teacher-selected documents to data-mining strategies.

Overall, the students declared feeling empowered to learn in a world of information overload (μ=3.05 on a scale of 1 to 4). Most (72%) felt that the balance between scaffolding and autonomy was adequate (3 or 4 on a scale of 1 to 4) at the end of the year. They nearly all (93%) declared appreciating the freedom (3 or 4 on a scale of 1 to 4), while many mentioned that this design demands much more work. Students demonstrated increasing autonomy in finding explanations themselves, as attested by wiki documents that contained quality information that the teacher had not provided.

Analysis of the answers to the questionnaire suggested that tolerance of uncertainty might be a key factor. Students differed greatly in terms of how they felt with the responsibility of validating knowledge themselves: asked about the fact that the teacher does not give the answers, on average they answered quite positively (μ=3.0 out of 4), but variance (σ=1.04) was high. Interestingly, answers to this question correlated strongly (0.64**) with feeling that they had developed knowledge-extraction capacities and also (0.56**) with seeing the wiki as a good support for structuring ideas. They did not correlate well with exam results (negative, non-significant), and were stable throughout the year. More than half of the students felt positively about having to find answers themselves. Asked about the fear that some of the found information might be wrong, they answered–at the end of the year–that this was no longer a problem, referring to checking sources, logical coherence, or the fact there is no single truth in science.

Together these results suggest that most pupils were at ease developing their own validation of knowledge but that a few felt uneasy without teacher validation. The effects of this discomfort and uncertainty in some students on their investment remain unclear, but might be related to personal and cultural views about challenging authority. However, these results provide reasonable evidence that students are tagging their knowledge with certainty, source and structure, metacognitive attributes. They appear to be building partly scientific knowledge in the sense defined herein.

We assume that working with peer-created documents of doubtful quality might have helped: knowing that what they are reading might be partially wrong requires a constant validation of information, leading to developing the attribute of uncertainty and source. This suggests a design feature: that students–once equipped with data-mining and text-organizing strategies–should be repeatedly confronted with documents as the main authority for validating their knowledge. It also suggests including a wide array of documents of uncertain quality as well as high-quality authentic references, so that their differences can be experienced. As it happens, the former is just what the internet provides, whereas the latter needs guidance. It is also worth noting that validating information from a swamp of information is an authentic skill that is of great importance for all of today's citizens.

The tension between students validating scientifically and striving for acceptable content rendition remains an issue for some teachers who worry that students might learn errors if the documents they are provided with are imperfect. We must, however, not confuse the quality of the produced document with the learning it supports. This research strongly suggests that imperfect documents can support good learning once students possess good validation strategies, and the design includes features to guide the inquiry: presentation to peers provides decisive feedback on the quality of the knowledge the students are developing, making them aware of where understanding is insufficient, which leads to more searching, rewriting and ultimately, better knowledge.

Results suggest that trust in the learning potential of the design must be established for students, especially high performers, to get involved. It might be critical to create an opportunity to establish the learning potential of the design, such as testimony from students at university.

6. Conclusions

To conclude, we propose that science teaching focus on helping students develop scientific knowledge referenced to certainty, justification, structure and source. We also argue that the new biology offers a vast array of authentic data and tools that can be harnessed to develop these attributes of knowledge in the design of biology teaching. These are authentic sequences and biological data, authentic tools for processing data, but also authentic literature and IT-supported authentic science-validation-learning environments.

In particular, we suggest that students not be protected from, but rather be confronted with abundant resources of varying authenticity in guided inquiry. Documents of uncertain value should be available, but the students must engage repeatedly in scientific validation of the knowledge produced. Meaningful documents can help students process information into their own scientific knowledge. This is the authentic science process.

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3 SUPPORTING LEARNING OF HIGH-SCHOOL GENETICS USING AUTHENTIC RESEARCH PRACTICES: THE TEACHER'S ROLE

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Abstract

In this study, we describe the support provided by a biology teacher during learning using a web-based research simulation that makes use of authentic research practices in genetics, including use of a heuristic strategy to compare mutated and normal versions of a character at all organizational levels. Authentic scientific practices include the use of conditional knowledge, namely coordination between declarative and strategic knowledge, which is not typically found in regular school tasks. Thus, it is unlikely that students will be able to carry out such coordination without guidance from their teacher. Our research question was what kind of support does a teacher provide during enactment of the research simulation and how does it facilitate students' ability to coordinate declarative and strategic knowledge? We observed one teacher and her students during the enactment of the research simulation in class. An iterative teaching cycle composed of three steps was identified: *planning* the research, *performing* the scientific practices, and *interpreting* the resultant data. Our analysis revealed that the support given by a teacher to promote students' use of conditional knowledge in a high-school biology classroom is similar to the use of such knowledge by scientists in the course of performing authentic research.

Keywords: authenticity; research simulation; teaching strategies; conditional knowledge; bioinformatics education

1. Introduction

1.1 Rationale

Hutchison (1922) suggested that "genetics offers an excellent opportunity for the teacher to present his subject from the research point of view and to demonstrate how human knowledge is advanced." With this in mind, we harnessed genomics research frontiers and tools to develop a web-based research simulation that enables learners to take part in authentic research in genetics (Gelbart & Yarden, 2001, 2006). In the simulation, students are introduced to the basic heuristic strategy used in the study of gene function, namely comparing the normal and mutated forms of a certain character and correlating the mutated and normal versions of the gene with the phenotypes of affected and healthy individuals, respectively (Vance, 1996). This comparison is carried at the phenotypic level using a classical genetic approach, and at the molecular level using laboratory-based molecular

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biology methods and computer-based bioinformatics tools, similar to the way in which geneticists perform genetics research today. This research simulation closely resembles the conductance of science *per se*, and in this sense it is authentic, as previously suggested by Gilbert (2004). This study examines the kind of support provided by a teacher during enactment of the research simulation in class, thus illuminating the enactment of an authentic environment under the conditions available in schools.

1.2 Theoretical background

The study stems from a theoretical perspective which views learning as a combination of the constructivist learning theory, namely a process of knowledge construction (Greeno, 1998), and the situated learning perspective which views learning as a process of enculturation into a community of experts (Brown, Collins, & Duguid, 1989). The constructivist learning perspective encourages active learning which provides the students with opportunities to construct their own knowledge. The situated learning perspective rests on the use of authentic activities, used by the culture of the particular discipline to acquire knowledge in that field. Thus, learning is a process of enculturation into the community of experts until, eventually, literacy in the domain is achieved (Brown et al., 1989). These two perspectives are not necessarily contrasting, since learning can be viewed as a combination of the two (Cobb, 1994).

One thing that should be considered when combining these two perspectives is that ordinary practices of the scientific culture, or authentic scientific activities, are usually distinct from school activities. Indeed, Chinn and Malhotra (2002) pointed out that inquiry tasks commonly used in schools evoke reasoning processes and epistemology that are qualitatively different from those employed in real scientific inquiry. This, then, raises doubt as to whether it is at all practical to strive for accommodating authentic scientific practices in schools, and what means should be developed to realize this expectation. Despite the fact that much of school work is non-authentic, there are calls (i.e., Buxton, 2006; Jimenez-Aleixandre & Fernandez-Lopez, 2010; Wong & Hodson, 2008) to face the challenge and make school science "as closely alike the conduct of science *per se* as is possible under the current conditions of mass education" (Gilbert, 2004). Our study focuses on how such a challenge was faced by a teacher in a high-school biology classroom, as we believe the teacher's role is essential in the process of incorporating authentic practices into schools.

Another theoretical perspective driving this study is the view of declarative, procedural and conditional knowledge. Alexander and Judy (1988) defined declarative knowledge as factual information, whereas procedural knowledge (or strategies) were defined as goal-directed procedures that intentionally evoke either prior to, during or after the performance of a task. Conditional knowledge entails the understanding of when and where to access certain facts or employ particular procedures (Alexander & Judy, 1988). Our view is that to engage learners in authentic research practices, the learners need to use their declarative knowledge (i.e., prior knowledge learned in the course of learning genetics in our case), and acquire the procedural knowledge (i.e., use of the bioinformatics tools and the heuristic strategy used by geneticists to compare between phenotypes at various organizational levels) and conditional knowledge required to carry out authentic research (i.e., combine the declarative knowledge in genetics with the procedural knowledge to reveal gene function).

The ability to use conditional knowledge is at the heart of performing authentic scientific research. Chinn & Malhotra (2002) differentiated between models of authentic experiments, which have many intervening events, and models of simple experiments, which have only the initial and final events. The overall greater complexity of authentic scientific research requires continuous coordination between declarative and strategic knowledge, as well as between the various intervening events, or stages of the scientific experiment (Falk & Yarden, 2009). Such coordination is not typical to regular school tasks and rarely appears in the learning materials, including textbooks, used in schools (Chinn & Malhotra, 2002; Yarden, 2009). Thus, it is unlikely that students will be able to carry out such coordination without guidance from their teacher.

1.3 Research question

Our research question in this case study was: What kind of support does a teacher provide during enactment of the research simulation and how does it facilitate students' ability to coordinate between declarative and strategic knowledge?

2. Methodology

2.1 Description of the research simulation

The research simulation serving as the basis for this study is a web-based learning environment in genetics which enables learners to participate in a simulation of authentic research through guided inquiry, using methods and tools that are commonly used by geneticists (Gelbart & Yarden, 2001, 2006). The simulation is closely related to the curriculum in genetics within the framework of the high-school biology majors program in Israel, designed to be taught toward the end of 30 hours of genetics instruction. It was developed on the basis of a research paper in the field of genetics in the current genomics era in which a mutated gene, which causes deafness in an Israeli family, was identified (Vahava et al., 1998). The paper was published before the completion of the human genome project, but nevertheless includes the use of bioinformatics tools and heuristics which are commonly used in contemporary biological research.

Through the research simulation, the students are introduced to the basic heuristic strategy of comparing normal and mutated forms of a certain character and correlating the mutated version of the gene with the phenotypes of affected individuals. While advancing through the simulation, the learners use this heuristic strategy in four out of the five assignments composing the learning environment: at the phenotypic level (assignment 1), chromosomal level (assignment 2), genome level (assignment 3), and gene level (assignment 4). In the fifth assignment, the students discover that the protein encoded by the gene functions as a transcription factor in embryonic hair cells in the ear. The research simulation provides opportunities for students to apply their prior knowledge in new situations, and generate new knowledge in the context of its use in authentic genetic research. Use of this simulation enabled learners to expand their genetic knowledge through recognition of disciplinary research practices (Gelbart, Brill, & Yarden, 2009). To support the learners' progression, each assignment includes interactive multiple-choice questions, as well as open-ended questions accompanying each results page. The questions were designed to enable the students to focus on the scientific data when obtaining the authentic research results, and to guide the solvers' attention to the main issues of the particular research stage.

2.2 Research population

A senior biology teacher with more than 15 years' experience in preparing students for the matriculation exams in biology participated in this study. This teacher chose to teach the curriculum in genetics, which is elective within the biology majors' syllabus in Israel, and was documented during her first experience in enacting the research simulation in her classroom. Twenty-six 12th-grade biology majors participated in the activity, working in pairs, each pair sharing one computer.

2.3 Data analysis

The students and teacher were videotaped and audiotaped in the classroom. The enactment lasted about 150 minutes. The tapes of the enactment were fully transcribed and qualitatively analyzed bottom-up following Shkedi (2005). All data were divided into episodes and episodes were classified into primary categories. Subsequently, general categories emerged, and all units were mapped and reorganized according to those general categories. In this paper, we focused on the following general categories: 'goal of the research', 'strategic knowledge' (including knowledge of 'heuristic strategy' and 'tools'), 'declarative knowledge', 'conditional knowledge'. An independent researcher independently mapped all episodes into the emerging categories and the inter-rater agreement reached 100% following discussions between the raters.

3. Findings

3.1 Structural characteristics of the lesson

An iterative teaching cycle composed of three steps which were repeated in all five assignments was identified during the analysis of the transcripts: *planning* the research, *performing* the scientific procedures using the heuristic strategy and the bioinformatics tools, and *interpreting* the resultant data in each of the assignments. The teaching cycle began with a whole-class *planning* discussion, with the aim of supporting students' understanding of the research design, followed by a *performance* step. During the *performance* steps, the students were asked by the teacher to use the heuristic strategy and bioinformatics tools which are integrated in the research simulation to obtain authentic research results, and to answer the supporting questions, in each of the assignments. During the *performance* steps, students worked in pairs in front of computers, while a whole class discussion was conducted during the other two steps. Following each of the *performance* steps, an *interpretive* discussion was conducted by the teacher, with the aim of supporting students' understanding of the research results and evaluating the conclusions; this was followed by a whole-class *planning* discussion aimed at supporting students' understanding of the design of the next research step. The *planning* discussions lasted about 70 minutes, the *interpretive* discussions about 30 minutes, and the rest of the time was devoted to the *performance* steps. Thus, the teacher devoted about half of the lesson to the *planning* discussions. Here, we focus on the analysis of these latter discussions, which enabled us to examine how the teacher initiated students' thinking about authentic features of the research simulation. In the other two steps, the teacher supported students' analyses of their results and answered their questions, but did not initiate the interactions. Thus, focusing on the *planning* step enabled us to focus solely on the teacher's performance in using the authentic research simulation in class.

3.2 Supporting the students through the *planning* discussions

The questions asked by the teacher during the *planning* discussions enabled her to support the students' thinking toward understanding the research design and tools. The essence of those discussions was identified as guiding students' attention to the research goal at each particular research stage, and eliciting students' suggestions of the heuristic strategy and tools that might be used to achieve that goal. The support given by the teacher during the *planning* stage was composed of the following four components: i) promoting awareness of the need for a heuristic strategy; ii) promoting acquisition of the heuristic strategy using a concrete tool; iii) eliciting suggestions of an alternative tool; iv) coordinating the heuristic strategy for different research steps. Each of the four components is described below in the context of the discourses that took place in the transition between assignment 1 and 2, assignment 2, assignment 3, and assignment 4, respectively.

i) The transition between assignment 1 and 2: promoting awareness of the need for a heuristic strategy

The teacher's guidance of students' attention to the research goal elicited students' suggestions of the potential strategy that could be applied to achieve this goal. Based on the research rationale and heuristic strategy presented at this stage of the research simulation, the following discourse evolved (the use of strategic knowledge is underlined, the use of declarative knowledge is in bold; T is teacher):

91. T: "Now that I know that the illness is dominant [a dominant trait], does it help me tell a person who comes for genetic counseling 'you'll suffer or you won't suffer from the illness'?"

92. Shiri: "No, it just calculates the probability…"

93. T: "If I want to give this person a certain answer, <u>what should I do now?</u>"

94. Many voices in classroom: "maybe do a DNA test", "test his DNA"…

95. T: "Test his DNA…Do you have any clue what a DNA test includes? What does it mean? <u>What am I going to do</u>?"

96. Orr: "First we should know where it [the gene] is located."

97. T: "First I should understand where it is located…<u>How can I know where it is located</u>?"

98. Yaron: "Perhaps you can take the DNA from the ill people and the DNA from healthy people and compare them?"

*99. T: <u>"I'll take</u> <u>**a-l-l the DNA from healthy people and a-l-l the DNA from ill people**</u> <u>and compare them?</u>"*

100. Shiri: "But the DNA contains blue eyes and brown eyes and many other different traits…"

*101. T: "Exactly. **If we compare all the DNA, we'll find many different traits**… so <u>another way is needed</u>."*

102. Yaron: "Is it possible to compare only the [DNA/chromosomal] region that is connected to hearing?"

103. T: "Only the region that is connected to hearing?"

104. Alona: "Do you know where it is located?"

105. T: "Very soon we'll find it out together."

106. Tomer: "According to the mutation maybe…"

107. T: "For now, I don't know where it is located. I would like to show you a way in which scientists worked to actually identify the location of this gene."

Immediately after the students identified the most reasonable inheritance pattern for the deafness (in assignment 1), the teacher initiated a discussion by asking a question that focused their attention on the main goal of the research (utterance 91). The question introduces the students to the applied aspect of the research, finding a solution to the specific problem, namely, helping a person find out whether he/she is going to suffer from progressive deafness. This question is followed by a chain of questions about the potential heuristic strategy that can be used to achieve this research goal (underlined in utterances 93, 95, 97, 99, 101). This chain of questions proceeds from general (utterances 93, 95) to more specific ones (utterances 97, 99), in which the heuristic strategy is questioned, and possible concrete tools that might enable carrying out the actual comparison start to emerge from the discussion (utterances 99, 101).

Another important aspect of the teacher's questions is their focus on considering an appropriate declarative knowledge in genetics when designing a research strategy (bolded in utterances 99, 101). The discussion is terminated when the teacher introduces the students to the basic goal of this step in the research, i.e., to locate a gene in the genome, which emerges in the discussion about an appropriate bioinformatics tool (utterance 107). In this discussion, the teacher promoted students' understanding of the research goal, their understanding of the heuristic strategy of comparing between affected and healthy individuals at the chromosomal level, and their awareness of the importance of declarative knowledge in genetics when choosing the preferred bioinformatics tool. This demonstrates how the teacher promotes the use of conditional knowledge while learning using the research simulation.

ii) Assignment 2: promoting acquisition of the heuristic strategy using a concrete tool

The teacher guided the students' attention to the research goal and elicited their suggestions for a potential heuristic strategy and bioinformatics tool that could be applied to achieve this goal, as demonstrated in the following citation taken from the discussion that evolved around the worked-out example integrated into the introduction to assignment 2 (use of strategic knowledge is underlined, use of declarative knowledge is in bold):

136. T: "I'm trying ***to identify the location of the gene according to the polymorphic markers that <u>appear systematically in [the genome of] the deaf people and do not appear in [the genome of] the people with normal hearing</u>****."*

137: Yaara: "Ah, polymorphic markers [which appear] only among the deaf people…"

138. T: "Look at the pedigree and tell me, do you see any correlation? ***<u>Do certain types of polymorphic markers appear only among [the genome of] the deaf people</u>****?"*

142. Many voices in classroom: "Yes, number 1 and number 3, number 1 appears only among the deaf people."

143. Some voices: "Why not number 2?"

144. Susan: "Because number 2 also appears among the hearing people."

151. T: "That's right, ***<u>so only [polymorphic marker] number 1 differentiates deaf from hearing people</u>****."*

153. Yaara: "Number 1 is the only marker that appears among the deaf people and does not appear among the hearing people."

This discussion can be perceived as a continuation of the previously cited discussion (utterances 91-107 above) since here, the teacher is also guiding the students' attention to the research goal (utterance 136) and to the potential heuristic strategy that can be applied to achieve that goal (underlined in utterances 136, 138, and 151). However, in contrast to the previous example in which the heuristic strategy was discussed theoretically, here the teacher uses linkage analysis as a concrete tool which enables her to refer to the heuristic strategy that can be applied to locate a gene in a genome (bolded in utterances 136, 138, and 151).

Toward the end of discussing the worked-out example, the teacher once again focuses the students on the applied aspect of the research goal (utterance 231, below). This question is followed by two other questions which elicit students' suggestions of the heuristic strategy that could be applied to achieve the research goal (233 and 237). Interestingly, these questions are similar to those posed by the teacher during the transition between assignments 1 and 2 (i.e., utterances 91, 95 and 99 above, are similar to utterances 231, 233 and 237, below) (use of strategic knowledge is underlined):

231. T: "As a genetic counselor, are you closer now to being able to tell a person whether he will be deaf at the age of 40?"

232. Yaron: "Only if he'll test his DNA."

233. T: "<u>What kind of a DNA test is required now</u>?"

234. Alona: "gene mapping"

235. Yaron: "with the genetic markers, because I don't know the sequence of the gene yet…"

236. Susan: "to take a healthy person and an ill person and to compare their DNA"

237. T: "O.K., so I'll <u>test the whole DNA, the complete chromosome</u>…?"

238. Yaron: "No, only the region of these markers."

The teaching pattern of focusing students on the research goal and eliciting their suggestions for the relevant heuristic strategy, which prompts students to proceed from suggesting a general strategy (underlined in utterance 233) to providing a concrete tool to carry out this comparison (underlined in utterance 237), is repeated here. Here, the teacher continued to promote students' awareness of the need for a heuristic strategy by enhancing their awareness of the appropriate disciplinary strategic thinking. The teacher prompted the use and understanding of the heuristic strategy, which in turn, encouraged a consideration of genetics knowledge as an integral component of the strategic thinking while suggesting the appropriate tool to carry out the comparison. The analysis of this stage of the research simulation also demonstrates how the teacher promoted the use of conditional knowledge among the students.

iii) Assignment 3: eliciting suggestions of an alternative tool

In the *planning* step for assignment 3, the students are introduced to the fact that the chromosomal segment they have identified using the linkage analysis in assignment 2 is 10 million base pairs long and can therefore contain many genes. The citation below is taken from a discussion enacted by the teacher while showing an animation demonstrating the relative size of the identified segment on human chromosome number 5. The discussion is based on the research rationale and research heuristic presented at this stage of the simulation (use of strategic knowledge is underlined):

286. T: "As scientists, for now we know some important facts: we know that the deafness gene is located on chromosome number 5. Here is chromosome number 5. But this segment is 10 million bases long, and 10 million bases is quite a big number… <u>How can I find where exactly the gene is in here</u>?"

287. Orr: "Maybe now we can do a DNA test, to compare it to a healthy person?"

288. T: "<u>In these entire 10 million base pairs you'll have pretty many different sequences</u>…"

289. Orr: "So let's divide it into segments."

299. T: "And…? <u>Even if you divide it, you'll still have many different sequences</u>… anyway, there is a much more elegant way, do you think that they [the scientists] are looking for the deafness gene only in humans?"

300. Ilana: "Ah, maybe [they do it] also in animals?"

301. T: "There are model organisms in which many genes have been identified, and if I take a model organism in which I already know exactly where a deafness gene is located, and I've identified its DNA sequence… let's say, for instance, a mouse, <u>maybe I'll be able to compare the deafness gene in mice and in humans</u> and in this way it will direct me to that particular gene in humans, if I recognize its DNA sequence..."

The teacher initiates the discussion by summarizing what is known and what is not yet known at this stage of the research, by evaluating the conclusions that were reached in assignment 2 using the linkage-analysis tool and the heuristic strategy. The teacher uses the evaluation as a way of guiding students' attention to the research objective at this stage. The teaching pattern of focusing students on the research goal (utterance 286) and eliciting their suggestions of applicable tools (underlined in utterances 286, 288, 299 and 301) is repeated here. However, these questions elicit the students' awareness of the need to include an additional tool to achieve the research goal (the use of a model organism, utterance 301). The teacher's question "*How can I find where exactly the gene is in here?*" (utterance 286) includes the research goal to locate a gene in the genome, and the potential tool that can be used to achieve this goal, which are both nested in the question aimed to elicit students' suggestions as to how to use the heuristic strategy.

iv) Assignment 4: coordinating the heuristic strategy for different research steps

In assignment 4, the students are asked to use the basic heuristic strategy at the DNA level, i.e. to compare the normal and mutated alleles of the candidate gene and to locate the mutation that differentiates between deaf and hearing people. In the discussion cited below, taken from the *planning* step for assignment 4, the teacher evaluates the conclusions reached using a model organism in a way that guides the students to the research goal (underlined in utterances 425, 427, 429) as well as to the heuristic strategy that can be used at this stage (bolded in utterances 425, 427). Thus, the teaching pattern of focusing students on the research goal and eliciting their suggestions of heuristic strategy that is applicable to achieving this goal is repeated here. The discussion cited below, which is based on the research rationale and heuristic strategy presented at this stage in the simulation (assignment 4), can be perceived as a continuation of the discussion cited previously (utterances 286-301), since at this stage of the research simulation, the teacher's questions elicit students' awareness of the need to coordinate between the alternative tool and the basic heuristic strategy (use of strategic knowledge is underlined, use of declarative knowledge is in bold):

425. T: "Now that I've identified ***a sequence in mice which is very similar to a sequence of a human gene****, is it done? Do I know everything?"*

426. Lila: "No, you still want to know whether your patient has it [this sequence]."

427. T: "Right, ***the deaf person himself, I mean, I suspect that this sequence is the gene that is involved in deafness****, but what do I not know yet?"*

428. Lila: "if it [the gene] exists in deaf people"

429. T: "So this gene has received the status of a candidate gene [is now considered a candidate gene], what should my next step be?"

432. Ilana: "to compare the gene of a deaf person to this candidate gene"

433. Omer: "the candidate gene and a gene from your patient"

434. Yaron: "to compare between ill and healthy people"

435. T: "What would you consider a proof?"

436. Ron: "That it exists in ill and healthy people."

437. Ilana: "That they both will be identical, no, not identical, but very similar…"

438: T: "What am I looking for?"

439: Orr: "a difference"

440: T: "A difference but a fair amount of similarity, right?"

In this discussion, the teacher poses questions that evaluate and guide students' attention to the conclusions reached in the previous step (bolded in utterances 425 and 427), and elicit students' suggestions of the heuristic strategy that can now be applied (underlined in utterance 429). Toward the end of the discussion, the teacher poses a question that guides students to predict the results of the research step, i.e. "the proof" (utterance 435). Following the discussion, the teacher guided the students to use another bioinformatics tool to execute the appropriate comparison (data not shown).

4. Discussion

In this study, we characterize the teaching strategies of a teacher enacting an authentic research simulation in genetics that involves identifying a gene in the genome. We focused our analysis on the *planning* discussions enacted by the teacher at the beginning of each of four out of the five assignments included in the research simulation. Those discussions enabled the teacher to facilitate acquisition of awareness of the need for a heuristic strategy to achieve the research goal, and facilitated coordination between the heuristic strategy and authentic bioinformatics tools in the different research steps. These discussions also facilitated coordination between strategic knowledge and declarative knowledge in genetics in choosing the appropriate tools to carry out the research. Our analysis revealed the support given by a teacher to promote students' use of conditional knowledge in a high-school biology classroom, similar to the use of such knowledge by scientists in the course of performing authentic research. This pedagogical approach enabled the teacher to engage learners in the scientific "culture" of acquiring new knowledge, thus supporting both the constructivist and situated learning perspectives, as previously suggested by Cobb (1994).

Wong and Hodson (2008) previously argued that teachers should acknowledge the context-dependency of scientific practices and knowledge generation. This study clearly demonstrates how a teacher led her students to use authentic scientific practices, while leading them to use conditional knowledge which involved the use of their genetics knowledge, and applying this knowledge in practicing a basic heuristic strategy and authentic scientific tools.

In a previous study, we characterized research-oriented learners who are deeply engaged in the research, and who recognize different aspects of the authentic research practices and deal with its complexity. These were contrasted with task-oriented learners, who are not constantly involved in the research steps, an approach which leads to perceiving the research simulation as a set of simple procedural tasks (Gelbart et al., 2009). Interestingly, understanding and awareness of the research objective and of the available heuristic strategies in each of the research steps, and coordinating between different research steps in the framework of the research design, all of which were facilitated by the teacher throughout the *planning* discussions, were identified as part of the research practices that differentiate between research-oriented and task-oriented learners (Gelbart et al., 2009). It was found that the research-oriented learners seized more opportunities to recognize these research practices consistently than the task-oriented learners. Thus, the research-oriented learners may have made use of conditional knowledge more often than the task-oriented learners. In view of this, we suggest that the use of conditional knowledge given consistently by the teacher through the *planning* discussions enabled her to dictate a research-oriented approach. This approach enabled the learners to be mindful of the research instead of focusing on "doing" and "performing" the task.

The authentic scientific practices available to the students in the research simulation can be classified as a hybrid between “computer-simulated experiment” and “databases”, following Chinn & Malhotra's (2002) classification. The databases used in this study are the various genomes’ databases which are mined using authentic bioinformatics tools that are commonly used by geneticists; both are freely available to the general public on the World Wide Web (NCBI, 2004). Exploring the use of those databases using the bioinformatics tools by high-school students will enable exploring possible authentic scientific conduct in the high-school environment. We plan to carry out such studies, using this research simulation and a new one that is currently under development.

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Section 2

Various teaching strategies for the teaching of biology

4 TEACHERS' AND STUDENTS' USE OF CONCEPTS OF EVIDENCE IN JUDGING THE QUALITY OF AN INQUIRY

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Abstract

The objective of this study is to explore the extent to which students from upper secondary school and science teachers from different science disciplines recognize concepts of evidence (CoE) in a student's inquiry report. These CoE help enlarge the students' procedural understanding and their ability to ensure the accuracy, reliability and validity of inquiries in the research contexts of biology, chemistry and physics in secondary school. Six students and six teachers of various science disciplines were involved in this qualitative study. They first judged a student's inquiry report by using a think-aloud task. Afterwards, the students were interviewed to survey their knowledge of ensuring accuracy, reliability and validity in scientific inquiries. In addition, 38 upper secondary school students (age 16-17) filled in a questionnaire on this issue. The results showed that students make use of CoE that support the accuracy, reliability and validity of an inquiry to the same extent as teachers, but with a different focus. The findings of this study will be used in the design of a teaching-learning trajectory about learning to inquire in the different science disciplines.

Keywords: concepts of evidence; explorative study; inquiry; procedural understanding; upper secondary school

1. Theoretical background

In many curricula, secondary education students learn to perform inquiries in biology, chemistry and physics. When students perform an inquiry, they need to have at least some understanding of substantive facts, be able to use necessary practical skills and have some procedural understanding of how to construct a fair test and how to use evidence in reasoning (Figure 1) (Gott & Duggan, 2007; Schalk, Van der Schee, & Boersma, 2007). Nevertheless, in science curricula this procedural understanding is often trivialised and mostly deals with social goals, such as communication of knowledge claims (Abd-El-Khalick et al., 2004).

In performing inquiries, students make observations or conduct experiments in order to find an answer to the inquiry question. When they draw a conclusion, they have to argue why the obtained results lead to that conclusion and not to another one. As Lawson (2009) points out, this line of reasoning is not primarily aimed at convincing others, but *"rather as one of discovering which of several possible explanations of a particular puzzling observation should be accepted and which should be rejected"* (p. 2).

Recent educational research in chemistry (Van Rens, Pilot, & Van der Schee, 2010) and biology (Schalk, Van der Schee, & Boersma, 2009) shows that the use of concepts of evidence (CoE) (Gott, Duggan, Roberts, & Hussain, n.d.) is convenient to improve students' procedural understanding. A part of the total range of CoE can be used by students to ensure the validity, reliability and accuracy of an inquiry in the school science subjects (Gott & Duggan, 2003).

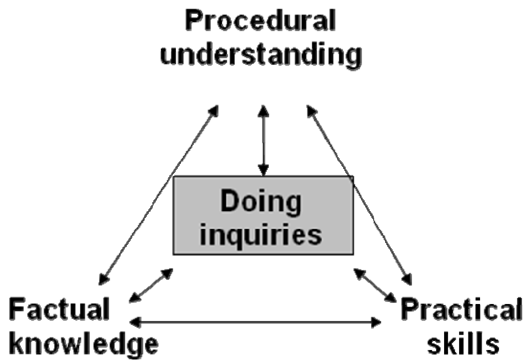

Figure 1
A model for performing inquiries in the school science subjects

It can be expected that when students in secondary school perform inquiries in biology, chemistry and physics, their procedural understanding will improve when they learn how to use the CoE to ensure accuracy, reliability and validity in all of these science subjects (Gott & Duggan, 2003). However, validity, reliability and accuracy have slightly different meanings in the different disciplines. For example, in biology, results can only be reliable when a representative sample of a population has been taken. To get reliable results in an experiment in physics, one has to repeat the measurements. These different meanings can confuse students, especially when the analogy in supporting empirical reasoning in both experimental contexts is not explained to them (Millar, Driver, Leach, Scott, & Wood-Robinson, 1987).

For all inquiries with the objective of improving students' procedural understanding, the teacher has to choose which CoE are relevant and make them explicit to the students. To do this in an appropriate way, teachers should know how to interpret and use the CoE in each specific science inquiry context in their science discipline. For this explorative study, we selected relevant CoE based on ensuring quality in biology, physics and chemistry inquiries. This selection is hereafter termed 'relevant CoE'.

2. Key objectives and hypothesis

This study is part of a larger study on learning inquiry in the school science disciplines. It aims at identifying principles that can be used in designing a teaching-learning trajectory that will enhance students' ability to ensure the accuracy, reliability and validity of an inquiry in the different school science subjects. The following research questions guided this explorative study:

1) To what extent do students from upper secondary school and science teachers from different school science subjects recognise CoE that can be related to accuracy, reliability and validity in a student's inquiry?
2) Is there a resemblance between biology, chemistry and physics teachers in the recognition of CoE in relation to accuracy, reliability and validity?

3) What do students know about the meaning of accuracy, reliability and validity in inquiry contexts?

Our hypothesis was that biology, chemistry and physics teachers would make more use of relevant CoE to judge the accuracy, reliability and validity of an inquiry than would students. In accordance with Germann & Aram (1996): experts and novices differ in their knowledge and application of procedural understanding and practical skills. It was thus expected that all teachers would be more expert in judging the accuracy, reliability and validity of inquiries than students, due to their academic degree in one of the science disciplines and their previous experience with inquiries in the classroom.

3. Methods and data analysis

This qualitative study involved a think-aloud task, interviews and a questionnaire.

3.1 Think-aloud task

Six upper secondary school students (aged 16-17 years) from three different schools and six science teachers from five different schools in the Netherlands participated in a think-aloud task (Bowen, 1994). The students and science teachers were from different schools. All participating students were studying biology, physics and chemistry at the upper secondary school level. The teachers had at least five years of teaching experience at the upper secondary school level and were familiar with judging student inquiry reports. Two of them were biology teachers, two taught chemistry and two were physics teachers.

For the think-aloud task, a student-written ('scientific') article about the influence of chocolate on the physiology of the human body was selected. Two students (age 16-17) had written this article as part of a chemistry inquiry project (Van Rens, Van der Schee, & Pilot, 2009). This student-written article can be found in the appendix of the digital version of this paper at http://www.onderwijscentrum.vu.nl/nl/research/researchers/researchers-names/saskia-van-der-jagt/index.asp. Henceforth, the student authors of the article are termed 'student researchers'; 'students' refers to those who participated in our explorative study.

Before beginning the think-aloud task, the student-written article was analysed by two of the authors to determine the relevant CoE that were, or should have been used by the student researchers. These relevant CoE were selected from previous research by Gott et al. (n.d.) and Schalk (2006) and reformulated for the student-written article.

In this paper, the rephrased descriptions of the relevant CoE in this specific student inquiry report are called 'items' in order to distinguish them from 'relevant CoE'. This list of items was independently constructed by two of the authors, with an interrater agreement of 96%. For the rest of the items, a discussion took place till consensus was reached. The list ultimately consisted of 47 items contributing to the accuracy, reliability or validity of the inquiry (see Appendix).

The participating students and teachers were asked to judge the quality of the inquiry as described in the student-written article by thinking aloud. The meaning of 'quality of an inquiry' was not specified. The participants were stimulated to speak out their thoughts and got questions to clarify their judgements. The responses of the participants were audiotaped and transcribed verbatim. The citations used in this paper were translated from the Dutch.

The students' and teachers' responses were independently categorised as one of the 47 items by two of the authors. The agreement between the two authors was 84%. Differences in categorisation were discussed until consensus was reached. Subsequently, the mentioned items were related to the overarching concepts validity, reliability and accuracy.

3.2 Interviews and questionnaire

Five students that participated in the think-aloud task were also interviewed about their knowledge of the meaning of accuracy, reliability and validity in inquiries. One student was not interviewed because he had to get back to class directly after the think-aloud task. The responses of the students were audiotaped and transcribed verbatim.
Thirty-eight students (age 16-17) from upper secondary schools filled in a questionnaire with three open-ended questions on the meanings of accuracy, reliability and validity in the context of inquiries. The students were instructed to write down all of the information that occurred to them.

The answers from the interviews and questionnaires about ensuring accuracy, reliability and validity when performing inquiries were independently categorised by two of the authors as:

1) Use of correct relevant CoE
2) Use of incorrect relevant CoE (e.g., while answering the question about accuracy a participant referred to a relevant CoE that contributes to reliability)
3) Use of everyday language to describe the concept being asked about (e.g., accuracy is determined as ‘doing something neatly’)
4) Nonsense/ambiguous answer
5) No answer

Sometimes an answer consisted of more than one statement and–if necessary–these were categorised separately. The interrater agreement between the two authors for the scores of the responses in the interviews was 75% and on the questionnaire, 86%. Different scores were discussed until consensus was reached.

4. Results

4.1 Judging the quality of an inquiry

Table 1 contains an overview of the number of items on validity, reliability and accuracy mentioned by the students and teachers during the think-aloud task. The range of items mentioned by the students was between 10 and 16 different items per student. For the teachers this range was between 7 and 23 different items per teacher. The participants could mention at most 47 different items: 22 about validity, 13 about reliability and 12 about validity (see Appendix).
When we look at these results qualitatively, some items were mentioned more clearly and more often by the participants than others. For example, five students mentioned logical reasoning in the theoretical framework of the judged student-written inquiry article, the measurement intervals of the independent variables and the importance of keeping other influential variables constant. It is remarkable that four of these five students repeated that other variables should be kept constant a couple of times during the think-aloud task. Four of the students were acquainted with the contribution of a good research question to the validity of the inquiry and the importance of using the results of the inquiry when drawing a conclusion. About ensuring reliability, four students recognised that the student researchers measured the blood pressure of each representative before starting the experiment, but none of them stated that the student researchers neglected to do the same with the experiment on pupil divergence. Four of the students mentioned that the student researchers should have repeated

their measurements, but it was not clear whether all of them precisely understood the importance of repeating measurements to find the deviation around an average value.

Table 1
Comparison of the number of averaged mentioned items and their percentage of the maximum numbers by six students and six science teachers

	Average of the students	**Average of the science teachers**
Total number of mentioned items (n=47)	13.5 (28.7%)	15 (31.9%)
Number of mentioned items about validity (n=22)	6.5 (29.5%)	7.3 (33.2%)
Number of mentioned items about reliability (n=13)	3.3 (25.4%)	3.5 (26.9%)
Number of mentioned items about accuracy (n=12)	3.7 (30.8%)	4.2 (35.0%)

Five teachers referred to the quality of the research question and pointed to the evaluation of the accuracy of measurements of pupil divergence in the student-written article, although none of them stated that the student researchers had neglected to evaluate the accuracy of the blood pressure measurements. Four teachers judged the quality of the theoretical framework. They all mentioned the logical reasoning in the theoretical framework as well as the validity of the relation of this framework to the subsequent parts of the inquiry. Four teachers stated that the tables and graphs needed appropriate headings corresponding to the kind of information shown and brought up the importance of making recommendations for further research. In addition, four teachers said that it is important to keep other influential variables constant, to justify the chosen sample size and explain its representativeness, and to repeat the measurements. Although three teachers referred to using the results from the inquiry to found the conclusion and restricting the conclusion to the evidence from the inquiry, none of them talked about the validity of the conclusion relative to the research question.

The students and teachers had a more or less equal score, but it was revealed that two-thirds of the total number of items mentioned by all students together were directly recognisable in the student-written article. The science teachers talked more often about items that were neglected by the student researchers.

4.2 Differences between the teachers

The differences and similarities between the teachers' results in light of their science discipline are summarised in Table 2. It should be borne in mind that this comparison is based on the results of three times two teachers and only gives an indication of the differences in focus of teachers from the different school science subjects.

The main difference between the biology, chemistry and physics teachers was seen in their judgment of items that help ensure the validity of the inquiry. The biology teachers' scores were highest in all categories, and they appeared to follow the empirical reasoning in the article more than the teachers from the other disciplines. Furthermore, the two chemistry teachers looked at the inquiry at different levels.

Table 2
Comparison of the results of teachers from the different school science subjects

		Number of items about validity (n=22)	Number of items about reliability (n=13)	Number of items about accuracy (n=12)	Total number of items (n=47)
Chemistry	Teacher 1	5	4	2	11
	Teacher 3	8	4	6	18
Physics	Teacher 2	2	1	4	7
	Teacher 4	4	1	3	8
Biology	Teacher 5	12	7	4	23
	Teacher 6	13	4	6	23

Teacher 1 looked mainly at the practical skills of the student researchers while teacher 3 made comments on their procedural understanding. For example, referring to the graphs, teacher 1 said: *"The results, they did it quite neatly, drawing a table, I always tell students: first draw a table and then a matching graph. I don't see many problems with it."* Teacher 3 looked at the same graphs and focused on the validity between the data in the graphs and the conclusion. He said: *"It is clear that you have to draw a graph to visualise the results. You can directly notice that white chocolate has no effect on the first human test subject, because the blood pressure fluctuates all the time. And the blood pressure of the other human test subject ended lower, after rising first. Actually, they didn't measure a lowering of the blood pressure as they state in the conclusion."*

4.3 Knowledge of the students

4.3.1 About accuracy

During the interviews, one student used a correct relevant CoE to explain the meaning of accuracy in scientific inquiries: *"read out the measurement values with different people"*. All students mentioned that repeatability and reproducibility of the inquiry can be related to the reliability of an inquiry. Two students also used everyday terms to answer the question about accuracy. Similar results showed up in the questionnaire: four of the students used a correct relevant CoE to explain how accurate measurement values can be obtained during inquiries. Three students used a CoE that helps ensure reliability instead of accuracy: *"It is important to keep other influencing variables constant…every time you repeat the experiment"*. Thirty-two students answered in everyday terminology, such as *"doing something neatly"*.

4.3.2 About reliability

Two interviewed students made use of correct relevant CoE to explain how the reliability of an inquiry can be ensured. One of them mentioned the influence of diversity in a sample population on the reliability of an inquiry; the other stated that a researcher has to be sure that the variety in outcomes is not caused by measurement errors. Three students referred to CoE that help ensure validity or accuracy. All students explained in everyday language *"reliability can be ensured when researchers use sources of information that can be trusted"*. In the questionnaire, four students wrote down a correct relevant CoE to explain how to ensure reliability. Eight students used a CoE that deals with the validity of an inquiry. Twenty-eight of the students used everyday language to describe how to ensure reliability, mostly by giving synonyms–in Dutch–for *trustworthy* and *faithful* or by writing down the isolated words 'facts' and 'theories', without specifying their importance to reliability.

4.3.3 About validity

During the interviews, four students referred to correct relevant CoE that help ensure the validity of an inquiry, for example, by saying: *"In any case, the conclusion should be an answer to the research question and it has to be based on the results of the inquiry you have done"*.
One student mentioned a CoE about ensuring reliability: *"You have to keep the other variables constant"*. One student used everyday terminology to describe how the validity of an inquiry can be maintained. These results differed from the answers in the questionnaire. More than one-third of the respondents did not give an answer. None of the other students made use of a CoE to explain the meaning of validity. Sixteen students wrote down everyday language such as *"performed without any shortcomings"*. It sounds like these students were thinking of disabled people–in Dutch: 'invalid'.

4.3.4 Knowledge versus performance

Most interviewed students seemed to have a gap between their knowledge about ensuring the quality of an inquiry and their performance during the think-aloud task. For example, during the interview, one student explained how to deal with more than two variables: *"To get reliable results, you have to keep all variables constant, except the ones that are important for the inquiry."* However, while judging the student-written article, she did not notice the use of more than two variables and its influence on the results and conclusion.

5. Conclusion and interpretation

From the results, it can be concluded that students and teachers make use of relevant CoE in equal amounts to ensure the accuracy, reliability and validity of an inquiry, but have a different focus on the recognisable versus neglected items in the student-written article. This result does not correspond to our expectation that teachers–because of their experience–would mention more relevant CoE than students. It is surprising that students know such a lot about ensuring the quality of an inquiry.

A possible explanation for this result can be found by looking at the role of inquiries in the science curricula in the Netherlands in the past few decades. Inquiry projects became a major part of the curricula in around 1996. Teachers were expected to enact inquiry teaching in class, but were not trained on how to integrate these projects into their teaching. Only some teachers underwent a training course to become more expert in teaching students to inquire. As shown in the study of Gyllenpalm, Wickman and Holmgren (2009), teachers do not differentiate in their reasoning between methods of inquiry and methods of communication about inquiry. In our study, the same hybridisation can be recognised: teachers often talk about the products of inquiries while judging the quality of the inquiry. Based on this, it is not surprising that teachers do not use CoE to a large extent while judging the quality of a student-written article.

The difference between the teachers from different science disciplines can be interpreted by looking at the research contexts of their disciplines in more detail. While performing an inquiry in biology in upper secondary schools, one frequently has to deal with the natural variation of (formerly) live test subjects. A biological researcher always has to deal with limited reproducibility and repeatability of an inquiry because of this natural diversity (Pantin, 1968). It is possible that ensuring accuracy, reliability and validity in the present curricula in secondary schools is taught more explicitly in biological inquiry contexts than in chemistry or physics. As a consequence, the teachers might have judged the student-written article as they are used to judging the inquiries in their own subjects. This corresponds to a study of the UK Science Community Representing Education: most science teachers in secondary schools are confident in the research contexts of their own discipline, but are not convinced of their teaching skills in other research contexts. This problem appears to be more serious in physics than in biology or chemistry (SCORE, 2008).

About the meaning of accuracy, reliability and validity in science inquiry contexts, it can be concluded that students from upper secondary schools have some appropriate knowledge. Looking at the results of the questionnaire and interviews, it appears that the interviewed students have better abilities to mention correct relevant CoE about ensuring validity than the 'questionnaire students'. The results on accuracy and reliability were equal. A methodological reason for the difference in the validity results can be that the interviewed students were more focused on scientific reasoning than the others because of the think-aloud task they had performed just before the interview. In retrospect, it would have been better if the students had been interviewed before starting the think-aloud task to minimise this influence. On the other hand, the interviewed students mostly mentioned CoE other than those they had recognized in the student-written article, as illustrated in section 4.3.4: this student was probably told about influencing variables without improving her procedural understanding of the importance of controlling these variables in an inquiry.

In summary, we can state that these initial conditions are not disappointing where students are concerned, but that the knowledge of science teachers has to be expanded to give them the opportunity to teach how to ensure the quality of an inquiry more completely, with more reference to procedural knowledge and more coherently with the performance of students during inquiries.

6. Limitations

Because of the small number of participants, we have to be careful about generalising our conclusions. We tried to optimise the results by choosing participants from different schools. Another weakness of this study is that the conclusions are based on the performance during a think-aloud task and on interview results, so we do not know how students use evidence in the classroom while inquiring. However, the conclusions on judging the quality of an inquiry are similar to results of previous studies in the Netherlands and Sweden (Gyllenpalm et al., 2009; Schalk & Yuksel, 2009). Furthermore, although we selected a representative example of a student-written article from a database, it can be questioned whether the students and teachers would have arrived at similar results if another student-written article had been used in the think-aloud task. Finally, we realise that understanding CoE influences the understanding of the nature of scientific knowledge. However, we did not incorporate this broader perspective into our study, although it would have been interesting.

7. Implications

The results and conclusions of this explorative study will be used as hypothetical design principles for the next phases of our research about learning to inquire in different school science inquiry contexts. More knowledge of students' reasoning provides a starting point for the design of instructional and learning materials, such as rubrics–a formative assessment instrument (Arter & McTighe, 2001; Germann & Aram, 1996)–wherein the degree of mastery of each relevant CoE will be described. In addition, the instructional materials will be used to bridge the gap between the students' focus on recognisable items and the teachers' focus on neglected items. For example, teachers could first talk with students about what they have done and try to improve their inquiry based on the present results. Next they could give students feedback on elements they neglected.

It remains important in a new situation to figure out participating students' prior knowledge about ensuring the accuracy, reliability and validity of an inquiry. This information can be used to decide on the next steps in improving students' procedural understanding. Teachers need training to gain more insight into the improvement of procedural understanding and the use of CoE in the different science subjects before they can teach it. We expect that the findings of this explorative study will be useful in supporting our interventions to improve students' procedural understanding.

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Appendix

The following table was used to score the judgements of the students and teachers. The list consists of 47 different items which were all given an identifying number. For the purpose of our data analysis, we distinguished items about validity, reliability and accuracy. We also separated the recognizable items in the student-written article from the items that were neglected in the student-written article. Item 17 *"Results have not been interpreted by the students who did the experiments"* was removed from the list during the data analysis, as this item was considered to reflect communication about an inquiry more than students' procedural understanding.

Recognisable in the student-written article

No.	Description
	Validity
1	summary of the inquiry as described in the article
2	logical reasoning in theoretical framework
3	relation of theoretical framework to other parts of the inquiry
4	validity of research goal [blood pressure]
5	validity of research goal [pupil divergence]
6	quality of research question
7	stating of features to be observed [blood pressure, pupil divergence]
13	relation between experimental procedure and research question
15	table and graph with appropriate headings and captions
16	table and graph to sum up the results
18	use of results to found the conclusion
19	conclusion that matches the research question
20	conclusion that is restricted to the evidence of the inquiry
25	references that fit in with the inquiry
	Reliability
9	control experiment/blank [blood pressure]
22	evaluation of the reliability of the inquiry
23	consistency of conclusion with similar inquiries of other researchers
24	quality of references
	Accuracy
8	calculation of the amount of chocolate/cacao [control variable]
10	intervals of the independent variables
11	range of the independent variables
12	range and intervals of the instruments
14	scale distribution in the graphs
21	evaluation of accuracy of measurements [pupil divergence]

Neglected in the student-written article	
No.	Description
	Validity
26	refer to literature
27	specify the research question with operational questions
28	give a hypothesis about intended inquiry
29	give a prediction about intended inquiry
42	make a graph of the results of the inquiry [pupil divergence]
44	give a nomination of the type of relation [causal, correlation, functional]
47	evaluate the validity of the conclusion
49	give recommendations for further research
	Reliability
30	set apart the independent variable and dependent variable
32	perform a control experiment/blank [pupil divergence]
33	describe the expected influence of measurements on the outcome
35	keep other influencing variables constant
36	justify the sample size and its representativeness
40	describe the influence of measurements on outcome
43	repeat measurements
46	evaluate reliability results [blood pressure]
48	compare results with results of other experiments
	Accuracy
31	describe the appropriate sensitivity and range of instruments
34	describe expected spread of the dependent variable
37+39	calculate average values, deviation of measurement and statistical significance
38	indicate possible outliers
41	describe possible influence of human errors on measuring values
45	evaluate the accuracy of measurements [blood pressure]

5

DESIGN AND TEST OF OPEN-ENDED TASKS TO EVALUATE A THEORETICAL STRUCTURE OF MODEL COMPETENCE

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Abstract

Studies have shown that most students' conceptions of models differ from scientific conceptions (e.g. Grosslight, Unger, Jay & Smith, 1991). To describe scientific and everyday conceptions, Upmeier zu Belzen and Krüger (2010) developed a theoretical structure entailing two dimensions: 'knowledge about models' and 'modeling' which are subdivided into different aspects. This theoretical structure needs to be evaluated empirically.

This research project aims to operationalize and evaluate the theoretical structure using open-ended tasks. Fifteen tasks were designed and tested for understandability and consistency with the theoretical structure (N=912). The data were analyzed using qualitative content analysis (Mayring, 2003).

The article focuses on the findings concerning the dimension 'knowledge about models'. The analysis of student answers showed that difficulties mainly occur with the instructions and certain task contexts. Most student answers were consistent with the theoretical structure. The percentage distributions of the answers within each aspect corresponded to findings of other studies (e.g. Grosslight et al., 1991). One additional facet 'the uniqueness of models' was identified in student answers and needs to be considered. Moreover, students had alternative understandings of the term 'model', ranging from not perceiving certain objects as models to accepting everything as a model.

Keywords: models; model competence; theoretical structure of model competence; operationalization of a competence model; open-ended tasks.

1. Introduction

Models are an important part of scientific thinking and working methods. Thinking in models enables people to communicate about scientific topics and to gain flexible and transferable knowledge (Clement, 2000). Various studies have revealed that students reflect little on their thinking in and handling of models, and are not aware of the role models play in an epistemological process (e.g. Grosslight et al., 1991; Trier & Upmeier zu Belzen, 2009). Similar findings are given by PISA 2000 (Artelt et al., 2001) and 2003 (Prenzel et al., 2004), showing that students have difficulties in tasks where the handling of and thinking in models are essential to solving the problem. To relate scientific and everyday conceptions, Upmeier zu Belzen and Krüger (2010) designed a theoretical structure of model competence which needs to be evaluated empirically. The aims of this research project are to operationalize and evaluate the theoretical structure using open-ended tasks.

This article focuses on the findings of the design and testing of open-ended tasks to evaluate the theoretical structure for the dimension 'knowledge about models'. In addition, results regarding the content evaluation of the theoretical structure are shown.

2. Theoretical background

2.1 Scientific, students' and teachers' conceptions of models

Many different objects, such as toy cars, computer simulations, and formulas, are seen as 'models'. Despite this broad concept of the term 'model', there is one thing all models have in common: they are carriers of ideas and conceptions (Mahr, 2009; Stachowiak, 1973). Gilbert (1991) defines scientific work as a construction of models which represent concepts of the world. Therefore, models are the product and method of science. In biology education, the modeled part of the world is often called the original (Kattmann, 2006).

The model is characterized by two different relationships to the original (Mahr, 2009): the creation of a model object by observing the original (model *of* something) and the application of a model object by testing it and drawing conclusions on the original (model *for* something) (Mahr, 2009). These characterizations, model object, model *of* something, and model *for* something, are implemented in the theoretical structure (Upmeier zu Belzen & Krüger, 2010).

In contrast to these scientific conceptions, most students refer to concrete objects such as replicas when thinking about the term 'model', or describe differences between model and original regarding the color, shape, dimension, or material (e.g. Grosslight et al., 1991; Trier & Upmeier zu Belzen, 2009). Another student conception is that there are multiple models to one and the same original because of different views of the same entity, such as different angles or inside/outside. It is rather rare that students justify different models by noticing different hypotheses (Grosslight et al., 1991). Teachers show similar conceptions of models (e.g. Crawford & Cullin, 2004, 2005; Van Driel & Verloop, 2002). A common conception is that '*only one, "the correct model", is possible for a particular phenomenon*' (Justi & Gilbert, 2003, p. 1375).

2.2 Concept of competence

The concept of competence is based on the definition of Weinert (2001), who understands competence '*as referring to combinations of those cognitive, motivational, moral, and social skills available to (or potentially learnable by) a person...that underlie the successful mastery through appropriate understanding and actions of a range of demands, tasks, problems, and goals*' (p. 2433). This study focuses on the cognitive part of Weinert's definition.

2.3 Model competence

2.3.1 Theoretical structure of model competence

Model competence for the school subject biology is understood as the ability (Upmeier zu Belzen & Krüger, 2010):

- to gain purposeful new insights into biological topics using models,
- to judge models in relation to their purpose, and
- to reflect on the epistemological process using models.

Upmeier zu Belzen and Krüger (2010) developed a theoretical structure based on empirical studies (Crawford & Cullin, 2005; Grosslight et al., 1991; Justi & Gilbert, 2002, 2003). It entails two cognitive dimensions of model competence: 1. 'knowledge about models' (Table 1) with the aspects 'nature of models' and 'multiple models' and 2. 'modeling' with the aspects 'purpose of models', 'testing models', and 'changing models'. Each aspect is further divided into three levels which are based on Mahr's (2009) three perspectives: the perspective on the model object itself, the creation of models, and the application of models. These levels do not describe developmental levels, as the research on this aspect is not yet complete.

2.3.2 Dimension 'knowledge about models'

This article focuses on the dimension 'knowledge about models' (Table 1). This dimension describes individual cognitive concepts of models and deals with aspects of the nature of science. For the aspect 'nature of models', students compare the model with the original and comment on the extent to which the model is comparable with the original. Three positions are differentiated: a model is understood as a replication, as an idealized representation, or as a theoretical reconstruction (Upmeier zu Belzen & Krüger, 2010). The aspect 'nature of models' focuses on the perspective concerning the creation of models (Mahr, 2009). The aspect 'multiple models' refers to one and the same original being represented by different models. Students give varying explanations for these different models: they justify the presence of several models for one original by describing differences between the shown model objects, by arguing that the original allows the building of different models, or by noticing different hypotheses (Upmeier zu Belzen & Krüger, 2010). For the aspect 'multiple models', the levels describe the three perspectives of Mahr (2009).

Table 1
Structure of the dimension 'knowledge about models'
(Upmeier zu Belzen & Krüger, 2010)

Level / Aspect	I	II	III
Nature of models	replication of the original	idealized representation of the original	theoretical reconstruction of the original
Multiple models	differences between different model objects	the original allows the building of different models	different hypotheses about the original

3. Aims of the research project

The aims of our research project are to operationalize and evaluate the theoretical structure using open-ended tasks. Students' conceptions of models and modeling, and their impact on model competence, were determined during interviews (Trier & Upmeier zu Belzen, 2009). These served as background information for designing tasks. Compared to interviews, open-ended tasks are suitable for evaluating the theoretical structure of a larger sample in both (qualitative and quantitative) ways. Terzer, Krüger, and Upmeier zu Belzen (2009) realized these aims using multiple-choice, Krell and Krüger (2010) using forced-choice items, and Hänsch and Upmeier zu Belzen (2010) using hands-on assessment. These different approaches make it possible to cover different facets of model competence concerning thinking in, and handling of models.

4. Research questions

The first investigation was conducted to evaluate fifteen designed tasks:
To what extent do the student answers and comments indicate difficulties in understanding the tasks?
To what extent do the developed tasks enable students to answer at all three levels of the theoretical structure?
The tested and selected tasks were used to evaluate the theoretical structure:
To what extent are the student answers consistent with the theoretical structure?

5. Research design and method

5.1 Design of the open-ended tasks

For the first study, five open-ended tasks were designed for each aspect based on the theoretical structure. Each task consists of a short task context, a visualized biological model, and a standardized instruction (Table 2). The visualized figures represent functional, structural, and/or abstract models. The tasks were designed such that it should be possible to give answers at all levels.

Table 2
Standardized instructions for each aspect used in the first study

Dimension	Aspect	Instruction
Knowledge about models	Nature of models	Explain to what extent the model is comparable to the original.
	Multiple models	Explain why there are different models.

For the statistical analyses, the task pool needed to consist of three tasks for each aspect. These were selected based on whether the students understood the task context and if it was possible to give answers at all three levels (cf. 5.4, 6.1, 6.2). Three selected tasks of the aspect 'nature of models' were optimized and tested in a second investigation.

For the aspect 'multiple models', we could not continue to use either of the developed tasks and five tasks had to be redesigned, tested in a second study, and reduced to three tasks based on the above-mentioned criteria. Figures 1 and 2 exemplify tasks for both aspects with the above-described task structure, but with optimized instructions.

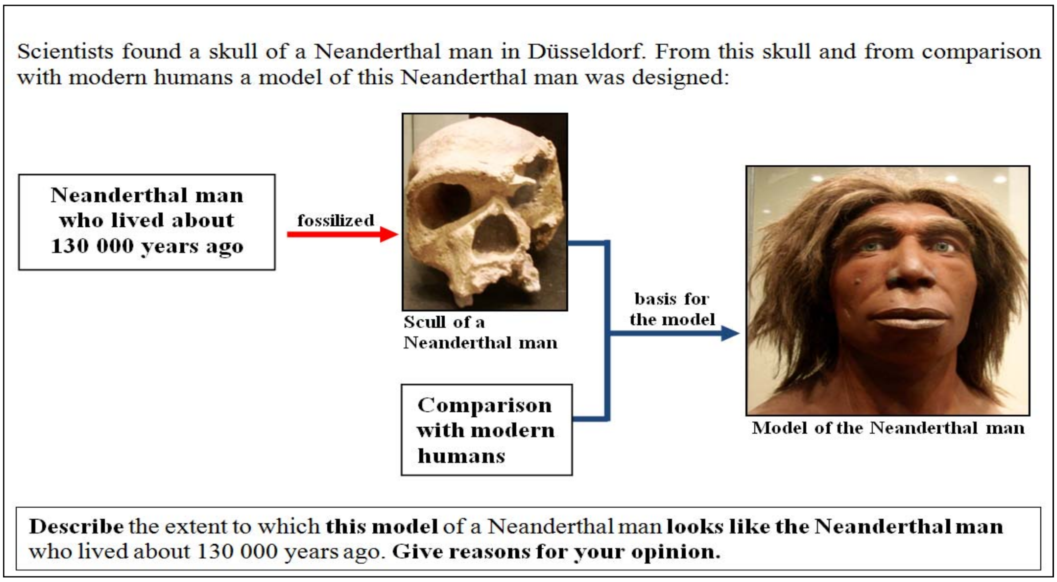

Figure 1
An optimized task for the aspect ‘nature of models’ used in the second study

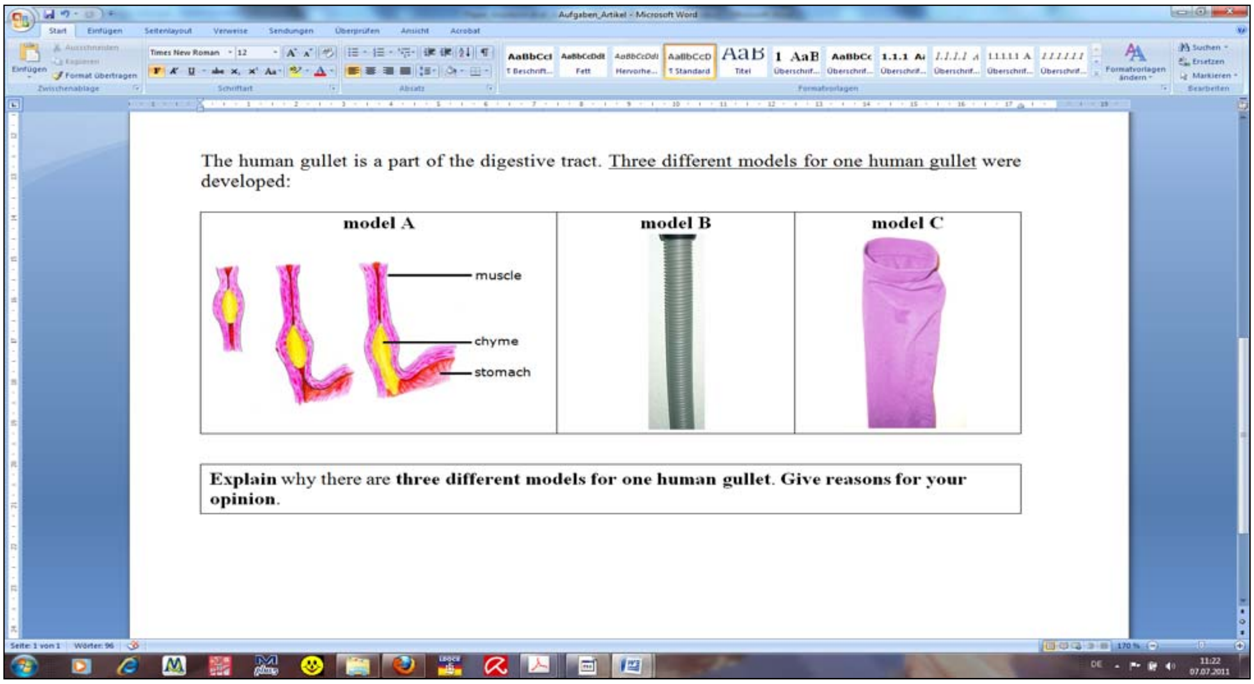

Figure 2
A redesigned task for the aspect ‘multiple models’ used in the second study

5.2 Sample

The first study with five tasks on each aspect was conducted with 406 7th and 10th-grade students (Realschule and Gymnasium, 12-17 years old). For the second study, three selected and optimized (nature of models) and five redesigned (multiple models) tasks were used and data were collected from a total of 506 8th, 9th and 10th-grade students (Realschule and Gymnasium, 13-18 years old). To obtain student answers at all three levels, different types of secondary schools and grades were chosen in both investigations. Since one student could not answer all tasks, the task pool was distributed in ten (first study) and five (second study) test booklets (multi-matrix design: Colbourn & Dinitz, 1996). Due to a test manual containing information about the research project, task format, and testing procedure, both investigations were standardized. In both studies, the students had 45 minutes to complete the test booklet. In the first study, each task was answered by about 100 students and in the second study, by about 130 (nature of models) or 70 (multiple models) students. Tasks relating to the same context were only compared with respect to students' responses if they were used in both studies.

5.3 Data processing

The data were analyzed by qualitative content analysis according to Mayring (2003), assisted by MAXQDA. Manual digitization and paraphrasing were used to obtain students' model competence. In an inductive approach, the student answers were summarized and categories were generated describing different students' conceptions of models. This categorization enabled a detailed description of each aspect. To evaluate the assigned student answers, additional coders were consulted. The assigned student answers from two coders were compared and differences were discussed until a consensus was reached (Gropengießer, 2001). Subsequently, the categories were assigned to the three levels of the theoretical structure (deductive approach).

5.4 Evaluation of the tasks

To determine whether students understand the tasks, a protocol was written during the investigation in which all upcoming questions and answers given by the test administrator were noted. In addition, the students were asked to make a note if they had problems understanding the text or figures. The level of correspondence between the instruction and the student answer is also a valuable indication of students' understanding of the tasks. In addition, the student answers were used to evaluate the extent to which it is possible to give answers at all three levels. If a student answered on different levels, his/her highest level was noted.

5.5 Consistency of the student answers with the theoretical structure

The student answers to the selected tasks were used to give some indication of the content evaluation of the theoretical structure. Therefore, the generated categories describing different students' conceptions were compared with the content of the theoretical structure.

6. Findings

6.1 Students' understanding of the designed tasks

6.1.1 Nature of models

The analysis of the student answers and comments showed a few difficulties in understanding certain parts of the task: a problem was caused by the term 'comparable' in the instruction: 'Explain to what extent the model is comparable to the original.' Some students used this term to answer the question, but they did not compare, or only insufficiently compared the model with the original: '*The mouth of the Neanderthal man is comparable with the mouth of the model'* (F1:82). The improved instruction (shown in Figure 1) led to more well-founded statements, for instance in the task 'Neanderthal man', there was an increase from 78% to 86% well-founded statements.

In addition, difficulties with certain contexts, such as DNA structure, were encountered. For this specific task, only 60% (n=102) of the student answers corresponded to the instruction and 17% of the students did not even answer this task. In contrast, only 8% (n=101) of the students did not answer the task 'Neanderthal man'. Therefore, those contexts were not used in subsequent studies.

6.1.2 Multiple models

Due to the imprecise and more open formulation of the instruction 'Explain why there are different models.' in the first study, 25% of the students (126 out of 510) justified the presence of different models with different originals. For this reason, 'one original' was referred to in the context and the instruction, as shown in Figure 2. The additional words were underlined in the context and highlighted in bold letters in the instruction. Despite these changes, 12% of the students (25 out of 204) in the second study still justified the presence of multiple models by different originals.

The data of the first study also revealed that students sometimes give short or no reasons for their opinion: '*There are two models in order to compare them with each other*' (F1:467). These reasons are important for a distinct assignment to the three levels of the theoretical structure. Therefore, the sentence 'Give reasons for your opinion.' was added to the instruction, to ensure well-founded statements. The optimized tasks (Figure 2) show pictures of models, making it easier to clearly identify more visual differences between the models such as different colors, different materials, or different perspectives.

As previously mentioned, students had difficulties understanding certain contexts, such as DNA replication. For this specific task, only 48% (n=102) of the student answers corresponded to the instruction; 16% of the students did not provide answers to this task. Contexts with such problems were not used further. In contrast, only 7% (5 out of 73) of the students did not give an answer to the redesigned task 'gullet'.

6.2 Student answers at all three levels

Most of the student answers to the aspects 'nature of models' (Table 3) and 'multiple models' (Table 4) could be assigned to the three levels of the theoretical structure. The developed tasks enabled students to give answers at their individual level.

6.2.1 Nature of models

Table 3 shows several prominent student answers for each level concerning the aspect 'nature of models'. Students at level I are characterized by an understanding of models as an exact copy or an almost exact replication of the original: '*The model shows how a Neanderthal man looked like*' (F1:476). In this context, some students show great confidence in scientific work and their technical tools: '*The figure of the Neanderthal man matches the truth because this picture was developed by experts*' (F2:36); '*Due to recent visualizing techniques, a copy of an extinct species can be developed very easily*' (F2:70). If students mentioned uncertainties concerning the appearance or noticed differences between the shown model and the original, they justified this either as a poor replication or by mentioning differences between their own ideas about the original and the model: '*The model does not look as primitive as the Neanderthal man should be*' (F1:451).

Students at level II doubt that the model can be seen as an exact replication of the original. They realize that it is not necessary to duplicate everything of the original and that a model only shows extracts: '*The Neanderthal man looks more or less like the shown model. The height, length, and the size of the jawbones are right…However, what the hair looks like cannot be said*' (F2:13).

At level III, students question the entire appearance of the model object and recognize the model as a theoretical reconstruction: '*The model is only a reconstruction or an idea which cannot match reality*' (F2:116).

A comparison of the percentage distribution of student answers shows striking differences between the three levels. The majority of the students (50%/68% for first and second test, respectively) could be assigned to level I, followed by level II (16%/15%). Only a few students gave answers at level III (4%/3%).

Table 3
Prominent student answers for the aspect 'nature of models' for each level

Level	Frequency of student answers: in absolute values and %, first test: (n=509)	Frequency of student answers: in absolute values and %, second test: (n=392)	Prominent student answers (student number)
I	253 (50%)	266 (68%)	*I think that the Neanderthal man does not look like the shown model because the model looks too fancy and the Neanderthal man should have a different look than that* (F1:505)
II	80 (16%)	59 (15%)	*I think that the model does not present the exact appearance of the Neanderthal man. However, it is possible to present an approximate appearance* (F1:408)
III	21 (4%)	12 (3%)	*The shown model is just a possibility of how a Neanderthal man could have looked. The bone structure has been recreated. ... However, they cannot be a 100 percent sure about that* (F1:156)

6.2.2 Multiple models

Table 4 exemplifies prominent student answers for each level of the aspect ‘multiple models’. Students at level I express their justification for the presence of multiple models to one and the same original by describing the model objects. They compare the model objects with each other and argue with different visualizations, materials, or material properties: ‘*Model B and C are different by their appearance. Model B is rather inflexible, whereas model C is really flexible. Model A is a drawing*’ (F2:64). An explicit reference to the original is not made. In fact, student F2:117 mentions the original ‘*I think only model A looks like a human gullet*,’ however, does not see the model as the result of a determined observation of the original (model *of* something).

Students that achieved level II justify the presence of multiple models to one and the same original by different key thematic aspects focused on by the modelers during the creation of the models: ‘*There are different models because you can turn your attention to different characteristics of the gullet. Model A shows muscle movements, model B the structure, and model C shows that the gullet is not completely inflexible. To show all these characteristics in one model is almost impossible*’ (F2:61). Here, an explicit reference to the original has been made.

At level III, students justify different models to one and the same original with different opinions of, or different hypotheses about the original, as exemplified in the following: ‘*Because there are different theories and opinions of the human gullet, there are different models. The scientists could also have different opinions*’ (F2:5).

Table 4 also shows the percentage distributions of the student answers. Most student answers in the first study (28%) could be assigned to level I, followed by level II (19%), whereas in the second study most student answers were given at level II (34%), followed by level I (27%). Level III (5%/15%) represents the lowest share in both studies.

6.3 Consistency of the student answers with the theoretical structure

For the aspect ‘nature of models’, the categories generated from student answers are consistent with the theoretical structure. For the aspect ‘multiple models’, the student answers show an additional perspective. As previously mentioned (cf. 6.1.2), 12% (n=204) of the students still justify the presence of multiple models with different originals, for instance: ‘*There is only ONE heart. Why do we need three models?*’ (F2:132); ‘*There are different models because there are different types of gullets. Additionally, the shape of the gullet can change after some years*’ (F2:352).

A further finding is that some students have alternative understandings of the term ‘model’. Figures that are clearly marked as models in the tasks are not understood as such. The alternative understandings of models are exemplified by the following statements: ‘*…because A is a real model, however, B is only a drawing*’ (F1:472) or ‘*Model B is a hose or a tube and model C looks like a sock*’ (F2:117).

Table 4
Prominent student answers for the aspect 'multiple models' for each level

Level	Frequency of student answers: in absolute values and %, first test: (n=510)	Frequency of student answers: in absolute values and %, second test: (n=204)	Prominent student answers (student number)
I	145 (28%)	56 (27%)	*Model B is firm and not so flexible, whereas model C is very flexible* (F2:118)
II	98 (19%)	70 (34%)	*Model A represents the gullet with its muscles and stomach. Model B shall show how the tube with its muscles (really) looks from the outside. With model C you can see how the gullet adjusts to its content* (F2:3)
III	28 (5%)	30 (15%)	*There are always different opinions of biological processes or structures. And one person could…probably imagine the gullet as something inflexible and not flexible. And some other person imagines the gullet as something really flexible…* (F2:49)

7. Summary and discussion

The results of the second investigation show that students understand the selected tasks. Initial problems concerning the instruction and the associated insufficient explanations could be solved.

The majority of the student answers for the aspects 'nature of models' and 'multiple models' could be assigned to the theoretical structure (Upmeier zu Belzen & Krüger, 2010). The percentage distribution of the student answers for the aspect 'nature of models' (Table 3) revealed that most students perceive models as a replication (level I) of the original. Although the chosen models, such as the model of the Neanderthal man, do not allow an obvious reference to the original, only a few students think of a theoretical reconstruction (level III). These results correspond with the study by Grosslight et al. (1991), who determined that students refer to concrete objects rather than to representations of ideas or abstract entities when thinking about the term 'model'.

The percentage distribution of the student answers for the aspect 'multiple models' (Table 4) in the first investigation demonstrates that most students explain the presence of multiple models by differences between the model objects in terms of color, shape, dimension, and material (level I). In the second study, most students justify the presence of multiple models by different thematic key aspects that modelers focus on during the creation of the models (level II). The conception of having different models because of different hypotheses about the original is rare in both studies (level III). Grosslight et al. (1991) note similar findings concerning levels I and II, showing that a prominent conception of students is that scientists could have different views of the same entities, such as different angles or inside/outside.

One possible reason for the prominent conceptions in both aspects of the theoretical structure might be a more frequent use of models as a substitute for the original or as a medium for transmitting information in biology lessons (e.g. Crawford & Cullin, 2004; Van Driel & Verloop, 2002).

For the aspect 'nature of models', the student answers are consistent with the theoretical structure. Referring to the aspect 'multiple models', the student answers show an additional facet: students justify the presence of multiple models with different originals even though there is a distinct reference to one original in the context and instruction of the redesigned tasks. Similar findings on the uniqueness of models are given by Justi and Gilbert (2003). Since the aspect 'multiple models' demands the conception of multiple models referring to one and the same original (Upmeier zu Belzen & Krüger, 2010), the facet of uniqueness is missing in the theoretical structure of model competence. Therefore, this perspective needs to be added to the aspect 'multiple models' as an additional perspective. However, to ensure that students have the conception of uniqueness of models, the following task has to precede the open-ended tasks: the students have to decide between the choices of 'one model to one original' or 'different models to one original'.

A further finding is that some students have alternative conceptions of the term 'model', for instance, they do not perceive drawings or analogies as models. According to Mahr (2009), everything can be perceived and function as a model. In that context, the theoretical structure does not need to be changed. However, there is a need to gain access to this understanding by asking students in a separate questionnaire.

8. Prospects

The findings of the second study concerning the uniqueness of models will be integrated and tested in further investigations. In spring 2011, the subsequent study will be distributed among a larger sample of students (N≈1000, grades 7-10) in order to evaluate the indications gained in the described studies and the theoretical structure of model competence. In addition to open-ended items, multiple-choice items (Terzer et al., 2009; funded by BMBF) and forced-choice items (Krell & Krüger, 2010) will be used. This study will allow a comparison of the findings of all task formats.

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6 USING A TEACHING-LEARNING SEQUENCE (TLS), BASED ON A PHYSICAL MODEL, TO DEVELOP STUDENTS' UNDERSTANDING OF SELF-ASSEMBLY

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Abstract

Self-assembly is a biological process in which free subunits combine to form molecular complexes. Despite being considered one of the 'big ideas' in molecular life sciences, only limited education research has been performed on this topic. The objectives of this study were to investigate students' learning of self-assembly in an authentic learning environment: a teaching-learning sequence (TLS). Twenty third-year biochemistry students in South Africa participated in the study. The TLS included a tutorial exercise with a physical model of a poliovirus capsid. A mixed-methods approach was employed to collect qualitative and quantitative data from interviews and written pre- and post-tests. A significant improvement in test scores was found, and it was observed that the TLS could support students' understanding of self-assembly. Some conceptual and visualization difficulties were also identified. Using the model in a TLS was associated with positive attitudes and engagement among the participants.

Keywords: external representation, interactive learning, post-secondary education, learning difficulties, molecular interactions

1. Introduction: rationale and theoretical framework

Self-assembly is a central concept in the molecular life sciences (e.g. Sears, 2008), because a variety of biochemical processes involve self-assembly, including virus capsid assembly. By definition, self-assembly is a process in which free subunits combine to form molecular complexes (Halley & Winkler, 2008). The process incorporates several scientific concepts that may be difficult for students to understand, including random molecular movement and various thermodynamic concepts (Banerjee, 1991; Gabel & Samuel, 1987; Garvin-Doxas & Klymkowsky, 2008). Considering these difficulties, which have mostly been studied at the upper secondary level, it is perhaps surprising to find that self-assembly is often sparsely described in university-level biochemistry textbooks. Furthermore, self-assembly has not been the focus of any educational research other than by our group.

According to a review of classroom-based science education research by Coll, France and Taylor (2005), group work and peer discussions are important teaching strategies to enhance students' cognitive and metacognitive skills and are therefore vital components of successful science teaching. Similarly, several research reports have provided evidence that supports the use of models as metacognitive tools in science education (e.g. Franco, 1999; Treagust, Chittleborough, & Mamiala, 2002). Other studies have also shown a positive effect on learners' cognitive development by introducing discussions of an exploratory nature with hands-on practical activities (Webb & Treagust, 2006).

In previous work, we observed that a 3D physical model of a poliovirus capsid facilitates students' learning of self-assembly (Höst, Larsson, Olson, & Tibell, 2010). In brief, the results revealed that many students are not familiar with how molecular complexes are formed. The physical model was shown to facilitate awareness of several aspects of self-assembly, for example, the importance of random molecular collisions. It was observed that many students who interacted with the physical model made fewer references to external influences, for example enzymes, on the self-assembly process compared to those who encountered a 2D picture. Interestingly, some students who interacted with the 2D picture suggested that enzymes could serve as generic 'drivers' of biochemical processes and events, including self-assembly. Similar results have been presented by Garvin-Doxas and Klymkowsky (2008), who found that students often emphasize the role of a 'driver' to explain processes with random components. Students in their study believed that diffusion only occurs when a concentration gradient is present, and hence students used the concentration as the 'driver' of this particular process. In this regard, the physical model may be less prone to supporting inappropriate reasoning about self-assembly than a 2D picture, possibly by representing the authentic nature of the process more clearly. In addition, the results suggested that the model can support and stimulate reasoning about self-assembly and thereby stimulate engagement of participants during group discussions.

Höst et al. (2010) focused on five facets that were considered essential for understanding self-assembly, namely, *random molecular collisions*, *influence of temperature*, *reversibility*, *differential stability*, and *error correction* (see appendix). Quantitative analysis showed significant improvement between the pre- and post-tests regarding students' understanding of the facets of *random molecular collisions*, *reversibility*, and *differential stability*, but not for the facets *error correction* or *influence of temperature*. The lack of observed learning gain for the facet *influence of temperature* could be partly explained by the students appearing to have a high prior knowledge from other domains, such as effects of temperature in organic chemistry and enzyme theory. However, data from group discussions and written responses indicated that the students had difficulties transferring their knowledge to the self-assembly context and often drew partly erroneous conclusions. It appeared to be challenging to discern the *error correction* facet from the model. This might be because direct observation of error-correction events during self-assembly of the model requires that the students periodically stop shaking the container and observe the contents, to discern what becomes of the complexes during the process. This suggests the importance of emphasizing the potential for errors during the exercise, so that the students become aware of the need for an explanation for the correction of errors. It is also important to make students aware of any strengths or limitations of the model (Schönborn & Anderson, 2010).

This paper describes the evaluation of a teaching-learning sequence (TLS) designed to teach the principles of self-assembly. TLS methodology is commonly used in the science education research tradition, and typically includes research into students' conceptions (Méheut & Psillos, 2004). In the present study, the TLS was based on the abovementioned 3D physical model, developed by Olson, Hu and Keinan (2007), in which we took cognisance of our previous above-described experiences. We addressed the following research questions:

1. What were the overall learning gains achieved by the students as a result of the TLS?
2. What changes in students' conceptual understanding could be observed after the TLS?
3. Did students show any conceptual or visualization difficulties with the principles of self-assembly?
4. What is the students' evaluation of the TLS and the physical model?

Three pedagogical models were used as theoretical frameworks to inform and guide our thinking regarding the design of the TLS, the design of the probes for understanding and the analysis of the qualitative data. These were the theories of Constructivism (e.g. Driver, 1989) and Active Learning (Treagust et al., 2002) and the model of Schönborn and Anderson (2009). Constructivists describe learning as an active process that enables students to make sense of new information, and as an interaction between prior student knowledge and new scientific theories. Active learning theory suggests that learning is successful if students are actively involved in learning (Treagust et al., 2002), if they can depict and organize important words and illustrations into logical mental models, and integrate the mental models with conceptual knowledge (Mayer, 2001, 2003). Schönborn and Anderson (2009) extended this thinking in their model of seven factors affecting students' ability to interpret representations. They emphasized the importance of the interdependent nature of possessing *both* sound cognitive and visual skills as well as appropriate conceptual knowledge in order to successfully interpret and learn from representations such as the virus model. In the present study, we used the above theories to ensure that the TLS involved tutorials that promoted active learning while we used a pre-/post-test research design to establish the nature of students' prior knowledge and development of understanding and difficulties during the TLS. In so doing, we also paid particular attention to developing the students' ability to use the virus model to visualize the process of self-assembly through application of the relevant scientific concepts.

2. Research design and methodology

2.1 Description of the model

A 3D physical model (Figure 1) was used for the study. The model is built from plastic using rapid prototyping technology, and is designed to mimic the self-assembly process of a poliovirus capsid. It allows the simulation of interactive self-assembly of a complete capsid by shaking a container with 12 identical subunits. Each plastic subunit has magnets along the edges to simulate the attractive forces between the corresponding protein subunits and to allow for formation of the complex.

Figure 1
The 3D physical model used in this study to represent the assembly of a polio virus capsid

2.2 Data collection and analysis

A TLS that included a group tutorial involving the use of the 3D physical model was developed in collaboration with pedagogical and biochemistry experts (Figure 2). The TLS was designed to overcome the difficulties observed in our previous study (Höst et al., 2010). First, an introductory session involved an interactive discussion with the students about the virus life cycle, to familiarize them with the context in which the investigated self-assembly process occurs. Second, an interactive group tutorial was conducted. A discussion facilitator supervised the tutorial, to structure and focus the discussion, and to promote scaffolding of student knowledge within an active learning environment. The tutorial followed a discussion guide that was designed to include specific questions matching all five facets and to avoid observed misinterpretations. Third, in a follow-up lecture, the principles of self-assembly were described together with some biological examples additional to the virus capsid. Here, the driving force and the five facets of self-assembly were discussed in detail. Any questions that arose during the TLS, as well as observed misinterpretations during the group work, were discussed. Both the discussion guide and the follow-up lecture were designed to get students to think critically about the limitations of the model.

The study group consisted of 20 third-year biochemistry students registered for a course on protein structure and function at a university in South Africa. All students completed written ethical consent forms. The students were divided into three groups during the tutorial. A mixed-methods study design (Figure 2) was employed to address the research questions presented above. Written pre- and post-tests, administered following the introductory session (pre-test) and the follow-up lecture (post-test), were collected from the 20 students. The pre-test and the post-test were identical, apart from the order of the items, which was different. Ten items, including two items for each of the five facets, consisted of statements which the students were asked to rate according to level of agreement on a five-point scale. An eleventh open-ended item asked the students to provide written descriptions of how they would explain self-assembly to a friend with limited experience of biochemistry. In addition, five of the students were interviewed approximately 10 days after the TLS to explore the nature of their understanding of the self-assembly process. The interview questions focused on students' attitudes to the TLS and the five facets of self-assembly.

Changes in students' understanding, including any evidence of difficulties, were investigated using both quantitative and qualitative approaches. Students' responses to the pre- and post-tests were scored by assigning a score of 5 for a correct response to an item, and 1 for an incorrect response. In-between responses were awarded scores of 4 and 2, and selecting the 'I

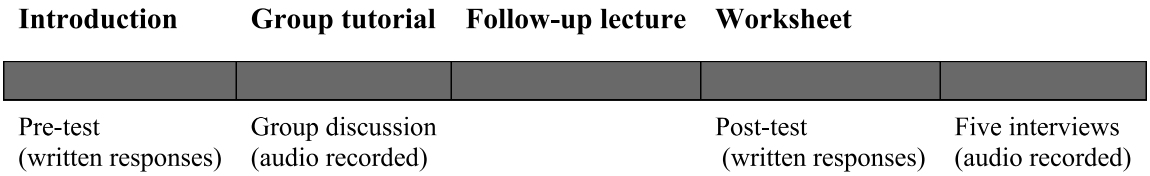

Figure 2

Research study design for investigating the TLS: the structure of the TLS is shown above the horizontal line and the data collection method below it

don't know' response was awarded a score of 3. For each facet, the scores on the two items were summed, and the effect of the TLS on students' test scores was checked using paired sample t-tests (n=20).

The open-ended responses to the pre- and post-tests and the interview transcripts were analyzed using qualitative content analysis (Graneheim & Lundman, 2004), looking for scientific knowledge and depth of intention. One aim of the content analysis was to elucidate the depth and character of students' learning. The analysis was systematic and performed in two rounds, one deductive and one inductive. In the deductive analysis, the model of the self-assembly process, defined by Höst et al. (2010) in terms of five facets, was used for categorization. In an inductive round, the responses were read for identification of additional themes according to the method of analytical induction (Abell & Smith, 1994). This analysis was used to identify students' conceptions about the process by assessing how they were able to elaborate upon the concepts in the context of an explanation or discussion, and further, to investigate how the physical model was used and how the students experienced the TLS and the physical model. Three experts in the field performed this analysis independently. In both rounds, the written responses and the transcripts were read several times, analyzed iteratively, and summarized independently by the three researchers. In the few cases of disagreement between assessments, a consensus was negotiated.

3. Findings: results and discussion

3.1 Learning outcomes achieved by the students

The quantitative analysis revealed significant improvements between pre- and post-test for *random molecular collisions* ($M_{difference}$=3.15, sd=2.34, t=6.01, α<0.005), *differential stability* ($M_{difference}$=2.00, sd=2.43, t=3.68, α<0.005), and *error correction* ($M_{difference}$=1.90, sd=2.55, t=3.33, α<0.005). The effect sizes were large for these results (i.e. eta-squared values>0.14). No significant differences were found for *reversibility* ($M_{difference}$=1.25, sd=2.71, t=2.06, α=0.053) or *influence of temperature* ($M_{difference}$=-0.30, sd=1.63, t=-0.825, α=0.419).

The results from the qualitative content analysis of the students' responses to the open-ended item on the post-test supported the above quantitative analyses. The majority (15 out of 20) of the students correctly included random collisions between subunits in their descriptions of the process. In addition, half of the students made references to *differential stability*, *error correction* and *influence of temperature* in their accounts. In contrast to the other facets, *reversibility* was only included in the post-test response by 5 (out of 20) students. In comparison, none of the students referred to any of the facets in their responses to the open-ended item on the pre-test.

The fact that many students exhibited a well-developed understanding of the influence of temperature is in apparent contradiction to the lack of a significant learning gain for this facet. However, this could be explained by a high mean score on the pre-test (M=8.3 out of a maximum possible score of 10), which limits the possibility of observing any learning gain from the test scores. Interestingly, some student difficulties concerning the influence of temperature were also found (further described in section 3.3).

The results presented in this study are based on data from 20 participating students. The quantitative and qualitative findings together constitute strong and reliable evidence for the success of the TLS in promoting understanding and revealing evidence of difficulties among the participants. Nevertheless, the relatively small sample size limits the possibility of generalizing the findings from the quantitative analysis to a larger population. However, the reproducibility of the quantitative findings are reinforced by comparing the results with findings from our previous study (Höst et al., 2010) (Table 1). In both studies, students' understanding of the facets *random molecular collisions* and *differential stability* is positively affected while the facet *influence of temperature* appears to be unaffected. However, the results diverge between the studies for the facets *error correction* and *reversibility*.

Table 1

A comparison of outcomes between the TLS and a previously conducted study (Höst et al., 2010). Significant (p<0.05) improvement between pre-and post-test is indicated by +, while a lack of improvement is indicated by 0

Facet	**Improvement**	
	TLS	**Previous study**
Random molecular collisions	+	+
Differential stability	+	+
Error correction	+	0
Reversibility	0	+
Influence of temperature	0	0

3.2 Changes in students' conceptual understanding

The most striking improvement in terms of learning gains was found for the facet *random molecular collisions*. Analyzing the interviews provides a more detailed understanding of the results. All interviewed students (5/5) said that they had not thought about the process prior to the TLS and that they took it for granted. The following excerpt illustrates how these thoughts were expressed:

- Did you know anything about self-assembly before the tutorial?

- No.

- Nothing at all?

- No…well I just took it for granted, cause it's self-assembly that it just happens [I: yes] but that's all that I know.

The data also show how some students tend to apply generic 'drivers' to biochemical processes and events (see Höst et al., 2010), as seen in the following two quotes:

- I didn't know it was spontaneous, I didn't [I: ok] I always…I thought it was some kind of factors that was influencing it actually happening.

- How can molecules just come and…and just make things, form a structure? [I: yes] That it actually has a self instruction [I: yeh] because you imagine that something like a structure will actually be induced by some factors…

It appears that the TLS challenges this idea and helps the students realize that the process is based on random interactions. In addition, the following student specifically describes her amazement over the random aspect of the process.

- Cause, when these things happen on its own and randomly…I just WOW [laughter] I haven't heard that before.

The shift in conceptual understanding is illustrated in the following quote by one of the interviewed students. She improved her score for *random molecular collisions* from a low pre-test score to a perfect post-test score. Furthermore, she did not mention randomness in the pre-test but consistently included it in her responses to the open-ended item in the post-test and other written responses, as illustrated by the following passage:

The process is random however if the interactions between the subunits are not "correct" or favored by the forces, their stability will be weak; therefore during random collision the complex will be broken down…

3.3 Conceptual and visualization difficulties

A few conceptual and visualization difficulties were revealed during analysis of the data. A more in-depth analysis is required to fully establish the nature of the difficulties, but a few examples are used here to illustrate some aspects. The first example concerns the facet *influence of temperature*, for which there was no significant improvement. It was found that the two test items presented for this facet differed in that the majority achieved high post-test scores on the item 'when the temperature decreases, each of the subunits move slower and collide with less energy', while little or no improvement was observed for the second item 'the stability of any complex of subunits increases with an increase in temperature'.

Insight into possible sources for this difficulty was gained from an interview. The student expressed the following two conflicting ways of reasoning and seemed uncertain about which was correct, choosing the incorrect view–that the stability of complexes will increase when the temperature is increased, when probed by the interviewer:

- If it's very high they [the capsid subunits] will be moving faster [I: mm] and hmm…well probably decrease the stability or maybe cause more collisions [I: mm] and more particles will form which means it will be more stable…[I: mm] I'm thinking this two ways [laughter]…"

The first half of this statement reveals an understanding of the first of the two test items, that as the temperature decreases the molecules will move more slowly, and vice versa (as in this quote). The second half concerns the second test item above, but the student wrongly assumes that the stability will increase with increasing temperature. It appears that the student connects the increased rate of collisions with an increased rate of product formation, which would be a reasonable assumption if it were a chemical reaction. However, it is not correct for self-assembly, since the relatively weak interactions (compared to the formation of chemical bonds) in the virus capsid will become insufficient at highly elevated temperatures. Thus, the student makes an inappropriate transfer of prior knowledge between chemical domains.

Furthermore, the student appears to confuse an increased rate of formation with increased stability. A possible interpretation is that this student erroneously assumes that an increased rate of formation implies a shift in equilibrium towards product formation, which would mean higher stability. Such confusion between kinetics and thermodynamics is a known misconception (Thomas & Schwenz, 1998). If this interpretation is correct, it would indicate that the difficulties displayed by this particular student may have two different sources, that is, partly incorrect chemical ideas and inappropriate transfer of prior knowledge from other chemistry topics.

In addition, another difficulty was demonstrated by a student who claimed that an increase in temperature will result in more errors, because subunits will move faster and therefore come together in the wrong way. This view is contradicted by the properties of the physical model, which might imply that some students find it difficult to discern the relevant model features that represent this aspect of the self-assembly process. Similar difficulties were found in our previous study (Höst et al., 2010).

A difference in learning outcome between this study and the previous one was observed for the facets *error correction* and *reversibility* (Table 1). A learning gain was observed for *error correction* but not for *reversibility*. The results were the reverse in the previous study (Höst et al., 2010). Possibly, the change in the discussion guide, to emphasize the occurrence of errors in the process, was successful in directing the students' attention to the *error correction* facet. Closer analysis of the results for the facet *reversibility* indicates that the students do improve their scores for one of the two items for this facet, but not the other. Care was taken to achieve a faithful translation from Swedish to English, so it is unlikely that the wording of this item causes the difference. Future analysis of the transcripts from the group discussions may provide clues to explaining this discrepancy between studies.

3.4 Students' evaluation of the TLS

Students' engagement in the TLS was generally high and the group exercise, including the physical model, was greatly appreciated. All five students interviewed highlighted the positive benefits of peer-engagement in the group discussion. Statements like the following were common.

- Yes…it was, really enjoyed it, it was relaxing… [I: mm] and we sat and we shared our thoughts we disagreed [I: yes] and in that we tried to find a conclusion [I: mm] and thereby also trying to improve our understanding [I: yeh] so it was really nice, yeh I really enjoyed it…even if time passed oh we have finished, we weren't even in a rush to go [Laughter] [I: yes] it was very inspiring and informative and stuff yeh [I: mm].

The physical model was also highly appreciated. Since the researchers acted as teachers in the teacher intervention, the students may have been biased towards positive responses in their evaluation of the TLS. Although this factor cannot be ruled out, the group discussions themselves contained many spontaneous expressions of enjoyment, which support the conclusions based on the interview data. The teaching context of group discussion activities can, in itself, promote positive attitudes among students, as suggested by recent reviews of classroom research (Coll et al., 2005).

During the interview, students were asked if the 3D physical model could be successfully substituted with another external representation of self-assembly, for example a 2D image. All interviewed students dismissed the idea of only using a 2D image. One young man made the following comparison.

- We could really visualize what happens in a cell compared to an image on a page.

Further, another student identified the possibility for interaction as one potential benefit of using this particular model instead of a 2D image:

- I think we were able to interact and we had to break the model up and put it together and we did this as a group so I think that was really nice.

Finally, many students expressed that experiencing how the physical model assembles on its own really helped them to understand aspects of the process. Below you will find two examples:

- It was nice to actually see a 3D version of it, it was really really nice [I: mm] and if you would have told me that, you know when asked if it would reassemble on its own? [I: yes] I would never have believed you if I haven't seen it for real…[laughter]…I was like oh that can't be.

- I could see, actually see that this is stable because of this…

4. Conclusions: educational implications of a TLS based on a physical model

In the present study, we show that the TLS developed students' conceptual understanding of the key principles of self-assembly, while also revealing certain difficulties. The students enjoyed the TLS and the model, which might, per se, contribute to our positive results. In accordance with our previous study (Höst et al., 2010), we can conclude that the model might decrease the risk of students developing ideas about a guiding principle in self-assembly. More specifically, using the physical model appears to help the students disentangle the facets *random molecular collisions*, *differential stability,* and *error correction* of the process. We suggest that this is explained in part by this inherently abstract molecular process becoming authentic for the students when they interact with the model. Despite some pre-knowledge of the effect of temperature on the movement of molecules, the students seem to have difficulties integrating the *influence of temperature* in their reasoning about the self-assembly process.

As suggested by several studies (Franco, 1999; Treagust et al., 2002), models can function as helpful cognitive tools in the science classroom. However, it is important to note that the students are not necessarily capable of transferring pre-knowledge from one domain to another. It is therefore also important for teachers to focus on verifying or questioning the students' ways of thinking and the validity and depth of understanding of their pre-knowledge, as well as to emphasize the limitations of the model and what facets it in fact illustrates. Future research will focus on a more in-depth qualitative analysis of the material and possibly studies with larger student numbers to enable generalization of our findings. This will allow us to improve the TLS, provide greater insight into the nature of student difficulties and how best to remediate them, with the ultimate goal of improving the learning and teaching of this important area of life sciences.

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Appendix

Facet	Definition
Random molecular collisions	Self-assembly proceeds through completely random collisions between subunits.
Reversibility	In self-assembly, interactions form and break continuously.
Differential stability	Multimeric complexes of subunits that form during self-assembly are increasingly stable as the number of subunits in the complex increases.
Influence of temperature	The stability of both correct and incorrect complexes during self-assembly decreases with increasing temperature, and vice versa.
Error correction	Self-assembly is self-correcting, since complexes with no biological function have low stability and all interactions are reversible.

(Höst et al., 2010)

7 CONCEPTUALIZATION OF IN-SERVICE BIOLOGY TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE (PCK) DURING A LONG-TERM PROFESSIONAL DEVELOPMENT PROGRAM

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Abstract

A case study of four in-service biology teachers revealed the possible relationship between pedagogical content knowledge (PCK) and the professional development process during a long-term course. Here we suggest a potential assertion of PCK components which enabled us to characterize a significant one: teaching strategies. Teachers in this study paid major attention to their unique teaching strategies in both their practice and their initiative development. The teaching strategies conception was found to be consistent and resistant to change. The teachers expanded their conception of teaching strategies over the course of the professional development program and developed their initiatives accordingly. We recommend that professional development designers be aware of this PCK component and find means of expanding it for better performance.

Keywords: pedagogical content knowledge (PCK); professional development; teaching strategy; conception; initiative

1. Introduction

A new program aimed at expanding science teachers' knowledge and empower them to improve science education in Israel was established at the Science Teaching Department of the Weizmann Institute of Science during the 2008-09 academic year. The new long-term program provides resources and professional support for knowledge expansion in both science and science education. Its main outcomes are designing and implementing initiatives to improve the teaching of science in high schools in Israel. The rationale for the biological part of this program lies in designing initiatives that are based on teaching needs as stated by the biology teachers themselves. This program addresses biology teachers' will, experience and knowledge, based on the well-known fact that teachers are an important resource for the implementation of changes in schools (Magnusson, Krajcik, & Borko, 1999; Parke & Coble, 1997; Tytler, Symington, & Smith, 2011; Van Driel, Beijaard, & Verloop, 2001).

Experienced teachers bring with them a unique teaching knowledge, termed pedagogical content knowledge (PCK) (Ball, Thames, & Phelps, 2008; De Jong & Van Der Valk, 2007; Lee & Luft, 2008; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Loughran, Mulhall, & Berry, 2008; Magnusson et al., 1999; Shulman, 1986). Many researchers have

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indicated that teachers' PCK guides their actions in teaching specific content in class (Lee & Luft, 2008; Magnusson et al., 1999; Van Driel et al., 2001; Van Driel, De Jong, & Verloop, 2002). However, little is known about the connection between biology teachers' PCK and the process of professional development in the course of developing initiatives in biology education–the focus of this study. As such, the study is based on the theoretical frameworks of PCK and professional development, which are briefly discussed in the following.

1.1 Teachers' knowledge base: PCK

Teachers and researchers agree that special knowledge is acquired by teachers during their teaching career. It was Shulman (1986) who first suggested referring to this knowledge as a special knowledge domain, the PCK. Researchers agree upon the nature of PCK as an integration of knowledge, skills and beliefs, acquired through teaching, and used in the context of teaching a specific content (Ball et al., 2008; De Jong & Van Der Valk, 2007; Lee & Luft, 2008; Loughran et al., 2001, 2008; Magnusson et al., 1999).

In an effort to analyze the PCK concept, researchers have variously categorized it, resulting in eight major categories of conceptualization (Lee & Luft, 2008; Park & Oliver, 2008; Van Driel, Verloop, & De Vos, 1998): 1. *knowledge of subject matter*; 2. *knowledge of representations and instructional strategies*; 3. *knowledge of student learning and conceptions*; 4. *knowledge of general pedagogy*; 5. *knowledge of curriculum and media*; 6. *knowledge of context*; 7. *knowledge of purpose* (some researchers refer to this component as *orientation toward science teaching and learning*); 8. *knowledge of assessment*.

PCK relates to teachers' knowledge, i.e. their professional knowledge base. This knowledge base refers to two different kinds of information: *knowledge* and *beliefs*. Knowledge refers to information that is certain, solid, dependable, and supported by research. Beliefs are what we think we know or may be coming to know based on new information; they are supported by experience, and people are strongly committed to them (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003).

Beliefs about the teaching practice are described in the literature in various ways (Van Driel, Bulte, & Verloop, 2007). In the literature on teachers' PCK, the term *orientation* toward teaching science is related to teachers' ideas about which subject matter is important to teach, and thus influences the choices teachers make in their teaching (Cohen & Yarden, 2009; Gess-Newsome, 1999; Magnusson et al., 1999; Van Driel et al., 2007). Teaching beliefs, from a constructivist perspective, are regarded as *conceptions* about the nature of science, scientific concepts, and how to learn and teach them (Da-Silva, Ruiz, & Porlan, 2006). Experienced science teachers have teaching conceptions that have been consolidated by their own professional experience, and these are usually stable and resistant to change. Sometimes this is because they feel satisfied with their teaching conception, and there is coherence between their goals, their conceptions, their educational practice and their perception of their students (Da-Silva et al., 2006); other times this may be because the conception is associated with a positive mood or because it was critical to the individual's survival (Sinatra & Mason, 2008).

Teachers' knowledge and beliefs inform the choices they make in terms of professional development (Loucks-Horsley et al., 2003), and may inform the designers of professional development programs on factors that they have to take into account while designing the programs.

1.2 Professional development

Teachers are able to take what they have learned from a professional development course and incorporate it into an ongoing program in the subject covered by the course. This places teachers' professional learning at the very center of what can be gained from such programs (Tytler et al., 2011). On the other hand, most subject-matter courses in teacher education programs are viewed by teachers as having little bearing on the day-to-day realities of teaching and little effect on the improvement of teaching and learning (Ball et al., 2008). There are no guidelines for which designs are right in a particular situation.

It is assumed that teachers need knowledge and skills to enhance the effectiveness of professional development programs and their ability to adapt to possible changes in their teaching. The concept of change itself denotes a "disruption in the status quo". Individuals possess a natural tendency to remain in a steady state, so any changes that disrupt this are viewed with caution and are only accepted if the perceived outcomes add value to the individuals (Hanley, Maringe, & Ratcliffe, 2008). It has been suggested that effective professional development programs should engage the teachers' knowledge and experience in decision-making for new curriculum and instructional issues as they reflect the connection between theory and practice (Parke & Coble, 1997). The professional development program examined in this study shifts the focus from teacher-training workshops, aimed at implementing curricula developed by others and sometimes removed from the teachers' experience, knowledge and beliefs, to promotion of the teachers' professionalism as curriculum developers. Promoting teachers' professionalism with acquisition of academic knowledge and participation in collaborative workshops may empower them to become more thoughtful about their profession (Parke & Coble, 1997). However, the process is rather complex, one reason being the importance of teachers' PCK base and its relation to the professional development program. Thus, the process of teachers' empowerment within a long-term professional development program is not straightforward.

The professional development program examined in this study was designed to help in-service teachers expand their knowledge in biology and biology education through designing initiatives that could be incorporated in the biology classroom. The ability to design and implement various types of science teaching initiatives that will be aligned with teachers' different PCK and students' different cognitive abilities and learning styles is seen as an important component in professional development (Hofstein, Carmi, & Ben-Zvi, 2003). Thus, this study's major objective was to characterize the possible changes in in-service biology teachers' PCK during the course of a long-term professional development program.

The specific research questions were:

1. What are the PCK components of the four biology teachers who participated in the program?
2. How do the various PCK components of these four teachers develop during the course of the program?
3. What are the relative proportions of PCK components related to teaching aspects in each of the four teachers?
4. How do the teaching strategy conceptions of each participating teacher develop over the course of the program?

2. Research design and methods

2.1 Research context

This research focused on four in-service biology teachers participating in a special professional development program established at the Weizmann Institute of Science. The main rationale of this program is to use the participating teachers' teaching knowledge, both scientific and educational, and experience to mutually design advances in the high-school biology program in Israel. The program's curriculum ran for eight hours weekly over the course of two academic years (Table 1). Each semester, the teachers participated in a different subject matter-oriented course in biology followed by a curriculum development course aimed at developing initiatives that might enhance biology teaching and learning in Israel. The course was named: "Initiatives development in biology". At the end of the day, the teachers participated in a basic science education course. The first author of this study was one of the instructors of the initiatives development course.

Table 1
Daily outline of the professional development program. Each period lasted approximately 45 minutes with two 15- to 30-minute breaks during the day

Periods	Course type
1-2	Biology course
3-6	Initiatives development course
7-8	Science education course

2.2 Sample

Of 27 biology teachers who submitted applications, five were selected to join the program, based on academic achievements, excellence in the teaching realm and motivation to develop initiatives. One of the five teachers missed numerous lessons in the first year and chose not to participate in the second year. Thus, this study focused on four teachers who fully participated in the professional development program. All teachers had M.Sc. degrees in biology and their teaching experience ranged from 6 to 17 years at the beginning of the program.

2.3 Research design

This study addressed the process of the teachers' professional development and the possible relations with specific PCK components during the course of initiatives development. Data were collected from multiple sources:

1. recorded lessons from the initiatives development course
2. recorded conversations about designing the initiatives and the participating teachers' reflections
3. e-mail correspondence between the teachers and researchers
4. the participating teachers' written assignments which were handed in to the initiatives course instructors
5. recorded presentations of the initiatives to other teachers

6. interviews with the program participants at the end of each year.

The data from the various sources were analyzed chronologically, according to the four phases of the course.

Phase 1: Eliciting prior knowledge and background. Conversations about teachers' dreams, teaching goals and the first meeting with the chief supervisor of biology education in Israel, assignments and e-mail correspondence about the teachers' professional background, expectations from the program and general ideas about initiatives in biology (Aug-Nov 2008).

Phase 2: Planning the initiatives. Lessons, conversations, assignments, e-mail correspondence, and initial presentations of ideas for initiatives and of preliminary parts of the initiatives to the group members, researchers in science education and the chief supervisor of biological education in Israel (Dec 2008-Feb 2009).

Phase 3: Assessing the initiatives. Lessons on initiatives assessment, reflective conversations about poster presentation of the initiatives, e-mail correspondence, questionnaires and interviews about the teachers' experiences after teaching and assessing a preliminary part of their initiative in class (Mar-Jul 2009).

Phase 4: *Writing and distributing the initiatives* to other teachers, researchers and science education students. Lessons on writing a teacher's guide, presentations of the initiatives, conversations, assignments, e-mail correspondence, and interviews with the participating teachers at the end of the program (Oct 2009-May 2010).

2.4 Data analysis

The groups' discussions, interviews, relevant e-mails, assignments, activities and lessons were fully transcribed. The data were divided into different episodes, which were classified according to their theme. We initially analyzed the PCK components according to the taxonomy suggested by Lee and Luft (2008), who summarized the main PCK categories appearing in the current literature, but we had difficulty aligning our data with a few of their categories. We therefore performed a qualitative analysis according to Shkedi (2003) and Chi (1997) and allowed categories of teachers' PCK to emerge from the data. The following steps were taken:

1. We read the transcripts several times and searched for recurrent categories and ideas as recommended by Shkedi (2003). Then the following four steps were taken: (i) forming primary categories from the collected data; segmenting the data into units, and categorizing every unit according to its content; (ii) developing more general domains; (iii) mapping all data according to the chosen domains; (iv) reorganizing the data according to the chosen domains. We then proposed assertions about the teachers' PCK components, and their possible relations with the teachers' professional development while designing the initiatives.

2. We attempted to capture the representations of the teachers' PCK as they were expressed in the data and to determine how those representations change with knowledge acquisition and actions, following Chi (1997). The verbal analysis added a quantitative dimension to our qualitative analysis.

Our assumption that the above methods would be successful in capturing the teachers' PCK components, although the data were not based on observations of the teachers' practice, is based on Van Der Valk and Broekman's (1999) "lesson preparation method" study. Those authors reported that this method is successful in the sense that teachers produce "rich" information about their PCK while reporting on their lesson design and teaching.

To validate the results, data were analyzed by the first author at two time points, six months apart. In addition, data were presented to five researchers in science education for peer validation twice during the data analysis. The first peer validation was used to examine the identity rate between the suggested PCK domains and their related components. The mean identity rate between the five researchers and the suggested classification of the three PCK domains and their related components was 92.3%. The identity rate of the "teachers' world" alone was 97.1%, the identity rate of the "students' world" alone was 83.3% and the identity rate of the "initiatives' world" alone was 96.6%.

The second peer validation examined the suggested analysis of the possible changes in the teachers' PCK along the program. Twenty-five episodes were given to three science education researchers who were asked to classify each episode according to the suggested PCK classification. The overall validation rate was 85.6%. Moreover, interviews were used for interpretive validity with the participants following the analysis of the teachers' PCK change. The relevant results on PCK dynamics were presented to each teacher, who were asked to express their opinions on the accuracy of the results. The validation rate was 94%.

3. Results

3.1 PCK components of the four teachers from the program

The teachers' PCK components were analyzed from the bottom up according to Shkedi (2003). Nineteen PCK components emerged in the course of this analysis, and were grouped into three main domains: teachers' world, students' world and initiatives' world (Figure 1). The components are numbered chronologically and described in detail below:

1. *Knowledge and beliefs about the teachers' world*, namely, about teaching science. This includes knowledge and beliefs about: i) difficulties in biology teaching; ii) the personnel that accompany the teaching (e.g. school principal or chief supervisor of biological education); iii) assessment of related contents; iv) teaching strategies; v) subject matter; vi) curriculum; vii) available teaching facilities.

2. *Knowledge and beliefs about the students' world*, namely, about students' learning processes. This includes knowledge and beliefs about: viii) students' prior knowledge; ix) students’ thinking skills; x) students' motivation to learn science; xi) means to promote students’ meaningful learning; xii) students' interest outside of the school context; xiii) the influence of science learning on students' future life.

3. *Knowledge and beliefs about the initiatives' world*, namely, about the process of development, assessment and distribution of initiatives. This includes knowledge and beliefs about: xiv) writing useful teachers' guide materials; xv) the process of initiative development; xvi) personal feelings during the development process; xvii) modes of assessing initiatives; xviii) means of distributing initiatives; xix) possible collaborations during initiative development.

Most of the above PCK components have strong correlations with the categories suggested in the literature. The initiatives' world contains components that are very specific to initiative development and thus may not be adequately correlated to the literature categories.

Figure 1
The three main domains of PCK emerging from this research

3.2 Changes in the teachers' PCK components during the course of the program

To reveal possible changes in the four teachers' PCK during the course of the program, we examined the research data according to the four phases of the course. Initially, we asked the teachers, in various ways, to describe their work, in order to capture the teachers' PCK prior to their learning in the initiatives program. In the three subsequent phases, we looked for possible changes in the teachers' PCK during the program and during the development of their initiatives.

Verbal analysis of the data following Chi (1997) revealed the proportion of each PCK component among the participating teachers and its change (Figure 2). Close examination of the data revealed some mutual patterns of the teachers' PCK components along the four phases of the course.

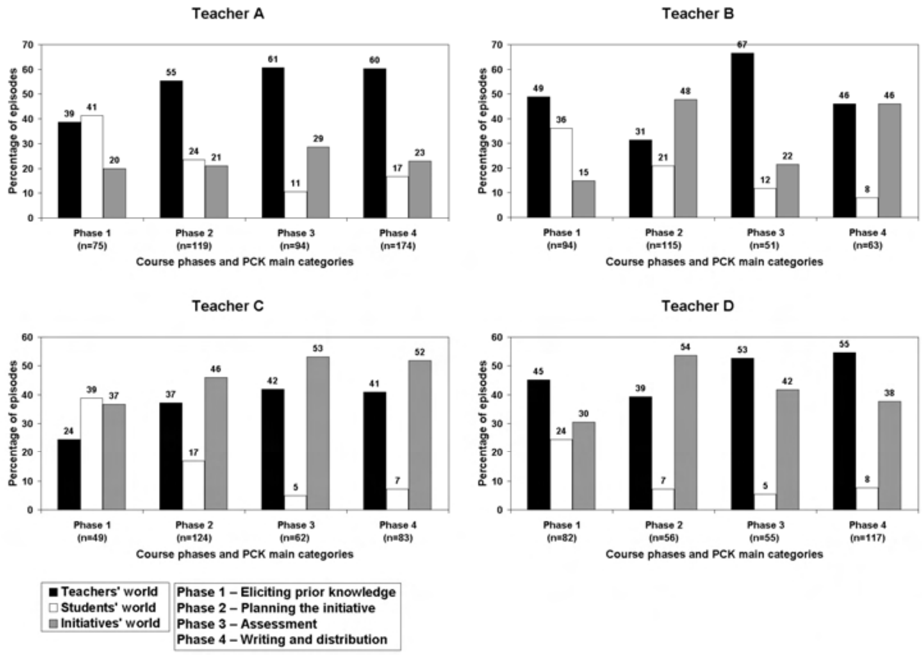

Figure 2
Distribution of the PCK domains for the four participating teachers through the four phases of the two-year program. Above each column, the percentage of each PCK domain is shown

The relative proportion of the initiatives' world remained steady or grew during the course of the program (Figure 2). The increase was expected, due to the course's contents and goals. These teachers were offered to design initiatives for the first time in their career, and thus they concentrated on themes related to initiative design, implementation and distribution. In contrast, the relative proportion of the students' world component decreased dramatically during the course of the program, particularly during phases 2 and 3. Since the teachers related less to the students' world in the materials collected during the course of the study, the meaning of the students' world component for the teachers' PCK cannot be revealed, due to the absence of discourse about this world.

The most interesting finding was an increase in the relative proportion of teachers' world as the course progressed and the fact that it stayed relatively high during phases 2-4. Thus, the teachers' world held significant weight in the teachers' PCK during the initiatives program. These results led us to carefully examine the components of the teachers' world to understand which PCK component is more important to the teachers during the course.

3.3 The relative proportion of teachers' world components in the teachers' PCK

In this section, we focus on the findings regarding the teachers' world. Presented in Figure 3 are the relative proportions of components of the teachers' world from episodes during the four phases of the course.

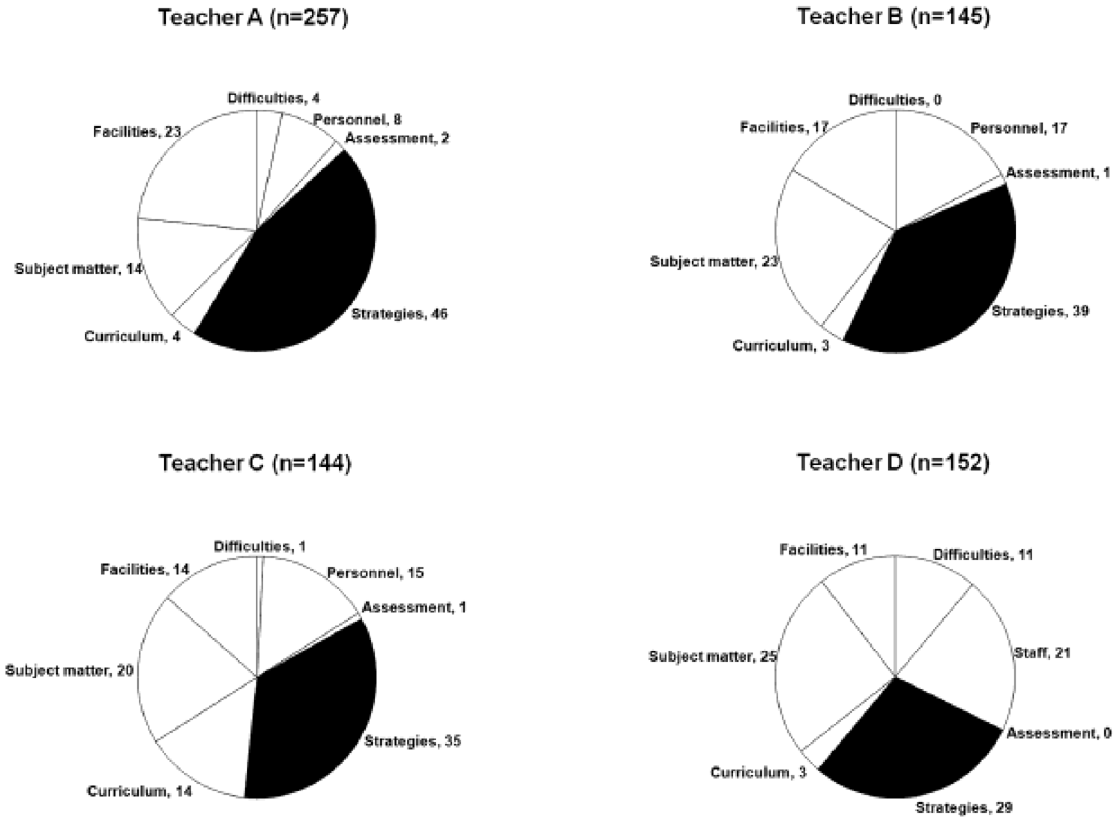

Figure 3
Percentage of teachers' world PCK components during the initiatives course

The most frequent teachers' world component for all four teachers was teaching strategies. All four teachers dedicated a third or more of their attention to this component. Although other patterns differed within the teachers' world data, the consistent dominance of the teaching strategies led us to focus on this component to reveal its significance to the teachers' professional development process.

3.4 Changes in the teaching strategies component for each teacher during the program

Teachers A, B and C each consistently related to a different, unique teaching strategy, which could be defined as the teachers' conceptions about teaching strategies due to their consistency and uniqueness. These teaching strategy conceptions expanded during the initiatives course, as described in detail below. Each teacher is described as a case study.

Teacher A increased her attention to the teachers' world during phases 2-4 of the study (Figure 2). In addition, Teacher A dedicated 45% of her attention to the teaching strategies component (Figure 3). At the beginning of the program, Teacher A concentrated on connecting the contents of several concepts and processes in biology as a leading teaching strategy concept aimed at helping students learn meaningfully. In phase 2, she developed an initiative that uses laboratory-based skills to strengthen biological knowledge that had been previously learned in class. In that way, Teacher A expanded her teaching strategy conception to a strategy that connects skills and content. Teacher A ended the program developing a different initiative that enables the student to use high-order thinking skills, such as inquiry-based laboratory skills, to learn new contents. Thus, Teacher A further expanded her teaching strategy conception to one that works to connect high-order thinking skills and knowledge construction, in order to scaffold meaningful learning.

Teacher B dedicated 39% of her attention during the program to the teaching strategies component (Figure 3). Her attention to the teachers' world showed a particular increase in phase 3 (Figure 2). Teacher B developed bioethical dilemmas together with Teacher C. Teacher B had a very strong conception about teaching using interesting stories from everyday life. In the first phase, she described her teaching strategy as random, connected to everyday life stories in order to motivate her students to learn. In her initiative design in phase 2, she concentrated on a story about a family with a genetic disease. She saw this story as the main scaffold of an initiative that might scaffold the students' knowledge. As the course continued, she began to understand the importance of teaching according to the teaching sequence of the syllabus and of planning the lesson in advance. This occurred in phase 3, when she assessed and reflected on her initiative after teaching it in her class, and she thus expanded her teaching strategy conception to be more ordinate and syllabus-related. Along with the improvement in her teaching strategy, Teacher B improved the contents of the initiative by bringing other stories that better explained the dilemmas in question. By the end of the program, she was still looking for "interesting stories" to teach and insert into her initiative design, and a relatively high percentage of her attention was still on the teachers' world (Figure 2).

Teacher C was Teacher B's partner in developing bioethical dilemmas. Teacher C's attention to the teachers' world increased during phases 2-4 (Figure 2); 35% of Teacher C's attention was given to the teaching strategies component. Teacher C had a very strong conception about teaching biology as a means of educating her students on human values. Her main focus was on collecting arguments for and against the dilemmas from various aspects: religious, economic, legal, moral and political. In the initial phase, she paid relatively little attention to the importance of scaffolding biological knowledge in her practice; she gave relatively less attention to the teachers' world (Figure 2). At the end of phase 3 and during phase 4, Teacher C began to seriously refer to the scaffolding of biological content knowledge in her initiative as well as in her practice. In phase 3, she reported that she had become more aware of meaningful learning and spent time establishing students' understanding while teaching: in addition to humanity education, she began asking questions, and thus establishing students' knowledge, evidencing an expansion of her teaching strategy conception.

Teacher D's data show that although about a third of her attention was focused on the teaching strategies component (Figure 3) and she increased her attention to the teachers' world in phase 3-4, unlike the other three teachers, she did not hold a central conception about teaching strategies. Most of the data show that during the meetings, Teacher D mainly asked the others about their teaching strategies. During phase 1, she did not speak about her teaching strategies at all, but instead spoke relatively more about her difficulties in teaching biology. Teacher D was the least experienced of the four, and it appears that she had not yet developed her unique teaching strategy conception. Along with difficulties in her practice, she experienced difficulties in developing her initiative, which consisted of adapted primary literature articles in ecology. As the program continued, Teacher D felt that she had had a good experience in teaching her initiative. She reported in phase 3 that her students had shown interest in the content of the article, even during a school trip to the desert. After asking many questions about the right way to teach articles in class, Teacher D decided to teach them using a strategy of students' knowledge construction via teacher's questions. Along with the progression in the initiatives development (phases 3 and 4), Teacher D stopped complaining about teaching difficulties and kept referring to the teachers' world (Figure 2) in trying to construct her teaching strategy conception.

These data show that the three experienced teachers of this program (A-C) had developed their unique teaching strategy conceptions during their long years of practice. The only teacher who did not have a clear teaching strategy conception tried to establish it during the professional development program. Nevertheless, all four teachers showed progress in their practice throughout the course of the program.

4. Discussion

For many teachers, professional development programs are an opportunity for professional renewal (Tytler et al., 2011), where they become students and thus engage their own existing knowledge in the acquisition of new knowledge. In our program, the teachers not only learned new scientific and science education knowledge, they also developed new initiatives on the basis of their knowledge, professional experience and needs. As such, the course requirements combined knowledge with practice, and it was therefore expected that the teachers would use their PCK as a basis for further professional development. Science teachers are regarded as having conceptions about the nature of science, about scientific concepts and about how to learn and teach them (Da-Silva et al., 2006). This study proposes that conception about teaching strategies is a significant component of in-service teachers' PCK.

The experienced teachers that took part in this research had unique conceptions of teaching strategies that were resistant to change. The high proportion of the teaching strategies component in the research data implies that this is a significant factor in the teachers' practice and professional development. Although conceptions are resistant to change, they are capable of expansion. The less experienced teacher in this study had not yet established her unique teaching strategy conception. However, she attempted to form one throughout our program.

Designers of professional development programs should be aware of the unique teaching strategy conceptions that each teacher may hold. They can then focus on expanding them for better performance or try to help a teacher who does not hold any such conceptions to establish one.

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8 STRATEGIES TO IMPROVE UNDERSTANDING AND USE OF HIV/AIDS CONCEPTS BY GRADE 11 BIOLOGY STUDENTS IN SOUTH AFRICA

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Abstract

Transformative learning is a philosophy that argues that education should empower students to use knowledge to construe experience and resolve social problems such as HIV/AIDS. In South Africa, attempts to reduce the spread of HIV include incorporating HIV/AIDS education in the biology curriculum. However, there is a dearth of knowledge regarding the effectiveness of biology-based HIV/AIDS education. The current study therefore aimed to identify strategies that can be used to enhance biology students' understanding of HIV/AIDS and promote the use of this knowledge in their daily lives. A predominantly qualitative mixed-method approach with Delphi technique was used to gather and analyse data from secondary-school biology students and teachers, as well as HIV/AIDS experts specializing in medicine and research. Findings show that most students rely on knowledge learnt in biology to make decisions related to HIV/AIDS. Participants suggested that HIV/AIDS education should be taught collaboratively by teachers, people living with HIV, and HIV/AIDS experts. Biology concepts and teaching strategies that could enhance students' understanding of HIV/AIDS, and which are not part of the current biology curriculum, were identified. Overall, the study showed that to be transformative, biology-based HIV/AIDS education needs to adopt an inclusive, critical theorist approach.

Keywords: HIV/AIDS; biology; transformative learning.

1. Introduction

Education has the potential to transform lives through acquisition and utilization of knowledge and skills (Baumgartner, 2001). However, this potential rests within the philosophical parameters that frame education in a given context (Healy & Perry, 2000). The philosophy of education determines: i) concepts that should form part of the curriculum, ii) the strategies for teaching, and iii) the process of learning in any given context (Cohen, 1999; Healy & Perry, 2000; Hlebowitsh, 2006). For instance, where general science literacy is the priority, essentialism may be used as a philosophical basis for selecting foundational scientific concepts that will be taught (Cohen, 1999). Thereafter, constructivism can be an ideal learning and teaching strategy (Thompson, 1995).

1.1 Theoretical background

The area of HIV/AIDS education is an intriguing one, particularly in South Africa where HIV/AIDS remains a serious challenge almost 30 years after its discovery (Dimmock, Easton, & Leppard, 2007). Although education-based attempts have been made to promote HIV/AIDS awareness, some scholars argue that these attempts lack effectiveness (Bertrand, O'Reilly, Denison, Anhang, & Sweat, 2006; Page, Ebersohn, & Rogan, 2006). Other scholars blame this ineffectiveness on inadequate and scientifically inaccurate HIV/AIDS information being taught in schools (Anderson & Beutel, 2007; Dorrington, Johnson, Bradshaw, & Daniel, 2006). There is therefore a need to improve the standard of HIV/AIDS education in schools guided by a lucid HIV/AIDS education philosophy, and by improvement of content knowledge as well as the manner in which HIV/AIDS is taught (Anderson & Beutel, 2007). This transformation should focus mainly on biology education where scientific knowledge related to HIV/AIDS is taught (Anderson & Beutel, 2007; Baumgartner, 2001; Department of Education, 2003).

There is a dearth of knowledge on whether the current biology education in South Africa is providing students with adequate knowledge to change attitudes, subjective norms and perceived behavioural control in the context of HIV/AIDS (Guo et al., 2007; Hansen, Jensen, & Solgaard, 2004). According to the theory of planned behaviour, attitudes, subjective norms and perceived behavioural control are factors that determine behaviour (Ajzen, 1991). However, the theory of planned behaviour acknowledges that behaviour is not directly influenced by knowledge (Ajzen, 1991). In the context of HIV/AIDS, behaviour such as promiscuity has been labelled the major factor propelling the spread of HIV (Anderson & Beutel, 2007). Given this, scholars such as Baumgartner (2001) argue that through transformative learning, students' behaviour can be changed. The philosophy of transformative learning explains how beliefs, formulated within cultural contexts influence meanings derived from experiences (Mezirow, 1991, 1996). Consequently, transformative learning can transform students' perspectives about themselves and their world (Baumgartner, 2001). Such learning is based on empirical-analytical discovery (Mezirow, 1996) and the understanding underlying meanings of values, ideals and feelings. Scholars (e.g. Freire, 2000; Mezirow, 1991) agree that learning should provide students with life skills and knowledge that can be used in dealing with real-life challenges. As a result, biology education should lead to the empowerment of students in matters such as HIV/AIDS (Baumgartner, 2001).

1.2 Objectives and research questions

Based on the above arguments, the current research aimed to identify strategies that can be used to enhance biology students' understanding of HIV/AIDS and the use of this knowledge in their daily lives. To contextualize this aim, the following research questions were asked:

1. Are the concepts related to HIV/AIDS currently taught in biology used by students in their decision-making?

2. What can be done to enhance the understanding and use of HIV/AIDS-related concepts for biology students?

These questions were asked based on the acceptance that the biology curriculum teaches students various HIV/AIDS-related concepts and skills that foster the ability to "construct and apply knowledge" (Department of Education, 2003). As a result, by understanding these concepts, students will have some ability to use the knowledge in their lives in the context of HIV/AIDS.

With respect to data collection and analysis towards answering the above research questions, three areas were attended to: i) determining the tendency to apply HIV/AIDS-related knowledge currently taught in biology to real life, ii) identifying HIV/AIDS-related concepts that should be taught in biology to transform lives, and iii) identifying teaching strategies that will best help students understand HIV/AIDS.

2. Methodology

A predominantly qualitative mixed-method approach based on a modified Delphi technique was employed for data collection and analysis (Clayton, Perera, & Burge, 2006; Hatcher & Colton, 2007). In a Delphi study, a series of rounds are used for data collection (Hatcher & Colton, 2007). Normally, the first round is unstructured, which allows respondents to freely identify important issues (Boath, Mucklow, & Black, 1997). A structured questionnaire is then formulated using data from the first round (Clayton et al., 2006). Respondents answer the questionnaire, and their findings are used to formulate a third-round questionnaire. Once the responses are stable, i.e. they do not produce any new knowledge, the researcher may decide to stop collecting data. The number of rounds of data collection therefore varies from one study to the next (Clayton et al., 2006).

2.1 Sampling

In selecting students and teachers to participate in the study, a non-probability convenience sampling approach was followed. A group of nine schools from Umsunduzi district were selected for participation based on their location and school type. This resulted in the selection of two rural government schools, two urban government schools, three urban private schools and two township government schools. Class size ranged from 25 to 28, with some schools having more classes for a particular grade than others. Within these schools, a total of 308 grade 11 students aged between 15 and 18 years were enrolled in biology and participated in the study. Twelve biology teachers working in these schools also participated in the study. Participating HIV/AIDS experts (n=19) were selected using a non-probability purposive method. The group was comprised of nine medical microbiology researchers working on HIV/AIDS and tuberculosis, and 10 medical practitioners working as pathologists, nursing staff and medical doctors. Participating HIV/AIDS experts were graduates who were familiar with the biology curriculum but had never participated in biology curriculum development. Ethical clearance and consent were received from all participants and relevant stakeholders according to the guidelines of the University of Pretoria.

2.2 Questionnaire design and validation

To collect data in the first round of the Delphi method, respondents were asked to complete an open-ended questionnaire (Clayton et al., 2006; Hatcher & Colton, 2007). Respondents were asked to indicate (in their opinion):

1. whether HIV/AIDS-related concepts currently taught in biology are used in making decisions related to HIV/AIDS, such as the use of condoms;
2. which concepts related to HIV/AIDS should be taught in school biology in order for students to adopt safe behavioural practices in the context of HIV/AIDS;
3. which teaching strategies could best help students better understand the concepts related to HIV/AIDS stated in 2.

Questions related to (1) above were only answered by students as they were only applicable to them.

The questionnaire was validated for face and content validity through a separate panel of experts comprised of six science education teachers and an English-language expert (Golafshani, 2003; Guion, 2002). Through three rounds of assessment, this panel of experts provided their comments and recommendations for the questionnaire, which were then used to revise all of the questions.

2.3 Data collection and analysis

The final questionnaire was then administered for the first round of data collection where **r**esponses were analysed to identify the most prominent themes using inductive coding as described by Thomas (2003). The first step of the analysis was a close reading of the textual responses (Creswell, 2008). The text was read in detail so that the researchers could familiarise themselves with the content. Then the researchers identified themes that emerged from the data (Creswell, 2008; Thomas, 2003). These themes were also based on meanings of actual phrases used in specific text segments (Creswell, 2008; Thomas, 2003). At the end of this process, the researchers had generated a list of recommended themes which according to the respondents in question are critical to enhancing students' understanding of HIV/AIDS and the usability of biology in real life.

Having obtained data from the first round, a second round of data collection was carried out (Clayton et al., 2006; Hatcher & Colton, 2007). For data collection, a questionnaire consisting of closed-ended and open-ended questions was developed and administered (Hyrkäs, Appelqvist-Schmidlechner, & Oksa, 2003). The closed questions were statements to which the respondents were to indicate whether they strongly agreed, agreed, disagreed or strongly disagreed. In designing the questionnaire, the researchers used results from the first round. For example, if in the first round it emerged that *visuals are necessary to teach about HIV/AIDS*, then the questionnaire would include an item probing agreement or disagreement with this view. Only those concepts that were recommended by over 60% of the respondents in the first round were investigated in the second round of data collection. The questionnaire was validated in a manner similar to the first questionnaire. Data collected in the second round were then subjected to a mixed method of analysis that involved inductive analysis as well as working out descriptive statistics, such as frequencies and means (Creswell, 2008). No further data were collected as the researcher observed constancy in the findings such that further data would not have a significant impact on them. With reference to findings in section 3 below, respondents quoted are indicated next to each quote in brackets, “L” indicating a learner, “T”, a teacher and “E” an HIV/AIDS expert.

3. Findings

The first-round questionnaire using the modified Delphi method revealed a number of issues regarding the teaching of HIV/AIDS in biology that were later verified in round two. To avoid unnecessary redundancy, only final findings are presented.

3.1 Students’ use of HIV/AIDS-related knowledge currently taught in biology

To determine whether knowledge taught in biology is used in real-life situations, students were asked to indicate how often they use knowledge learnt in biology about HIV/AIDS to make decisions about their sexual lives (Table 1). A statistically significant 59% of the students indicated that they always use HIV/AIDS knowledge learnt in biology when making decisions related to HIV/AIDS (Table 1). This was true even if they were not sexually active. However, a significantly low 4% of the students suggested that they do not use biology knowledge (Table 1). While this figure is low, it is noteworthy in that not all students use HIV/AIDS knowledge taught in biology in their lives. A number of reasons were provided for this. Qualitative analysis of the data revealed one student (L074) who argued that when "*presented as dry facts, which is usually the case, knowledge is not usable*" in real life. Another student (L008) indicated that knowledge should be "*practical and relevant to the lives of students*." The point of relevancy of biology was also raised by student L033 who argued that "*many [students] choose not to [use knowledge learnt in biology] because they do not see [what is learnt at] school as part of real life.*"

Table 1
A summary of students' (n=308) responses indicating how often they use biology knowledge in their decision-making related to HIV/AIDS

Response	Always	Frequently	Seldom	Never	No response
Proportion	182 (59%)	74 (29%)	28 (9%)	12 (4%)	12 (4%)
95% CI for mean	48.5 to 75.5	60.7 to 63.3	58.2 to 65.8	56.4 to 67.6	56.4 to 67.6
Difference	-120	-12	34	50	50
Degrees of Freedom	307	307	307	307	307
t-test statistic	17.550	17.550	17.550	17.550	17.550
Significance level	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001

One respondent, a student (L301), also suggested that biology teachers "*do not teach students to [use] their knowledge in real life*." This view implies that more needs to be done to translate what students learn in class to real life. Nevertheless, other respondents were positive and argued that "*[Biology is] very important. With the right education students are given the tools to approach life and make the right decisions*" (E08). Given the sentiments that biology is, to some extent, neither relevant nor usable, the researchers went on to identify potential content knowledge that could be used to improve HIV/AIDS education through biology.

3.2 Content knowledge

Regarding content knowledge related to HIV/AIDS, respondents stated that the concepts currently presented in biology are not adequate to transform behavioural preferences of students. Through inductive coding of the data, concepts related to HIV/AIDS that need to be taught in biology in order for students to adopt safe behavioural practices in the context of HIV/AIDS fell within five themes: i) properties of HIV/AIDS, ii) HIV-transmission mechanisms, iii) results of infection, iv) immunity against HIV/AIDS, and v) life skills (Table 2). A total of 18 concepts characterized these themes; some were scientific while some were related to life skills. For example, *sex education* is more of a life-skills concept while the *life cycle of HIV* can be better understood in the construction of scientific knowledge.

Table 2
A list of concepts that respondents, i.e. students, teachers and HIV/AIDS experts, felt need to be introduced into the biology curriculum. The recommended concepts were suggested by over 60% of respondents in the first round of data collection and by the proportion given in column 3 in the second round.
Example quotes were taken from both rounds of data collection

Theme	Recommended concepts	Frequency (%)	Example quote
Properties of HIV/AIDS	General knowledge about HIV	94	Teach us general knowledge about HIV (L212) Teach more and more about HIV 'cause in our school I don't even remember when last they taught us about it (L219)
	Multiple infections	72	The real danger of multiple partners and multiple infections (E05)
	Life cycle of HIV	72	They must be taught the life cycle of HIV (T04)
HIV modes of transmission	Mother-to-child transmission	89	Mode of transmission, prevention of infection, mother-to-child transmission and other STDs (E07)
	How to use condoms and other prevention strategies	67	Why and how to use condoms as a method of preventing sexually transmitted diseases (E07)
Results of infection	Effects of AIDS	89	More emphasis on what AIDS does to you (E03)
	Symptoms	83	They must know the symptoms (T03)
	Progression from HIV infection to AIDS	89	Teach them how HIV gives AIDS (E01)
	Opportunistic infections	89	Opportunistic infections that an HIV-positive patient can get and the effects of each infection (E05)
	Risk of contracting sexually transmitted infections (STIs)	56	About different types of STIs and how you can get an STI especially if you have HIV (L300)
Immunity against HIV/AIDS	Curability of HIV/AIDS	89	Teach them about the lack of antiretrovirals available to the public and poor-health facilities (E05)
	Protection strategies and immunity	67	Emphasis that they should protect themselves by taking necessary precautions (E06)
	Treatment	67	We should be taught what to do when you have HIV (L212)
Life skills	How to support people living with HIV (and self)	67	How to support people with HIV/AIDS (L223)
	Sex education	56	They must teach students about sexual intercourse (L228)
	Testing	67	The importance of having an HIV test before having sex (E03)
	Decision-making	83	To make informed decisions/choices (L010)
	Responsible behaviour	83	The importance of responsible behaviour and the reasons for making good life decisions should be taught (T03)

From Table 2, it appears that the respondents feel that HIV/AIDS education within biology needs improving. The findings seem to indicate that some participants believe that general knowledge about HIV/AIDS must be taught. For example, respondent L212, a student, feels that "*general knowledge about HIV*" needs to be taught. However, it appears that other participants would like to see an in-depth look at the subject instead of a superficial general view. In-depth concepts that were recommended include the "*life cycle of HIV*" (T04) and the "*progression from HIV to AIDS*" (E01).

Results also show that participants feel a need to integrate scientific knowledge into real life. For example, while listing scientific concepts that must be taught, participants also indicated that life skills that could help students apply knowledge must be taught. For example, one participant (L010) indicated that students need to be taught how to make informed decisions. This view suggests that students need to be able to use knowledge (learnt in biology) when making decisions. In support of this view, another participant argued for the development of reasoning skills related to application of knowledge during decision-making (L010). Overall, participants seem to suggest that HIV/AIDS knowledge in biology needs to be integrated with skills that will help students apply this knowledge in their daily lives.

While the findings generally indicate the need for HIV/AIDS education, some respondents appeared to feel otherwise. This is because some respondents felt that exposure to topics such as sex education somewhat stirs up the desire to experiment with sex among students. One student (L005) in particular argued that "*students should not be taught how to use condoms because it increases the number of students who are sexually active and some don't use condoms properly.*" As a result, some blamed exposure to sex-related knowledge for the increased sex rate among students and consequently HIV infections. In fact, some students (4%) argued that knowledge is not enough to change students' unsafe behavioural practices. Instead, only life skills such as decision-making skills are important, as these do not only relate to HIV/AIDS but to other social challenges as well.

Overall, with regards to content knowledge, findings suggest that there are concepts currently taught in biology that need to be emphasized and clarified. In addition, there are those concepts that are not currently taught but should be considered.

3.3 Mode of presentation of HIV/AIDS-related concepts

Respondents were also asked about the mode of presentation of HIV/AIDS knowledge that might improve students' understanding of HIV/AIDS concepts as well as the ability to apply that knowledge. Findings revealed that respondents believe HIV/AIDS education in the context of biology should not only be based on what is in the textbooks, which is the case in most impoverished schools in South Africa. Participants (e.g. E03) felt that "*some textbooks are not written in the context of those reading them and thus are irrelevant to local settings*." As a result, it was suggested that "*different modes be used to teach HIV/AIDS-related knowledge*" (E03). Participants in this regard argued that some biology teachers are not well equipped for teaching HIV/AIDS-related concepts (Table 3). As a result, it was recommended that extra support from community members be provided. In this regard, participants recommended that medical practitioners and researchers, community leaders and HIV-positive individuals be involved in HIV/AIDS education (Table 3).

Table 3
HIV/AIDS teaching strategies recommended by respondents
The recommended strategies were suggested by over 60% of respondents in the first round of data collection and by the proportion given in column 3 in the second round.
Example quotes were taken from both rounds of data collection.

Category	Recommended strategy	Frequency (%)	Quotes from respondents
Human models	Experts to teach about HIV	60	Medical doctors should be brought in to actually show graphically the results of HIV/AIDS (L001) Educate teachers so they can educate students. Being an educator does not necessarily mean you are well informed (E04)
	Exposure to HIV-positive individuals	75	Students must be taken to institutions for people with HIV and they must see for themselves the dangers of the disease (T04) We can have people with HIV talk about their experiences (L206)
Conceptual models	Explicit messages	92	Don't sugar-coat HIV, tell it like it is, a very cruel and unforgiving illness (E05) Teachers must be open to talk about HIV/AIDS when students ask (L232) Knowledge should be practical so that students can apply it (T02)
	Make it more exciting	50	Many children are bored by the topic of AIDS (E03)
Visual models	Use pictures	65	More of those videos and gruesome pictures showcasing the brutality of the disease (L020) Students must see for themselves pictures of HIV/AIDS patients (E01) Give them true visuals so that they can see how harmful the virus is (T09)

Participants also recommended the use of conceptual and visual models (Table 3). These models might include the use of written or spoken text, and motion (i.e. television) as well as still pictures to provide a detailed description of HIV/AIDS. Through these representations, participants argued that a realistic and explicit reality of HIV/AIDS should be portrayed.

4. Discussion

The main objective of the current study was to identify strategies that can be used to enhance biology students' understanding of HIV/AIDS and the usability of such knowledge in their daily lives. The critical aspect of the study was to gather data from students, teachers and HIV/AIDS experts, none of which have ever participated in curriculum development. This was important because the current biology curriculum, designed by curriculum specialists, to some extent is not able to attend to some of the issues related to HIV/AIDS (Anderson & Beutel, 2007; Dorrington et al., 2006; Page et al., 2006).

Based on the findings of the study, the authors argue for an inclusive approach to curriculum development. As shown in the current study, students, teachers and HIV/AIDS experts also have some critical recommendations for HIV/AIDS education in biology. Some of the recommendations are in agreement with the literature. For example, the idea of using visualizations to teach biology concepts is in agreement with scholars in visual literacy (e.g.

Mayer, 2001; Wastelinck, Valcke, Craene, & Kirschner, 2005) who suggest that transformational learning occurs from words and pictures rather than from words alone. Furthermore, previous studies have shown that students who use text alone do not show greater concept understanding than students who use diagrams and pictures to learn (e.g. Mayer, 2001). Even though other recommendations of the current study (e.g. Table 2) have not been tested, the authors believe that given the variations in local settings in South Africa, as well as the context-specific effects of HIV/AIDS, it is important to have a curriculum that will cater to local settings (Freire, 2000) so that learners can better understand HIV/AIDS, particularly within their context, through constructivism (Baumgartner, 2001).

Also emerging from the data is the need to translate knowledge into practice, as some students fail to transfer classroom knowledge into real life. In this regard, findings suggest that there is a gap between the classroom experience and the real-life experience. This view is in line with Anderson (2007) who argued that there is a gap between education (including research) and practice. Therefore, for biology to be relevant, effective and transformative, students need to be taught actionable knowledge as well as the skills required to translate knowledge into practice (Hlebowitsh, 2006). In fact, there is a need for an integrated curriculum that will enable students to use knowledge in their lives, where students can integrate their classroom experiences with their daily lives.

Furthermore, the authors argue that for the biology curriculum to be transformative in the area of HIV/AIDS, there needs to be a paradigm shift in the philosophy of biology education (Baumgartner, 2001; Healy & Perry, 2000). For instance, the current study shows that the views of respondents on HIV/AIDS education through biology vary. As a result, if the Department of Education alone imposes the concepts to be taught, then an essentialist philosophical stance is being followed (Cohen, 1999). However, if other stakeholders are allowed to contribute to curriculum development, as suggested by the findings of the current study, then a critical theorist perspective would be adopted (Healy & Perry, 2000). In this case, this means adoption of the notion that the reality of HIV/AIDS is shaped by various local factors that are crystallized over time, and a collective view is the closest to reality. The authors therefore argue that in order for students to better understand HIV/AIDS, the uniqueness of local challenges must be recognized and context-specific knowledge must be used to address such challenges.

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Section 3

Teaching and learning biology in primary schools

9

CONCEPTUAL CHANGE IN PRIMARY SCHOOL CHILDREN FOLLOWING A MODERATE CONSTRUCTIVIST LESSON DEALING WITH DECOMPOSITION

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Abstract

Students' preconceptions should be the initial point for any restructuring of conceptions. Results of previous studies show that children in primary school attribute ecological processes to very simple cause-and-effect chains and usually do not recognize biological cycles. This research project focused mainly on the principle of the biological cycling of matter.
Interviews conducted with students from four different third-grade classes showed that their explanations of the process of decay are incommensurable with scientific concepts. Two of those classes were subjected to an experimental classroom study. They had the opportunity to watch the process of decay in a compost case fitted with a window. This learning environment based on discovery learning by hands-on experience with authentic materials enabled restructuring the students' conceptions during classroom discourse. The two other classes (controls) did not get any lessons about the cycling of matter.
Interviews conducted with the students from all classes later showed that those from the experimental classes had restructured their conceptions about the process of decay to cycling processes. The students of the control classes did not show any conceptual change.

Keywords: ecological education; primary school; cycle of matter; conceptual change; qualitative content analysis

1. Starting point of the experiment

In 1979, Eulefeld was already describing environmental education "as an education of the examination of the natural, social and built environment with the goal to develop the preparedness and competence to act to ecological laws" (Eulefeld 1979, cited in Gärtner & Hellberg-Rode, 2001). Analyzing studies dealing with the topic of environmental education, it becomes clear that indeed "green" topics (e.g. caring for plants) are often the subject matter of the lesson (de Haan, 1999). Ecological topics, however, which could give insight into the relationship structures between single branches of an ecosystem and their mutual dependency, are rarely broached. In addition, in textbooks for primary schools, ecology is seldom covered; even when it is, it is often insufficiently demonstrated or explained (Baisch & Schrenk, 2002).

This is all the more astonishing because since the Earth Summit in Rio de Janeiro in 1992, the central theme of "effective" and "sustainable" development has determined the outlook of environmental education. The postulation of a "redirection of the education towards a sustainable development" (Chapter 36, Agenda 21 BMU 2002) is seen as an essential requirement for improving people's ability to involve themselves with environmental and developmental questions. This claim was affirmed 10 years after Rio in the "Johannesburg Declaration on Sustainable Development". In the closing statements of the Earth Summit, the goals and principles of Agenda 21 were reaffirmed. More clearly than before, the role of education was emphasized as a component of sustainable development. The general assembly of the United Nations explained, in December 2002, that the years 2005-2014 would be the world decade of "education for a sustainable development". The UN-Decade, put into effect under the leadership of UNESCO, works primarily on the goal of harnessing the principles of sustainable development in national education systems, thereby helping with the implementation of Agenda 21. In the process, an array of measures will be recommended from UNESCO for an action plan. Among these measures is the request to revise textbooks, curricula and materials–especially for preschools and primary schools–towards adoption of Agenda 21's goals. Intensification of research on the topic "Education for sustainable development" has also been stipulated with some insistence (UNESCO Commission, 2003).

However, a fundamental understanding of sustainability and related insight into the urgency of nature conservation require knowledge of ecological systems and principles. The resulting consequences of a basic ecology education include a theory-based analysis of the ecosystem concept and "basic ecological principles, e.g. energy conversion and energy flow, cycle of matter, integration, balance and stability" (Gärtner & Hellberg-Rode, 2001).

2. Student conceptions of the cycling of matter

The question of which aspects and contents can and should be used in an established elementary ecological education is still vastly unexplored. If one takes the conceptual-change theories as a basis, in which students have to actively change their existing preconceptions to be able to construct more adequate scientific concepts (Chi, 2005; Duit, 2000; Möller, 2001), the questions of content and student conceptions about ecological concepts need to be followed up, because these build a starting point for the structuring of teaching-learning processes. The few existing studies have focused only on student conceptions of key individual ecological concepts, without relating them (Bell-Basca, Grotzer, Donis, & Shaw, 2000; Hellden, 1995; Leach, Driver, Scott, & Wood-Robinson, 1996). The results show that primary school-age children attribute ecological processes to simple cause-and-effect contexts; they normally have no idea about the preservation of matter and do not recognize cyclic processes as such. These results are not surprising, bearing in mind that ecological processes often elude direct observation due to their spatial and temporal dimensions. Such processes must be made visible so that they can be experienced, thereby enabling the construction of adequate, scientifically measured conceptions.

The focus of this research project was therefore on the principle of the ecological-organic cycling of matter. In this project, we examined if and how existing preconceptions change over the course of a teaching-project which enabled the children to directly observe the process of composting and presented them with the chance, in line with a moderate constructivist-oriented learning environment, to check their conceptions regarding the decomposition of organic materials and to change them as necessary.

3. Questions

The following central questions were examined:

1) Which conceptions do students have in primary school regarding the ecological principles of the cycling of matter?

2) Can already existing conceptions be altered or broadened with the help of teaching-like projects? More precisely: Does direct hands-on discovery learning with a compost case in a moderate constructivist learning environment contribute to the construction of adequate conceptions regarding the ecological principles of the cycling of matter?

3) Do children have the ability to develop a general explanatory conception from their context-specific experiences for the process of recycling organic material?

4) Do primary school-age children already have the ability to understand complex ecological processes and to develop sustainable conceptions, or does this produce excessive demands prematurely?

The following general hypothesis was formulated:

Concrete discovery learning of the ecological process of decomposition in a moderate constructivist-oriented learning environment will benefit primary school children by changing their preconceptions towards “more adequate” conceptions regarding the ecological principles of the cycling of matter.

4. Work plan

The focus of the research was the change in students’ conceptions by long-term observation of the composting processes in relation with concrete discovery learning. For this purpose, the studied classes were given a compost case for the entire survey period, which the children observed with the help of an attached piece of acrylic that enabled viewing as much as possible of the subsiding rotting processes. An accompanying lesson intervention was carried out, which made learning possible in a moderate constructivist learning environment.

In line with this investigation, 100 individual interviews and 32 group interviews were carried out (all children who were questioned in the one-on-one interviews also participated in the group surveys. However not every child in the group surveys took part in the one-on-one interviews). The surveyed children came, in each case, from two experimental classes and two control classes. Prior to the lesson intervention, 25 students in the 3rd and 4th grades were surveyed using half-standardized individual and group interviews. A combination of individual and group surveys was chosen. Since the battery of questions was extensive and the surveyed elementary students should not be overstrained, the two central batteries of questions were emphasized (decomposition, role of rotting in the cycling of matter) in individual interviews and the underlying subjects (plant metabolism, animal growth) were emphasized in the group interviews, particularly in view of the theoretical assumption that the children have very little previous knowledge of the latter areas. Therefore, a relaxed conversational atmosphere was created, which was also the standard for the subsequent individual interviews, although listening to the answers of others can encourage the students’ own thoughts, so that more ideas or co-constructions can be developed than in the one-on-one interview (Bortz & Döring, 2002, p. 318). In parallel, 25 children from the control group were surveyed about their conceptions. During the surveys, stimulating material in the form of pictures or word cards, objects and a video clip, which showed a rotting process in fast motion, were used. While the two experimental classes wrote down their experiences of discovery learning with the compost crate in an observation and study journal accompanied by seven lesson modules, the two control classes received no treatment. Eight weeks after the intervention, the experimental and control classes were surveyed again in individual and group interviews.

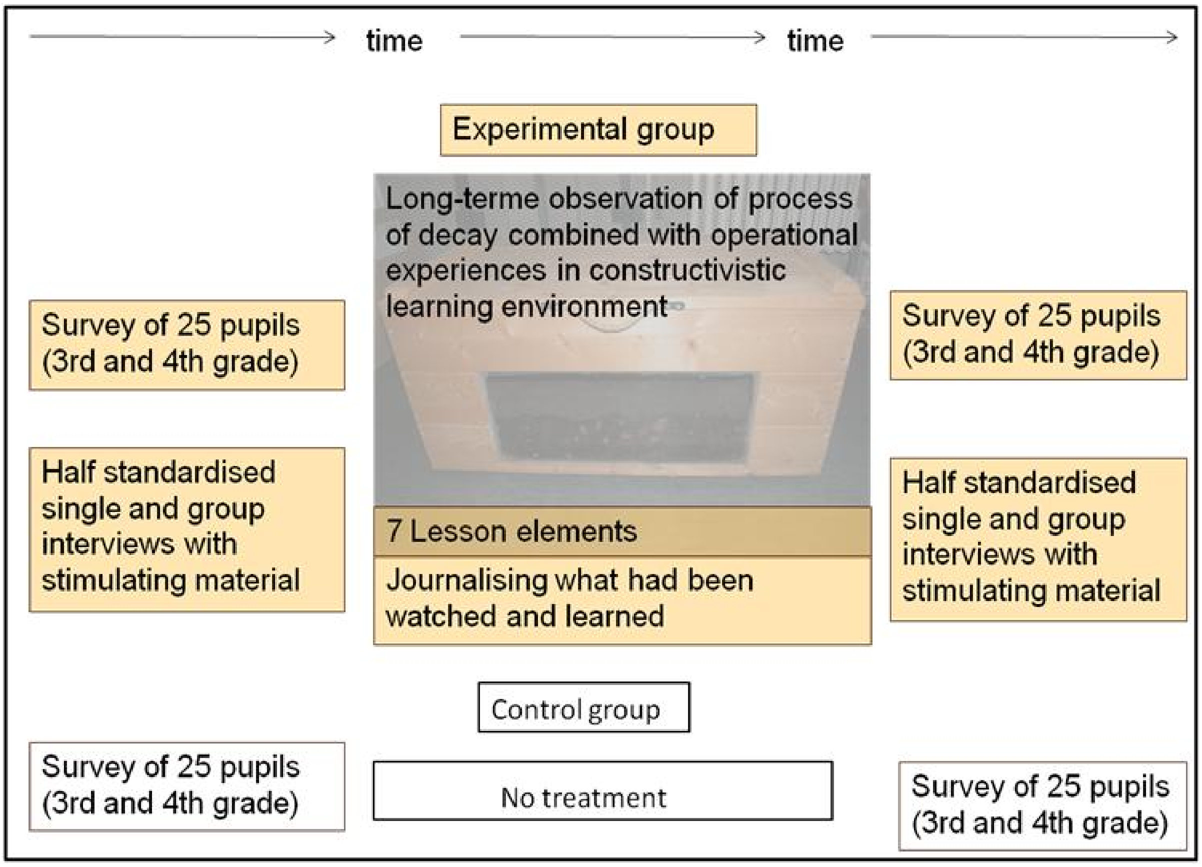

Figure 1
Examination design

Leach et al. (1996) give the main features of the cycling of matter as:

(a) the sources of matter for plant growth

(b) the needs of plants

(c) the sources of matter for animal growth

(d) the process of decay

(e) the role of decay in the cycling of matter

These main features constituted the frame of orientation for the survey.

The central features were partitioned into questions, and these questions were the central components of each feature.

For the group interviews, we selected those features which have a general aspect related to understanding ecology (question 1 in section 3).

For the individual interviews, we selected those features which were topics of the intervention.

The respective batteries of questions were presented as follows (Baisch, 2009):

4.1 Group interview

Food sources for plant growth/Requirements of plants

- What do plants need to live and to be able to grow healthy?
- What do carnivorous plants need to live and grow?

- What is soil?
- What is soil made of?
- Can plants grow in these substrata (gravel, sand, soil)? Why?
- Why does a plant grow hydroponically?
- Where does the wood that makes up the tree come from?

Food sources for animal growth
- What do animals need to live and grow?
- Where do they acquire these?
- Are they the same for all animals?
- Was happens to an animal when it dies?

4.2 Individual interview

Process of decomposition
- What happens to an apple which falls from a tree if nobody removes it?
- Where does this change come from?
- What happens here (video sequence in fast motion) with the rose hip?
- Where does this change come from?
- What happens in a compost case/on a compost pile?
- What happens to different materials (apple, plastic cup, onion peel) if I put them in the compost case/on the compost pile?
- What happens to a piece of apple if I close it airtight in a glass?
- What happens to a piece of apple if I put it on a plate?
- Using these terms (compost worms, earth, garbage, other animals), can you explain what happens in a compost case/pile?

Role of decomposition in the cycling of matter
- What happens to the leaves that fall in the forest in autumn?
- What happens here (varying decomposition stages of a leaf) to the leaf? Where does that come from?
- What happens to a tree that falls in a forest during a storm?
- Do the pictures (waste, compost worm, soil, young plant) have something to do with each other? If so, put them in a sequence and explain why you put them in that order.
- What happens if one pours paint on the forest floor? Does it hurt the trees and the animals?

The questions presented here were often altered to child-suitable questions during the survey. The individual interviews were centred on the materials and conditions of decomposition. Furthermore, the process of decomposition was regarded in different contexts. We wanted to determine whether the students would generalize their conceptions.

5. Intervention

The development of the intervention was implemented using seven lesson elements, which were developed following the considerations of a moderate constructivist lesson (Dubs, 1995; Gerstenmaier & Mandl, 1995)

-Context-based learning of authentic problems

(orientation on meaningful, complex problem areas)

Example: The students discovered a lot of animals from different species in the compost case. They wanted to find out what these animals existed on. What was their food? There was only soil and waste in the box.

-Learning as an active, constructive process

(own learning styles, emotional involvement, independent activity)

Example: The students could choose any kind of material and watch what happens to it in the compost case.

-Social and cooperative learning

(interactive negotiation of opinions and meanings)

Example: The students discussed what would happen with the different materials in the compost case.

-Self-directed and supported learning

(self-determination of learning, control and structuring with teacher's help)

Example: The students discovered that a lot of materials were eaten by the animals in the compost case. They also saw that plants grow very well in the soil from the compost case. With the help of the teacher they started to develop the presumed coherences into a cycle of matter.

The main focus was on concrete discovery learning with a compost case which stayed in the classrooms of the trial classes during the entire period of the intervention, and made it possible to directly observe composting processes. A number of weeks elapsed between individual lesson elements, the majority of them organized as a double-period, because school holidays and the time needed for the rotting processes had to be considered. Next to the examination of decomposition processes, soil analysis and planting trials became central elements of the lessons. These single components should be merged together into a cycle during the summary at the end of the intervention.

The varying stages of decomposition of the materials placed in the case were documented using photos and served as the foundation for meta-cognitive discussions. The same function was served by the observation and study journal, in which the children made notes and drawings about their predictions and respective trial results or graphic records, and which was used consistently for reflection. The structured analysis of the open-experiment phases was given a lot of time, just like the negotiation of opinions between the students. Altogether the children were given sufficient possibilities to experiment and check their own predictions, for example, they were able to put substances such as the shavings from pencil sharpeners into the case over the entire course of the intervention, in order to observe possible changes. For this purpose, the participating teaching staff gave the children appropriate time between lessons.

To provide an overview of the course of the intervention, the contents of the lesson elements are briefly outlined:

Element 1: introduction of the compost case and analysis of the living organisms

Element 2: attempts to decompose different materials

Element 3: observation of decomposition processes under varying conditions (mold formation, fermentation processes)

Element 4: synopsis and analysis of the decomposition attempts

Element 5: soil analysis

Element 6: growth conditions of plants

Element 7: soil cycle

6. Analysis

In this investigation, 100 individual interviews and 32 group interviews were carried out. The interviews were recorded with the help of mini-disc recorders, completely transcribed and by means of qualitative content analysis, evaluated as follows (Mayring, 2003):

- step-by-step analysis of the data set and developing a set (system) of categories
- theory-governed determination of the main content categories (deductive) and determination of the parameter values (inductive)
- phrasing of definitions, standard examples and explicit rules of coding for all categories.

With help from the techniques of the structured content analysis and the summary, a categorisation system was developed with the goal of obtaining statements about the students' preconceptions and interpretative framework regarding the decomposition and accordingly, the cycling of matter. For systematic evaluation and interpretation of the data, the computer software MAX_{QDA} was used.

7. Results

Selected results from the experimental class before and after the intervention are presented. These refer to the battery of questions on rotting and humus formation in the compost case (Baisch, 2009).

A central block of questions for the individual interviews dealt with rotting (Figures 2 and 3). The students were supposed to say something about what happens to an apple that falls from a tree and remains lying in the field, i.e. is not picked up (Figure 2). The children's answers were differentiated into explanation of the rotting process and the reasons responsible for it. In the descriptions, statements about physical, observable changes in the apple, i.e. color, size and smell, dominated. Changes in the apple's firmness were also frequently mentioned. Statements like "it becomes soft" or "the apple falls apart" could be assigned here. There was also a consistent description of "liquefaction" of the apple: "The inside becomes liquid and then flows out into the soil". In some statements, the fruit was connected with the term "soil". These statements could be divided into two different categories: "the apple goes into the soil" and "the apple becomes soil". In both cases, the fruit is then no longer visible, but only the second aspect describes a substantial change. How this process happens, however, was not often explained. Three sub-categories could be found:

a) The apple turns into soil, but how it happens is unclear.

b) The apple breaks down into many small pieces, which then are again soil.

c) The apple is eaten by animals and the excrement from the animals is soil. Along with this sub-category, the process of humus accumulation was described in the follow-up study considerably more often than in the preliminary investigation. In contrast, statements for the conclusion of the disappearance of the apple: "It disintegrates itself in the air", were exclusively made in the initial questioning.

This also appears in the students' answers to the question: What would eventually remain of an apple if it were to lie in the field for a whole year?

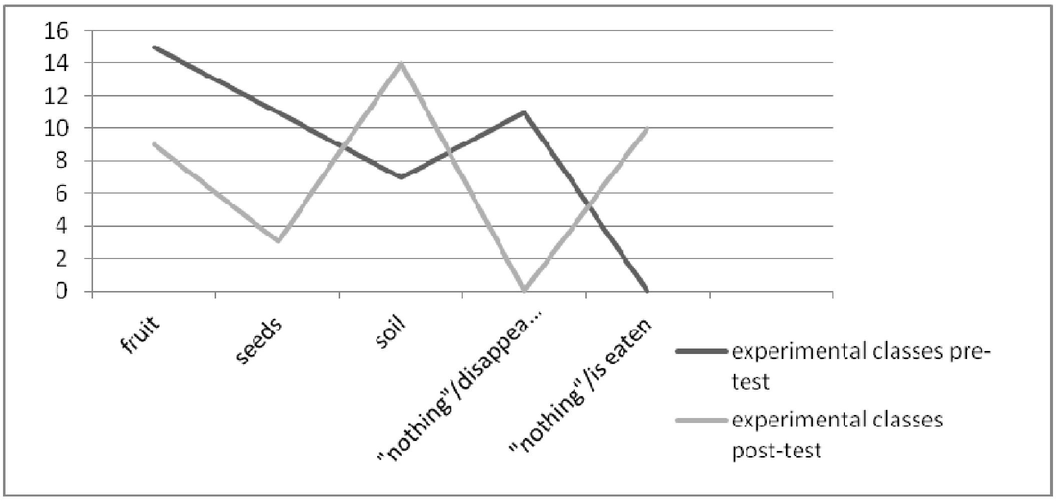

Figure 2
Final product of the rotting of an apple (multiple answers)

During the pre-test, 11 children had the idea that the fruit would disappear, but no child guessed this in the post-test. Also here, the statement emerged that after a year, nothing from the apple would be left. However, as rationalised here, no disappearance was mentioned; instead, decomposers were mentioned which would completely eat the apple. Altogether, it was noted that the role of decomposers was more clearly sensed after the intervention. This was also reflected in the increase in statements that only the seeds would be left, the rest having been entirely eaten. Interestingly, again and again, multiple answers showed up, indicating that the students guessed, for example, that the apple would become soil, but sometimes a part of it would be left. As a reason, varying external conditions were often named. The versatile descriptions of the rotting processes accompanied the question about what causes these changes. All statements were coded by reason and further sub-categories were created (Figure 3). After the biological and climatic reasons, mechanical, anthropogenic and natural influences were mentioned as causes of the rotting process.

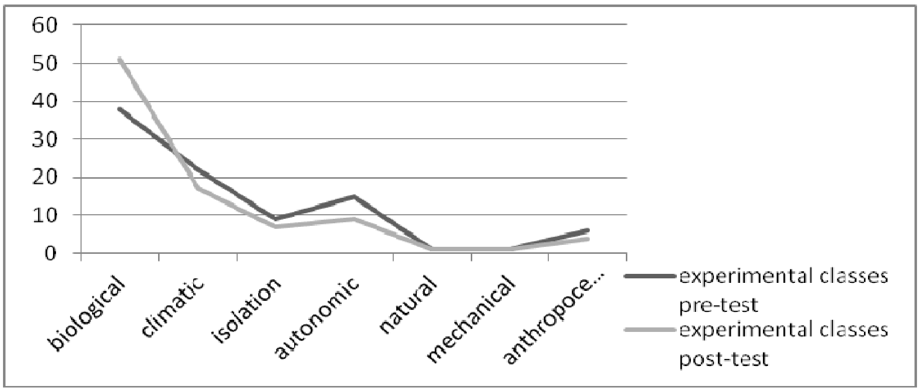

Figure 3
Causes for the rotting process (multiple answers were permitted)

Finally, the results from the battery of questions dealing with "humus formation in the compost" are described. The students were presented with cards with the terms biowaste, earthworms, other animals, and soil, which they placed in relation to each other and with the help of these, they explained the processes in a compost pile, i.e. the compost case. The majority of the children in the preliminary investigation could not link the terms to each other (Figure 4). The explanations ranged from “they are all just in the compost case” to “the animals eat the waste and somehow it turns into soil”. In contrast, in the follow-up investigation, the majority of children could, with the help of the above-mentioned terms, describe the process of humus formation in the case.

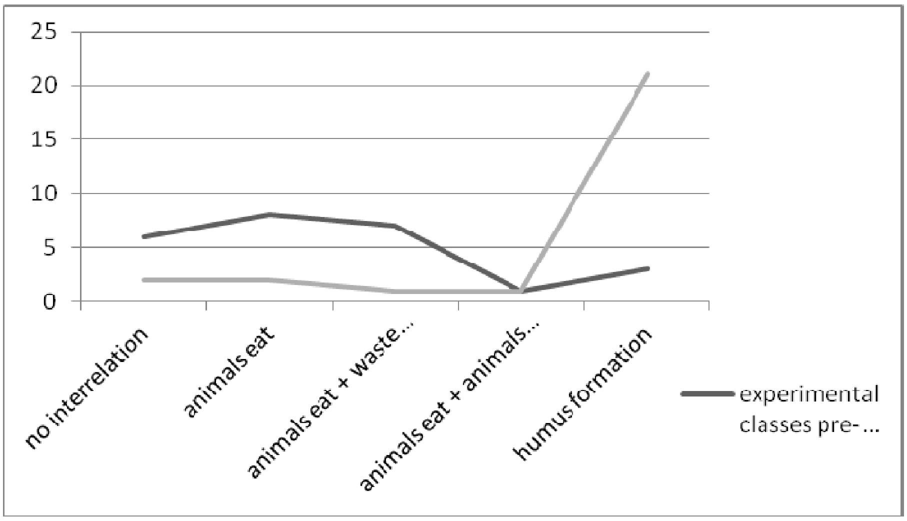

Figure 4
Ongoing processes in the compost case

Analogous results were obtained from a similar exercise, although it included a transfer task. Here the children were presented with four picture cards (biowaste, earthworm, soil, young plant), which were also supposed to be placed in relation to each other. Here as well, the results of the preliminary investigation showed that most of the children could not place the cards in causal relationships with each other (Figure 5). Less than a fourth of the children described the process of humus formation and identified the created humus as fertilizer for plant growth, or placed the picture cards in a circle to demonstrate that organic substances are always circulating in buildup and breakdown processes. The follow-up survey showed the opposite picture: most of the children succeeded in placing the images in relation to each other.

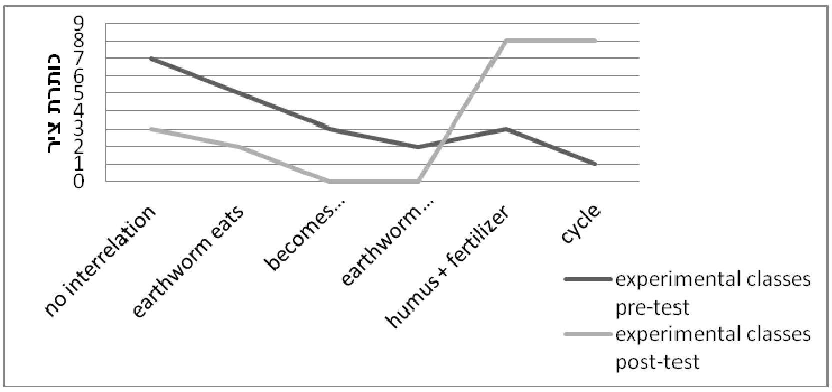

Figure 5
Description of the soil cycle

8. Summary

This study first dealt with the identification of central conceptions about decomposition of organic material and about the role of decomposition in the cycling of matter. The pre-tests showed that the students already have a multitude of conceptions about the process of decomposition, originating for the most part from a reflection of their own experiences. Descriptions of observable changes in the organic material dominated these experiences. However, statements could be found, over and over, in which the children assumed that the material would end up turning into dirt. Only a few students came up with concrete, sustainable associations of how this process occurs. The process was explained as either a mechanical decay of matter into ever-smaller pieces, which then sometimes turn into soil, or an essential gradual process, which is solely a question of time. In the pre-tests, the students also consistently formulated the assumption that the organic material somehow disappears, leading to the conclusion that they had no conception of the preservation of matter. Leach et al. (1996) came to similar conclusions in their research. For the question in the pre-test about the causes for these changing processes, statements which named biological factors dominated. Interesting in this case is the contemplation of the sub-categories, which were distinguished into consumers and visible and non-visible decomposers. It was often observed that the earthworm is involved with the decomposition processes. However the role of the micro-decomposers could only be described by a few individual children. During the pre-tests, the students showed an array of previous experiences and ideas concerning composting and the processes involved, but only a few showed sustainable conceptions. A multitude of organisms which are involved in the decomposition processes were named, but their importance in soil ecology was widely unclear.

In the post-tests, the process of soil formation was described in considerably more detail and was also made use of more often as an explanatory model, both for the question about the decomposition events of the apple and for that about the function of compost. The role of micro-decomposers was also considerably better realised. The assumption that things disappear was superseded by the idea that things get eaten by organisms and secreted again. In the experimental classes, exposure to the compost case clearly improved their conception of preservation of matter. Students also consistently made use of circular explanation models for their reasoning. Even though one cannot expect the students to understand the details of the decomposition process of organic substances into inorganic components, which are then again available to the plants for growth, a sustainable and connectable assumption model was created.

Carlsson (2002) mapped out a framework of orientation for ecological understanding, in which he described ways of thinking about about recycling as essential. Hellden (2005) described a longitudinal study on the conceptions of students about ecology, in which he demonstrated the importance of allowing students to observe ecological processes. Our study shows that students in primary school can already develop conceptions about decomposition and the cycling of matter which are quite adequate scientifically. Very often, biology in primary schools is reduced to topics such as “my favorite pet”, “from corn to bread” or “flowers in the garden”. It is possible, and indeed necessary that ecological topics, which give insight into the relationship structures between single branches of an ecosystem and their mutual dependency, be taught.

Revisiting the overall postulated hypothesis that concrete discovery experiences and learning about the ecological processes of decomposition in a moderate constructivist-oriented learning environment encourage the alteration of preconceptions in primary school children towards more adequate concepts, it can be concluded that it is confirmed by the results of this investigation .

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10 THE FEASIBILITY OF SYSTEMS THINKING IN BIOLOGY EDUCATION

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Abstract

Systems thinking in biology education is an emerging research topic, still faced with contrasting feasibility claims. Some studies claim that systems thinking can be readily introduced at the level of primary education; others claim that even in upper secondary education, the introduction of systems thinking requires a carefully outlined approach in order not to overly strain students' capacities. How can these contrasting claims be explained? An analytical procedure was used to map and compare the conceptual frameworks of the various studies, focusing on the selection of systems, references to systems theory and definitions of systems thinking. The analysis demonstrates that the frameworks include different elements of systems thinking. In particular, it shows that the main difference between the studies concerns the element of forwards and backwards thinking between concrete biological objects and abstract systems. The analysis contributes to a discussion about useful preparatory learning and teaching trajectories, preceding the formal introduction of systems thinking.

Keywords: systems thinking; systems concept; primary education; conceptual development; modelling

1. Introduction

1.1 Motive of the study

In the last few decades, the number of studies reporting on systems thinking in education has been on the rise. This is not a coincidence since recent systems theory now fits physical and social reality better than ever before, and analytical tools are available to predict possible future systems behaviour. Systems thinking is considered an important tool in decision-making and problem-solving (Hogan, 2000, p.22). Since it contributes to our optimal understanding of complex problems, it is desirable to "address the widening gap between current best understandings and analytical tools in the physical and social sciences (informed by complex systems) and the working knowledge of professionals, policy makers, and citizens who must deal with challenging social and global problems in the 21st century" (Jacobson & Wilensky, 2006, p. 13).

Noting the growing importance of systems thinking, we decided more than 10 years ago to investigate the introduction of systems thinking in upper secondary school biology (Verhoeff, 2003; Verhoeff, Waarlo, & Boersma, 2008). Our general conclusion was that the introduction of systems thinking in upper secondary education is feasible but not at all straightforward.

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Thereafter, a number of studies appeared on primary and lower secondary school students' understanding of dynamic systems. Much to our surprise, the results of those studies suggested that the introduction of systems thinking can be begun in as early as primary or lower secondary education (Ben-Zvi Assaraf & Orion, 2005; Evagorou, Korfiatis, Nicolaou, & Constantinou, 2009; Sommer, 2005). How can we interpret these contrasting claims?

1.2 The studies

Let us first introduce the various studies somewhat further. Using a pre-post test design, Ben-Zvi Assaraf and Orion (2005) investigated junior high school students' perception of the water cycle by implementing a teaching unit on water resources. The findings indicated that most students made some meaningful progress in their systems thinking skills. It was concluded that introduction of the first steps of systems thinking at the elementary level might enable them to reach the higher levels of systems thinking during junior high school (p. 557).

More recently, Ben-Zvi Assaraf and Orpaz (2009) published the results of a second study on students' understanding of earth systems, which included an adapted list of systems thinking components. Although this study did not recommend implementing systems thinking in primary education, it is included in our analysis.

Evagorou et al. (2009) used a pre-post test design to investigate the impact of a simulation-based learning environment on elementary school students (11-12 years old), focusing on the ecosystem of a marsh. Two tests were designed to probe the extent to which students could apply their systems thinking skills in new unfamiliar contexts. Their findings indicated that the learning environment provoked considerable improvement in some systems thinking skills during a relatively brief learning process. Therefore, they claimed that elementary school students have the potential to develop systems thinking skills and that the "introduction of systems thinking in elementary school is absolutely reasonable" (p. 671).

In her thesis, Sommer (2005) presented the results of a study in which third- and fourth-grade primary school students had investigated the white stork's relationships with the biotic and abiotic environment by, among other things, playing a computer game. Systems competence was tested in a pre-post test design. The results showed that the students' components of systems thinking in the area of system organization were well developed. It was concluded that the competence of systems thinking can already be acquired in primary school (p. 4).

In his thesis, Verhoeff (2003) presented the results of a design study aimed at introducing a first systems model based on the General Systems Theory. The first part of the learning and teaching strategy focused on the development of a general model of the cell as a system, while the second part focused on the introduction and application of the systems model. The study indicated that systems thinking can be introduced in upper secondary biology education, by using a carefully outlined learning and teaching strategy consisting of a sequence of modelling activities.

1.3 Research question

The five studies described above were not sampled from a wider pool of literature about systems thinking in science education. However, we do not think that this matters, given our research interest. The findings of the five studies alone suffice to raise the following research question:

How can the contrasting claims about the feasibility of systems thinking in primary and secondary education be explained?

Did Verhoeff needlessly spend quite some energy in upper secondary education on something that can already be rather effortlessly achieved in primary education? Or did the other studies overlook something essential that made Verhoeff's task so very difficult? Since some of the present report's authors were involved in Verhoeff's study, this is a matter of personal interest. But there are also issues of general interest, such as the methodological issue of how to 'measure' systems thinking and the didactical issue of how to usefully prepare the formal introduction of systems thinking. We will return to these issues in the final section.

2. Method of analysis

2.1 Outline of the procedure

In the educational literature, systems thinking is not unequivocally defined; in fact, it has been noted that there are as many lists of systems thinking skills as there are schools of systems thinking (Booth Sweeney & Sterman, 2000, p. 250). However, as one might expect, these differences cannot only be attributed to different schools of systems thinking, but also to the different domains in which systems thinking is applied, and to the objects that are considered systems in these domains. It makes a difference whether a toaster, a physician's practice or an elephant are being considered a system, since in these objects, partially different system characteristics may be recognised.

Consequently, we expected that the contrasting conclusions might be due to different definitions of systems thinking resulting from preferences for different 'schools', disciplines and the different objects presented as systems. Since the five studies handled a diversity of objects as systems, we decided to analyse their conceptual frameworks in terms of the general systems' theoretical characteristics identified in the literature on systems theory. The analysis consisted of searching the frameworks of the five studies for the presence of the systems' theoretical characteristics (Table 1). The frameworks were analysed by the first and second author and a few discrepancies were discussed until agreement was complete.

2.2 Systems' theoretical characteristics

In the historical development of systems thinking, three phases can be distinguished. Von Bertalanffy founded systems theory in the 1930s, but it was not until he published his General Systems Theory in 1968 (Von Bertalanffy, 1968) that systems theory was applied in a large diversity of disciplines. In the mean time, cybernetics developed in the 1950s (Ashby, 1956; Wiener, 1948; see also Bayrhuber & Schaefer, 1980), allowing some understanding of biological systems' dynamic behaviour. Nevertheless, for many years it was impossible to adequately describe the dynamic behaviour of biological systems. Therefore, for most biologists, systems theory or systems thinking remained a way of thinking about biological objects, without much impact on their research. This situation changed in the 1970s when, after the development of dynamic systems theories (e.g. Prigogine & Stengers, 1984; Thelen & Smith, 1994), including chaos and complexity theories, computers made it possible to process large data sets and to simulate the behaviour of complex biological systems. Drawing on the literature on all three systems theories, we compiled an overview of the basic systems' theoretical characteristics (Table 1).

Table 1
Systems' theoretical characteristics exemplified for biological systems
The concepts in italics were used as indicators for analyzing the frameworks of the systems thinking in the five studies (see Table 2).

Systems theory		**Systems' theoretical characteristics**
General Systems Theory	(1)	Systems have an *identity*, which makes it possible to identify them as objects. Systems like cells and organisms have a more distinct *system boundary* then populations and ecosystems.
	(2)	Systems consist of different *components* or *partial systems* of the same or different categories, which means that a system not only has its own identity, but is also a partial system in a higher order system. Biological systems' components are partial systems. The levels according to which biological systems can be categorized are indicated as *levels of biological organization* (e.g. the cellular and the ecosystem level).
	(3)	Systems' components (partial systems) perform different *function*s in the system (e.g. organs in an organism).
	(4)	Systems' components (partial systems) *interact* with each other (e.g. the *interaction* between a predator and its prey).
	(5)	A distinction can be made between open and closed systems. Open systems *exchange matter, energy and/or information with the environment, closed systems do not.* Biological systems are open systems, having an *input*, *throughput* and *output* of matter, energy and information. *Energy flows* and *cycles of matter* can be identified.
Cybernetics	(6)	Systems are *self-regulating*, which means that *feedback mechanisms* effectuate a reduction in exceeded values of systems properties and a return to original values (*set points*) or mean values. In biological systems, many values of properties are in *equilibrium* and *balance* around a mean value (e.g. the mean size of a population). At the level of the cell and the organism, this process is called *homeostasis*.
Dynamic Systems Theories	(7)	Open systems can be *self-organizing system*s, which means they go through a life cycle in which *emergent properties* result from interactions between components (partial systems). Biological systems are self-organizing systems that demonstrate *reproduction* at several levels of biological organization and have emerged in the course of *evolution*.
	(8)	During their lifetime, open systems are in equilibrium for limited periods of time. From such a *temporary equilibrium, the system will typically make a transition into* a *chaotic phase*, in which the predictability of future development is limited. From a chaotic phase, the system may develop into one of several new *equilibrium state*s. Biological systems demonstrate equilibrium for limited periods of time (e.g. a pond with or without duckweed).

Table 1 was used to characterize the conceptual frameworks of the five studies in terms of their explicit or implicit references to systems theory with systems' theoretical characteristics. For example, implicit reference to Cybernetics was identified when concepts such as feedback or self-regulation were mentioned.

3. Results

We searched in the conceptual frameworks of all five studies for the objects presented as systems, definitions of a system, references to systems theory, definitions of systems thinking, and a list of elements of systems thinking. An overview of the results of this analysis is presented in Table 2.

Table 2

Characteristics of the conceptual frameworks. The numbers in brackets following systems thinking elements refer to the systems' theoretical characteristics presented in Table 1. Numbers are not indicated when systems thinking characteristics could not be attributed unequivocally

Ben-Zvi Assaraf and Orion (2005)

Object(s)	Water cycle
Definition of a system	A system is an entity that maintains its existence and functions as a whole through the interaction of its parts. However, this group of interacting, interrelated or interdependent parts that form a complex and unified whole must have a specific purpose, and for the system to optimally carry out its purpose, all parts must be present. Thus the system attempts to maintain its stability through feedback. The interrelationships among the variables are connected by a cause-and-effect feedback loop, and consequently, the status of one or more variables affects the status of other variables. Yet, the properties attributable to the system as a whole are not those of the individual components that make up the system. (p. 519/520)
Reference to systems theory	Not explicitly, implicitly to Cybernetics
Definition of systems thinking and/or framework of elements of systems thinking	**The ability**: 1. to identify the components of a system and processes within the system (2, 4) 2. to identify relationships among the system's components (4) 3. to organize the system's components and processes within a framework of relationships (4) 4. to make generalizations 5. to identify dynamic relationships within the system 6. to understand the hidden dimensions of the system 7. to understand the cyclic nature of systems (5) *8.* to think temporally: retrospection and prediction (p. 523)

Ben-Zvi Assaraf and Orpaz (2009)

Object(s)	School environment; ecosystem of the poles.
Definition of a system	No
Reference to systems theory	Not explicitly, implicitly to Cybernetics
Definition of systems thinking and/or framework of elements of systems thinking	**The ability**: 1. to identify the components of a system and processes within the system (2, 4) 2. to identify dynamic relationships among the system's components (4) 3. to organize the system's components and processes within a framework of relationships (4) 4. to understand the cyclic nature of systems–a perception of the system as a whole (5) (p. 5)

Evagorou et al. (2009)

Object(s)	Marsh, pizzeria, forest
Definition of a system	Taken from Ben-Zvi Assaraf and Orion (2005) (see above)
Reference to systems theory	Not explicitly, implicitly to Cybernetics
Definition of systems thinking and/or framework of elements of systems thinking	Systems thinking is the ability to understand and interpret complex systems (p. 655). The identification of: 1. the elements of a system (2) 2. the spatial boundaries of a system (1) 3. the temporal boundaries of a system (1) 4. several subsystems within a single system (2) 5. the influence of specific elements of the system on other elements, or the whole system (4) 6. the changes that need to take place in order to observe certain patterns (6) 7. the feedback effects in a system (6) (p. 663)

Sommer (2005) (translated from German)

Object(s)	White stork, school
Definition of a system	(quoting Von Bertalanffy, 1968) Systems are sets of elements standing in interaction.
Reference to systems theory	General Systems Theory, implicitly to Cybernetics and Dynamic Systems Theory
Definition of systems thinking and/or framework of elements of systems thinking	Systems thinking is the representation of basic system characteristics in a person's thinking, and is composed of the following components:. 1. Identification of important components of the system, and their interrelations (2, 4) 2. Recognising and drawing system boundaries (1) 3. Organising system components and interrelations in a framework (2, 4) 4. Distinguishing characteristics of a system from characteristics of its components (2, 4) 5. Recognising dynamic interrelations 6. Predicting the results of changes (6) 7. Evaluating complex interactions in a system 8. Identifying and describing feedback processes (6) (p. 78)

Verhoeff (2003)

Object(s)	Cell
Definition of a system	According to the three systems theories. According to the General Systems Theory, a biological system has the following characteristics: 1. Biological objects can be seen as systems with an internal and an external environment separated by a systems boundary. 2. Living systems are open systems with a continuous exchange of material, energy and information with the external environment 3. Living systems are characterised by their form, function and behaviour. 4. Living systems are hierarchical; several levels of organisation can be distinguished. 5. At each level of biological organisation, living systems can be distinguished that are functional subsystems of the system at a higher level of organisation. (p. 40)

Reference to systems theory	Explicitly to General Systems Theory, Cybernetics and Dynamic Systems Theory
Definition of systems thinking and/or framework of elements of systems thinking	Systems thinking competence is the ability and willingness to link different levels of biological organisation from the perspective that natural wholes, such as organisms, are complex and composite, consisting of many interacting parts, which may be themselves lesser wholes, such as cells in the organism (p. 4). 1. Being able to 'think in levels of biological organisation' (2) 2. Being able to choose a certain systems perspective and use the subsequent descriptions of the system characteristics* as a guideline to understand biological phenomena (1, 2, 3, 4, 5, 6, 7, 8) 3. Being able to think backwards and forwards between general systems models and concrete biological objects and processes (p. 46) *The system characteristics referred to are arranged according to the different systems theories (pp. 37-43) and largely conform to the system characteristics in Table 1.

The results show that the studies focus on different objects as systems, ranging from the water cycle (Ben Zvi-Assaraf & Orion, 2005) and a pizzeria (Evagarou et al., 2009) to cells (Verhoeff, 2003).

Furthermore it can be noted that the studies of Evagorou et al., Sommer and Verhoeff present a definition of systems thinking. The definitions of Sommer and Evagorou et al. focus on general characteristics of systems, while Verhoeff's definition focuses explicitly on biological systems.

The results also show that only the studies of Sommer and Verhoeff refer explicitly to systems theory and that only the study of Verhoeff refers to all three systems theories. The frameworks of elements of systems thinking are sometimes partially (Sommer) or entirely based on systems theory or on a review of the literature on systems thinking (both studies of Ben-Zvi Assaraf, Evagarou et al., and partly, Sommer). The frameworks of elements of both studies of Ben-Zvi Assaraf and of Verhoeff are specified, respectively, to earth science and biology.

If the elements of systems thinking are considered, it can be seen that the first four studies generally refer in their elements to specific systems characteristics, while Verhoeff refers to different systems theories in his second element, and to the relation between biological objects and systems models in his third element.

To facilitate a comparison between the elements of systems thinking referring to systems' theoretical characteristics, the results presented in Table 2 are collected in Table 3.

Table 3 shows that references to all systems' theoretical characteristics from Table 1 were only found in the framework of Verhoeff. Not all elements of systems thinking refer to systems' theoretical characteristics. Some elements of systems thinking were not specific enough to allow an unequivocal identification of systems' theoretical characteristics. This was especially the case when elements of systems thinking referred to the behaviour of dynamic systems (e.g. the elements of systems thinking 5 of Ben-Zvi Assaraf & Orion and Sommer). Furthermore, systems' theoretical components from Cybernetics were found in the studies of Evagorou et al., Sommer and Verhoeff. Elements of systems thinking with unequivocal systems' theoretical characteristics from Dynamic Systems Theory were only found in the study of Verhoeff.

Systems' theoretical characteristic 3, that components of a system perform a function, was only distinguished in Verhoeff's study, and systems' theoretical characteristic 5, that systems should be considered open systems, was not found in the studies of Sommer or Evagorou et al. Since the system boundary can be considered one of its most basic characteristics, it is remarkable that this systems' theoretical characteristic is missing in both of Ben-Zvi Assaraf's studies. This correlates with the finding that in these studies, objects with an ill-defined system boundary were selected (see Table 2). Since in systems with an ill-defined boundary, the systems' components and the interaction between them are the most striking characteristics, it seems no coincidence that the corresponding systems' theoretical characteristics 2 and 4 were found in all studies.

Table 3

Correlation between the systems' theoretical characteristics (Table 1) and elements of systems thinking (Table 2). The numbers in the columns of the studies are the numbers of the elements of systems thinking represented in Table 2

	Systems' theoretical characteristics	**Ben-Zvi Assaraf & Orion**	**Ben-Zvi Assaraf & Orpaz**	**Evagorou et al.**	**Sommer**	**Verhoeff**
1	Identity and systems boundary			2, 3	2	2
2	Consists of different (categories of) components	1	1	1, 4	1, 3, 4	1, 2
3	Components (partial systems) perform functions					2
4	Interaction between components of the system	1, 2, 3	1, 2, 3	5	1, 3, 4,	2
5	Open systems with input and output	7	4			2
6	Self-regulation by feedback mechanisms			6, 7	6, 8	2
7	Open systems as self-organizing systems					2
8	Temporary phases of equilibrium					2

4. Conclusions and discussion

4.1 Explanation of the contrasting claims about the feasibility of systems thinking

Although Table 3 reveals some remarkable differences between the elements of systems thinking and the way in which they refer to systems' theoretical characteristics, these differences cannot account for the contrasting claims. If we take a closer look, however, we note that Verhoeff's framework contains one element of systems thinking that is not present in the other studies: the third element, that students should be able to think backwards and forwards between general systems models and concrete biological objects and processes. This requires that students be able to compare an abstract systems model with concrete biological objects and processes, and to understand which systems' theoretical characteristics an object should have in order to count as a system.

We suggest that the contrasting claims about the feasibility of systems thinking can be explained by whether or not the recognition of an object *as* a system is considered to be an essential element of systems thinking. We think that some additional support for this explanation can be found. Ben-Zvi Assaraf and Orpaz argue that "to understand whole systems, separate understandings of the parts will not suffice. One must acquire, rather, a holistic view of the system as an entity in itself, having characteristics beyond its mere parts" (2009, p. 21). However, in their discussion it is concluded that their findings "are consistent with Ben-Zvi Assaraf & Orion's earlier result that students perceive the water cycle system as a set of unrelated pieces of knowledge. They understand various hydro-biological processes, but lack the perception of the system as one unit" (2009, p. 22). In Sommer's study, we did not find evidence of students understanding the white stork system as a whole. What was measured instead was the increase in students' understanding of the number of relations between the system's components. The results from Evagorou et al.'s study on the pizzeria task demonstrate that the pizzeria as a system was not equally defined by all students (2009, p. 665).

4.2 A methodological note

Only Verhoeff's study focuses on a system (the cell) with a distinct system boundary, while in all other studies, the objects presented do not have distinct system boundaries (see Table 2). The pizzeria presented by Evagorou et al. may be defined as the building being an open system, influenced by its clients, or as the building including the clients; the latter interpretation is emphasised in the study. The water cycle in the study of Ben-Zvi Assaraf and Orion is not embedded in an ecosystem with a distinct system boundary (2005, p. 546). And the white stork in Sommer's study is living in two ecosystems, travelling between Africa and Western Europe. Summing up, it may be questioned if the objects selected in the four other studies are appropriate for testing students' understanding of systems. We therefore recommend that to test students' systems thinking ability, objects with distinct system boundaries need to be selected.

4.3 How to usefully prepare the formal introduction of systems thinking

We have tried to account for the contrasting claims about the feasibility of systems thinking by noting that the studies recommending the introduction of systems thinking in primary or lower secondary education did not measure students' ability to think forwards and backwards between concrete objects and systems models. What further supports this account is Verhoeff's finding that it is precisely the meaningful preparation for the required forwards and backwards thinking which turned out to be difficult to achieve. In the first part of Verhoeff's learning and teaching trajectory, a general model of the cell is developed by comparing free-living cells with those in organisms and attributing fundamental life processes to both types of cells. The intent in the first part was that students would develop not only a general model of the cell, but also a motive for the introduction of a general systems model in the second part. Although the study was successful in developing a general model of the cell, it was not successful in developing a motive for systems thinking. Consequently, the students did not experience the need to introduce a model that could equally be applied to cells, organs and organisms. The notion that a general systems model is indeed general, and that from a student's perspective it makes no sense to introduce it, was overlooked. The introduction of such a model as meaningful to students requires a more careful preparation.

In conclusion, we conjecture that it is worth elaborating learning and teaching trajectories on a variety of biological objects, such that in these objects or categories of objects a number of general characteristics are made explicit. In such an approach, in which similarities and differences are discussed, it may be helpful to represent the similarities in a model of the super-ordinate category. Considering students' prior knowledge and experience, it seems obvious to start at the level of the organism and descend from there to the level of the organ and cell, and ascend to the level of the population and community (Knippels, 2002). If students notice that the same characteristics can be recognised in objects of different levels of biological organization, a general systems model can be introduced, representing systems' theoretical characteristics that apply to objects on all of these levels. An alternative for such an inductive approach might be to search for basic cognitive structures underlying systems thinking, such as causality, form-function relationship and part-whole relations. Such basic cognitive structures are embedded in students' early bodily experiences (e.g. Lakoff & Johnson, 1999) and may be appropriate starting points for their conceptual development (Klaassen, Westra, Emmett, Eijkelhof, & Lijnse, 2008), including development of the systems concept.

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11 YOUNG CHILDREN'S REASONING ABOUT PHYSICAL FAMILY RESEMBLANCE AND ITS ORIGIN

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Abstract

This paper explores whether preschoolers recognize that children are more likely to share common physical traits with their parents than with other, unrelated human beings, and whether they grasp the origin of this family resemblance as biological (birth-bound) rather than psychological (intention-bound). In the context of individual semi-structured interviews with 90 preschoolers (aged 4.5-5.5 years) from four public kindergartens in Patras, we used (a) a modified five-case version of the 'functionality task' to trace preschoolers' reasoning about whether and why children are more likely to physically resemble their parents, even with regard to traits which are supposed to be unusual within the species, and (b) a modified three-case version of the 'wish-fulfilment task' to ascertain whether preschoolers' reasoning about physical family resemblance is intention-free. 6.7% of the participants consistently predicted that the child would have the peculiar physical trait of his/her parents because the parents gave birth to him/her; 52.2% of the participants consistently claimed an 'intention-free' character of inheritance by appealing to 'family resemblance' rather than to 'parents' intention' when making predictions about the child's physical trait. The children appear to need support in setting their focus on the 'child-parent' biological relationship and overcoming intentional reasoning.

Keywords: early years education; ideas about inheritance; ideas about physical family resemblance; intentional reasoning; teaching about physical family resemblance

1. Introduction

1.1 Theoretical framework

Research in early years education is strongly concerned with how young children start constructing their knowledge about the biological world (Carey, 1995; Inagaki & Hatano, 2006), and how they can be supported in this process with appropriately designed learning environments (Schroeder, McKeough, Graham, Stock, & Palmer, 2007; Solomon & Johnson, 2000).

It has been suggested (Wellman & Gelman, 1992) that even preschoolers hold naïve theories within three distinct biological contexts: growth, inheritance and transmission of illness. Regarding inheritance, children's naïve theory includes two essential components: (a) the idea that physical resemblance runs in families, and (b) the idea that this resemblance is causally linked to children's birth (Carey, 1995), while it has nothing to do with parents' intention. In other words, young children who have already developed a naïve theory of kinship are expected to recognize the occurrence of physical family resemblance, and also grasp this resemblance as birth-driven.

A series of sophisticated studies (Gelman & Wellman, 1991; Hirschfeld, 1994; Springer 1995; Springer & Keil, 1989, 1991) appear to provide significant evidence for the first component. Nevertheless, contradictory findings have been provided as well: preschoolers were reported as *not* having very strong intuitions that offspring share common physical traits with their parents (Weissman & Kalish, 1999). Moreover, establishing the presence of the second component of a naïve theory of kinship in young children's reasoning has proven to be more difficult (Carey, 1995). Children's problems in distinguishing between biological and adoptive parentage reveal a rather blurred view of the biological and social aspects of family membership before the age of 7 (Solomon, Johnson, Zaitchic, & Carey, 1996), although Springer's elegant study (1996) attributed this view to the eliciting tools that had been used.

On the other hand, contradictory findings have been reported with regard to preschoolers' ability to recognize that the physical traits of a child cannot be influenced by the intention of his/her mother. According to Springer and Keil (1991), preschoolers reject explanations of physical resemblance that draw upon maternal intention, while they prefer explanations that draw upon a material mother-fetus relationship during pregnancy. According to Weissman and Kalish (1999), preschoolers believe that maternal intention plays a role in the inheritance of physical traits, especially when it functions before the child's birth. Terwogt, Stegge, and Rieffe (2003) found a 'psychological' bias among their young informants when they gave them information about whose parent's phenotype was the desired one and then asked them to predict the offspring's phenotype by choosing among 'mother-like', 'father-like' or 'combined' phenotypes.

So, do preschoolers recognize the inheritance of physical traits? Are they able to explain it in an intention-free way? The contradictions in the formulated conclusions justify further exploration. This paper is part of a larger study aimed at shedding light on preschoolers' intuitive reasoning about several aspects of physical and behavioral family resemblance, in order to develop a learning environment that could potentially lead to a better understanding of inheritance. Our focus here is on what preschoolers think about whether and why physical resemblance runs in families.

1.2 Objectives

The research questions addressed here are:

(1) Do preschoolers realize that children are more likely to physically resemble their parents than other, unrelated human beings? How do they justify their claims?

(2) Do they realize that physical family resemblance has nothing to do with parents' intention or preference? How do they justify their claims?

Thus, the objective of this paper is to ascertain if preschoolers recognize that children are more likely to share common physical traits with their parents than with unrelated others, and whether they grasp the origin of this family resemblance as biological (birth-bound) rather than psychological (bound with parents' intention or preference).

2. Methodology

2.1 Study overview

Preschoolers (n=90, aged 4.5-5.5 years) attending four public kindergartens in Patras during the school year 2008-2009 were the study's informants. All of them were familiar with educational interactions since they had already completed several months of kindergarten, while they had never participated in formal learning activities about inheritance.

Children's reasoning in the context of inheritance was traced through individual, semi-structured, tape-recorded interviews lasting from 20 to 50 minutes, but most commonly not more than 25 to 30 minutes. The interviews were conducted in quiet places at the schools by the researchers, after the children had become familiar with them and gave their own assent for participating in the study. Children's parents had already been informed about the study and no objections were raised.

2.2 The interview protocol

The interview protocol was structured in six parts, two of which concern us here. In the first, children were engaged in a modified version of the 'functionality task' (Springer, 1995; Springer & Keil, 1989). More specifically, they were required to predict whether a child would resemble his/her parents with regard to physical traits which were rather unusual within the species, or would resemble all other human beings who did not have these peculiar traits but the usual ones.

Each of the five cases for which the 90 informants were required to make a justified prediction involved *one* specific peculiar trait. The cases differed in the nature of the trait in question: 'good' ('white heart' that helps a person remain healthy; 'sensitive hearing' that allows a person to hear very low sounds even from far away); 'bad' ('black heart' that makes a person get tired and sick; 'no eyebrows': a trait that causes blurred vision because of sweat entering the eyes), and finally 'neutral' ('red cheeks' that neither offers something good nor causes something bad). An example of how the children were asked about the inheritance of peculiar traits is the following: 'Humans usually have a red heart. Nevertheless, a man and a woman were born with a white heart that actually helps them stay healthy. These two people are now going to have a child together. What do you think about the heart of this child? Do you think that it will be white like the heart of his/her parents or red like the heart of all other people? Why do you think so?'

In the second part of the interview protocol concerning us here, the participants were engaged in a modified version of the 'wish-fulfilment task' (Schroeder et al., 2007; Weissman & Kalish, 1999), which included three different cases regarding the role of parents' intention in family resemblance. In each case, the participants were required to make a justified prediction about whether a child would have a specific *inborn* physical trait of his/her parents or the one that the parents deeply *wished* he/she would have. The cases differed in the nature of the intended trait in question: 'good' ('5 fingers' for the child despite the parental trait of '6 fingers') or 'neutral' ('white skin' for the child despite the parental trait of 'black skin'; 'blond hair' for the child despite the parental trait of 'red hair'). An example of how the children were asked about the role of parents' intention is the following: 'People with black skin usually make children with black skin. A man and a woman with black skin are going to have a child together and they very much wish that their child will be born with white skin. What do you think about the skin colour of their child? Will it be black like theirs or white like they very much wish?'

2.3 Overview of the analytical procedure

The tape-recorded interviews were transcribed and prepared for coding using the qualitative analysis software 'NVivo'. The coding process led to a series of 'categories', organized into a 'coding scheme' (Figure 1). Coding also led to a series of 'attributes' which were assigned to each interview with a specific 'value':

a) *'Peculiar traits: bio parents' trait–birth'* with values *'all'* (5), *'most'* (3-4), *'a few*' (1-2), and *'none'* (0).

b) *'Peculiar traits: bio parents' trait–physical family resemblance'* with values *'all'* (5), *'most'* (3-4), *'a few*' (1-2), and *'none'* (0).

c) *'Intended traits: bio parents' inborn trait–physical family resemblance'* with values *'all'* (3), *'a few'* (1-2), and *'none'* (0).

d) *'Intended traits: bio parents' intended trait–bio parents' intention'* with values *'all'* (3), *'a few'* (1-2), and *'none'* (0).

For instance, if a participant (a) claims, in four of the cases in question, that 'the child will have the peculiar physical trait of his/her biological parents because he/she was born from them', (b) claims in the fifth case that 'the child will have the peculiar physical trait of his/her biological parents because kids look like their parents', (c) does not claim in any of the cases in question that 'the child will have the inborn (and not the intended) trait of his/her parents, because kids look like their parents', and (d) claims in two of the cases that 'the child will have the intended trait, because that was the wish of his/her parents', then the informant's interview was given the values:

a) *most'* for the 'attribute' *'Peculiar traits: bio parents' trait–birth'*,

b) *'a few'* for the 'attribute' *'Peculiar traits: bio parents' trait–physical family resemblance',*

c) *'none'* for the 'attribute' *'Intended traits: bio parents' inborn trait–physical family resemblance'*, and

d) *'a few'* for the 'attribute' *'Intended traits: bio parents' intended trait–bio parents' intention'.*

The coding was performed independently by the first author and the group of the co-authors, and the inter-rater reliability was very good (Cohen's kappa: 0.90).

3. Findings

3.1 Children's reasoning about the idea of a species-incompatible physical family resemblance

(a) Claims

Our informants claimed 'correctly' that the child would have the peculiar physical trait of his/her parents 75.3% of the times they were asked (339/450 times); 22.8% of the times (103/450) they made the 'wrong' claim that the child would have the usual physical trait of the species, and 1.7% of the times (8/450) they made no claim at all.

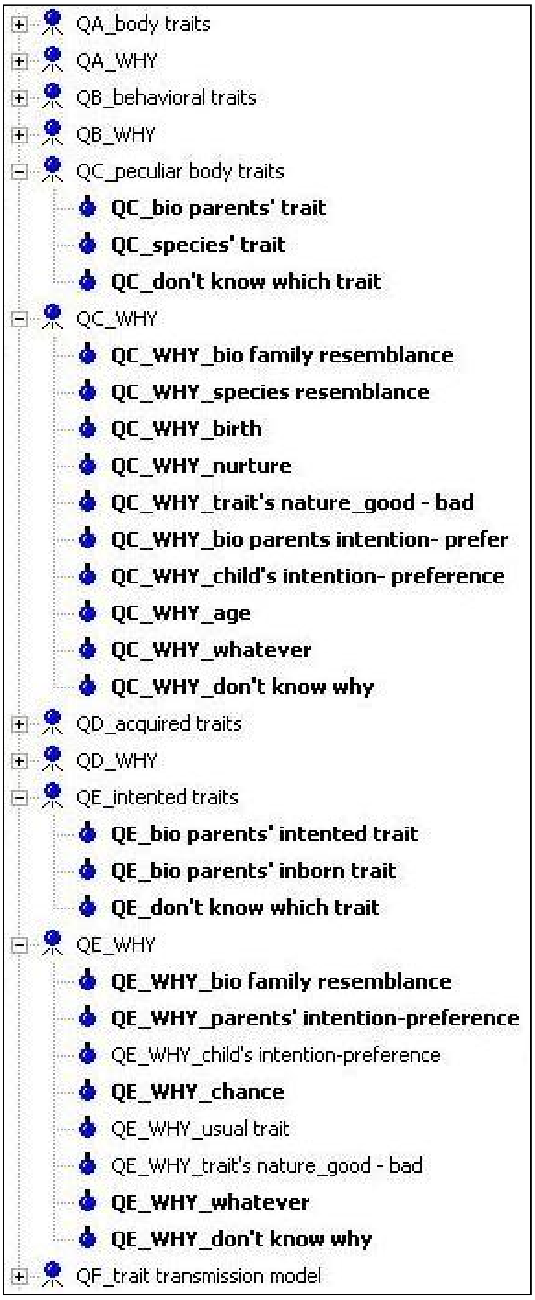

Figure 1
The coding scheme

(b) Justifications

The claim for the inheritance of the peculiar parental trait was mainly justified using the criteria of 'family resemblance' (215/339 times, 63.4%) and 'birth' (81/339 times, 23.9%). Thus, the offspring was expected to have the peculiar parental trait in question (a) because kids look like their parents, and (b) because he/she was born from them. In our participants' own words:

(a) *'If the parents have a white heart, then the child will have a white heart like them. And if they have a red heart, he/she will have a red heart like them'; 'The child will have strong ears and will hear everything… it cannot be otherwise…the child will be like his/her mom and dad'.*

(b) *'He/she will not have eyebrows because that's how he/she will be born from his/her parents…they are without eyebrows'; 'The child will have a black heart because he/she was born from his/her mother who got married to his/her father and his heart was black and her hear was black, too'; 'The child will have red cheeks because he/she was born from the parents with the red cheeks'.*

Moreover, children justified the claim of 'child-parent' resemblance by drawing upon a series of other criteria as well:

- 'Nurture': the child was expected to have the peculiar physical trait of his/her biological parents because he/she is raised by them (i.e. *'The child will have red cheeks. He/she will look like his/her parents and not like other people, because he/she is raised by his/her parents'*).
- 'Trait's nature: good/bad': the child was expected to have the peculiar physical trait of his/her biological parents because this trait was a good one (i.e. *'The child will have the white heart and not the red…to grow up and be strong and healthy').*
- 'Child's age'*:* the child was expected to have the peculiar physical trait of his/her biological parents because this trait was considered more compatible with the child's young age than the usual species trait (i.e. *'The child will have strong ears, because babies hear very well';* in other words, babies do not have hearing problems; these problems usually bother old people).
- 'Parents'' or 'Child's' 'intention-preference': the child was expected to have the peculiar physical trait of his/her biological parents because of the parents' or the child's intention or preference for it (i.e. *'The child will not have eyebrows because his/her mom and dad want him/her not to have them'; 'The child will have red cheeks because he/she wants to look like his/her parents').*

These criteria were traced 11 out of the 339 times (3.2%) that the informants were engaged in justifying this claim. Nevertheless, the remaining 9.5% of these times, they either explicitly stated their inability to provide a justification for their 'correct' claim and thus their responses were coded as 'don't know why', or they came up with a quite irrelevant 'quasi-justification' that was coded as 'whatever' (i.e. *'The child will have strong ears because his/her parents love him/her very much…if they didn't love him/her, his/her ears wouldn't be strong')*.

Going back to the target criterion of 'birth' and the consistency of its use for justifying this 'correct' claim, we note that 6.7% of the informants appealed to it in 'all' of the cases they had to explore (5), 8.9% appealed to it in 'most' of the cases (3-4), and 17.7% appealed to it in at least 'a few' of them (1-2) (Table 1).

Table 1

Children's consistency in using 'birth' to justify the 'correct' claim

'Peculiar traits: bio parents' trait-birth'	Number of children
'All' of the required times (5)	6/90 (6.7%)
'Most' of the required times (3-4)	8/90 (8.9%)
'A few' of the required times (1-2)	16/90 (17.7%)
'None' of the required times (0)	60/90 (66.7%)

Moreover, some of those children who used the target criterion of 'birth' 'none' of the required times (60/90, 66.7%) actually *did* use the criterion of 'family resemblance' either consistently (32.2%) or at least partially (5.6% 'most' of the times and 8.9% 'a few' of the times). The use of the latter may be considered an indication that our preschoolers *do* take into account the 'child-parent' relationship, although in a way that is more naïve than the one that considers birth. So, it seems purposeful to highlight our informants' combined use of this criterion with the target criterion of 'birth' *across* the five cases of the task (Table 2).

Table 2

Number of children who used 'birth' and/or 'family resemblance' to justify the 'correct' claim *across* the five cases of the task (*NA: non-applicable)

		'Peculiar traits: bio parents' trait–family resemblance'			
		'All ' (5)	**'Most' (3-4)**	**'A few' (1-2)**	**'None' (0)**
'Peculiar traits: bio parents' trait–birth'	'All' (5)	*NA**	*NA*	*NA*	6/90 (6.7%)
	'Most' (3-4)	*NA*	*NA*	5/90 (5.6%)	3/90 (3.3%)
	'A few' (1-2)	*NA*	9/90 (10%)	3/90 (3.3%)	4/90 (4.4%)
	'None' (0)	29/90 (32.2%)	5/90 (5.6%)	8/90 (8.9%)	18/90 (20%)

Thus 'promising' combinations such as 'birth-most & family resemblance-a few', 'birth-a few & family resemblance-most', 'birth-a few & family resemblance-a few' are offered by 5.6%, 10% and 3.3% of our informants, correspondingly. Nevertheless, the 'problematic' combination 'birth-none & family resemblance-none' is also present: 20% of the informants never came up with either the criterion of 'birth' or the criterion of 'family resemblance', which means that they left the 'child-parent' relationship completely out of their focus when predicting the child's physical traits.

Moving on to the 'wrong' claim ('species trait'), we note that it was grounded in the following criteria:

- 'Species resemblance' (32/103 times, 31.1%): the child was not expected to have the peculiar physical trait of his/her biological parents because he/she should look like most of the people (i.e. *'The child will not have red cheeks…he/she will have pink, to look like all the people'*).
- 'Trait's nature: good/bad' (15/103, 14.6%): the child was not expected to have the peculiar physical trait of his/her biological parents but the usual trait of the species because the latter is a good one (i.e. *'The child will have eyebrows like all the people, because if he/she does not have and he gets sweaty, then a drop of sweat or two drops will get into his eyes and he will not see very well').*
- 'Child's age' (5/103 times, 4.8%): the child was not expected to have the peculiar physical trait of his/her biological parents but the usual trait of the species because the latter was considered to be more compatible with his/her young age (i.e. *'The child will not have strong ears, because he/she is a baby and babies are not strong. Maybe when he/she gets older, his/her ears will get stronger and he/she can hear all the sounds').*
- 'Child's intention-preference' (5/103 times, 4.8%): the child was expected to have the usual trait of the species because that was his/her wish (i.e. *'The child will not have a black heart like his/her parents. He/she will have a red heart because he/she likes it').*

As shown above, these criteria were traced 55.3% of the times that the informants were engaged in justifying their 'wrong' claim (57/103 times). Nevertheless, the remaining 44.7% of these times, the children either explicitly stated their inability to provide a justification for their 'wrong' claim and thus their responses were coded as 'don't know why' (10/103 times, 9.7%), or they came up with an irrelevant 'quasi-justification' that was coded as 'whatever' (36/103 times, 35%) (i.e. *'The child will have the red heart because it has colour in it').*

3.2 Children's reasoning about the idea of a psychologically driven physical family resemblance

(a) Claims

Concerning the role of parents' intention in physical family resemblance, 64.1% of the times they were asked (173/270 times), our informants claimed 'correctly' that the child would *not* have their parents' intended trait, while 34.8% of the required times (94/270) they claimed that the child would have it, and 1.1% of the times (3/270) they provided no claim at all.

(b) Justifications

The 'correct' claim was justified almost exclusively (163/173 times, 94.2%) by appealing to the idea of 'family resemblance': the parents *cannot* have a child with a desired physical trait that they don't have themselves, because kids have to look like their parents. In children's own words:

- *'They cannot have a white child no matter how much they want it, because they are black and their child will be like them'; 'They cannot have a child with 5 fingers. If they think about it a lot and if they pray to God, they cannot have it, because their child will have as many fingers as they have';' The child must be like its parents: with red hair'.*

The remaining 5.8% of the times that our informants were engaged in justifying their 'correct' claim, they either stated explicitly their inability to provide a justification for it and thus their responses were coded as 'don't know why' (6/173 times, 3.5%), or they came up with an irrelevant 'quasi-justification' that was coded as 'whatever' (4/173 times, 2.3%) (i.e. *'The child will have 6 fingers because his fingers will be 6').*

It is worth noting that 'family resemblance' was used consistently by 52.2% of the participants (47/90). In other words, 52.2% of the children *did* appeal to this criterion in '*all'* three cases they had to explore, to justify their 'correct' claim. Moreover, 13.3% (12/90) used this criterion in 1-2 of the cases in question, while 4.4% (4/90) used (a) this criterion in 1-2 of the cases in question, *and* also (b) the criterion of 'intention' in the remaining 1-2 cases, thus offering the contradictory combination 'family resemblance-a few & intention-a few'.

Moving on to the 'wrong' claim ('bio parents' intended trait'), we note that most of the times that our informants were engaged in justifying it, they did so by appealing to 'parents' intention-preference' (57/94 times, 60.6%). Namely, they stated explicitly that a child may have a physical trait that their parents do *not* have, because the parents want it very much ('*The child will be blond because her parents want her to be blond very much'; 'Their child will be white because they make a big wish everyday'*). Moreover, 1.1% of the relevant times (1/94), they drew upon the 'child's intention-preference': *'The child will be blond because she likes blond hair more'.*

The 'wrong' claim was also based upon other criteria:

- 'Trait's nature: good/bad' (1.1% of the relevant times, 1/94): *'The child will have 5 fingers for being able to grip things better'.*
- Trait's familiarity ('usual trait') (5.3% of the relevant times, 5/94): '*The child will have 5 fingers because you and me…we have 5 fingers'..*
- 'Chance' (4.2% of the relevant times, 4/94): *'The child will be blond…It may be blond for example or it may be red-haired…mom doesn't know'.*

Finally, the remaining 27.6% of the relevant times that our informants were engaged in justifying their 'wrong' claim, they either stated explicitly their inability to provide a justification for it and thus their responses were coded as 'don't know why' (5/94 times, 5.3%), or they came up with an irrelevant 'quasi-justification' that was coded as 'whatever' (21/94 times, 22.4%) (i.e. *'The child will be white because he/she will not play in the sun').*

The criterion of 'parents' intention', which actually indicates the attribution of a psychological character to the origin of family resemblance, was used consistently by 15.5% of the participants (14/90). In other words, 15.5% of the children *did* appeal to it in *all* three cases they had to explore, to justify their 'wrong' claim. Moreover, 4.4% (4/90) used this criterion in 1-2 of the cases in question, while–as already mentioned–4.4% (4/90) used this criterion (a) in 1-2 of the cases in question, *and* also (b) the criterion of 'family resemblance' in the remaining 1-2 cases, thus offering the contradictory combination 'family resemblance-a few & intention-a few'.

4. Discussion

Our participants activated a series of criteria to justify their 'correct' claim about the physical traits of a child. Some of these criteria had nothing to do with the 'child-parent' relationship. More specifically, drawing upon 'traits' nature: good/bad', 'child's age' or 'child's intention-preference' to argue 'correctly' that the child would have the physical trait of his/her parents reveals a focus upon the trait itself (*the trait* is good/bad for the child, *the trait* is compatible/incompatible with the child's age, *the trait* is preferred or not by the child), renders the claim rather irrelevant to the biological dimension of the phenomenon and thus eliminates its value as an indication of an appropriate understanding. Part of this 'trait bias'–which was also expressed when justifying the 'wrong' claim–is quite similar to the 'psychological bias' broadly traced by Terwogt et al. (2003), but in our case it did not seem to be the general trend.

A significant number of informants showed the ability to take into account the 'child-parent' relationship when making predictions about the child's physical traits. It is worth noting that apart from the 6.7% of the children who appeared to have already solidly constructed the target – 'birth'-driven reasoning about the physical family resemblance – since they used it in *all* the cases they had to explore, there was also a number of informants (26.6%) who appeared to be in the process of constructing it since they used it in 'most' or at least in 'a few' of the cases in question. More interestingly, most of the latter (18.9%) came up with the promising combinations 'birth-most & family resemblance-a few', 'birth-a few & family resemblance-most', or at least 'birth-a few & family resemblance-a few'.

These findings – possibly along with the 32.2% who at least came up *consistently* with 'family resemblance'-driven reasoning strands – may add to the optimistic research line in this context (Gelman & Wellman, 1991; Hirschfeld, 1994; Springer 1995; Springer & Keil, 1989, 1991), since they seem to indicate an encouraging potential on behalf of the children. This indication is further enhanced by our findings on children's reasoning about the intended physical traits. More specifically, 52.2% of the participating children consistently claimed an 'intention-free' character of inheritance by appealing to 'family resemblance' rather than to 'parents' intention' for their predictions in the 'wish-fulfillment task'. Moreover, 13.3% appeared to be at a good starting point towards consistent, 'intention-free' reasoning, since they *did* come up with it in 'a few' of the cases.

This appears to contrast with Weissman and Kalish's (1999) claim that preschoolers believe in the influence of maternal intention or preference on the physical traits of the child, especially if the intention or preference is expressed before the child is born. Nevertheless, we also found children with 'intention-bound' reasoning: 8.8% of our informants claimed, in 'a few' of the cases of the wish-fulfillment task, that parental intention is powerful enough to result in a child with the intended trait, while 15.5% came up with this reasoning in 'all' three cases. Note that 10% of this 15.5% made their trait predictions in the 'functionality task' based on a consistent or at least very frequent use of the criterion 'family resemblance'. So it seems that for these children, the criterion of 'family resemblance' loses its (previously strong) predictive value, if directly confronted with the criterion of 'parents' intention'. This actually indicates difficulties in leaving the naïve device of intentional reasoning behind.

In summary, the children appeared to have the potential to move on to, as well as the need to be supported in, setting their focus on the 'child-parent' relationship (recall the 20% with the combination 'birth-none & family resemblance-none' across the five cases of the 'functionality task') and stopping the use of intentional reasoning (recall the 10% who did not manage to re-use their familiar criterion of 'family resemblance' to make intention-free predictions about the physical traits of the child in the 'wish-fulfilment task').

Building on Solomon and Johnson's (2000) suggestion, we intend to use the idea of 'genes' as a 'conceptual placeholder' to try to help children recognize the limitations of intentional reasoning when it comes to the transmission of physical traits and focus on the biological phenomenon of birth. The idea of 'genes' seems to be consistent with young children's 'psychological essentialism' (Gelman & Wellman, 1991), since it could potentially help them (a) describe, in a less abstract way, the 'constitutive essence' or 'innate potential' of living entities that they intuitively assume as an internal, not necessarily known, unchanging property, which is unique and determines their identity and external observable features, and (b) explain its origin.

This actually pre-supposes working with the concept of reproduction and promoting an appreciation of the contribution of both parents in the formation of the baby through their sperm and egg. The knowledge about reproduction and the construction of a naïve representation of various genes as 'very tiny, special things' that lie within parents' sperm and egg and 'decide' about the various physical traits of the derived child might help young children focus on the biological dimension of the 'child-parent' relationship and replace their appreciation of the role of parental intention or wish with an appreciation of the role of this tiny parental material.

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12

ANALYSIS OF THE EFFICIENCY OF APPLYING PROBLEM-BASED LEARNING TO BIOLOGY INSTRUCTION OF ELEMENTARY SCHOOL ECOLOGY CURRICULUM

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Abstract

In this paper a comparison is made between the level of efficiency obtained when using the problem-based vs. informative-illustrative biology teaching models in the framework of the ecology curriculum for the seventh grade in elementary school. The model of a pedagogical experiment with parallel groups [experimental (E) and control (C)] was applied on a sample of 177 students (13 to 14 years old) from four elementary schools in the municipality of Valjevo (western Serbia). The aim was to identify and measure the differences, and compare the efficiencies of these two models of teaching. Subsequently, the E group realized the ecology syllabus by applying the problem-based teaching, while the C group applied the traditional teaching model. The problem-based biology instruction was implemented in the E group in several stages: setting problems, finding solutions, analysing problems, solving problems and drawing conclusions. The informative-illustrative teaching model was implemented in the C group by classical teaching methods: oral presentations, illustrations and demonstrations. Using this experimental design, we determined that the problem-based biology teaching was more efficient in terms of scope of knowledge and application of knowledge in the examined teaching field.

Keywords: pedagogical experiment; problem-based learning; ecology contents; primary school; Serbia

1. Introduction

Biology teaching is characterized by a wide range of application of various forms, methods and means of instruction. It also provides opportunities for the application of numerous didactic models in accordance with the demands of different teaching situations. It is necessary to adjust these elements into a single integrated system, in order to achieve maximum optimization in the teaching process. The results of experimental research on the efficiency of different teaching elements primarily contribute to this optimization and generally suggest ways of creating a high-quality biology teaching process (Stanisavljević & Radonjić, 2009).

Solving problems is the highest form of learning, which translates into thinking and creativity. Problem-based teaching and learning of biology should be characterized by: the existence of difficulties/problems encountered by the students, the novelty of the situation, and independent activities targeted to individual students to solve a given problem (Duch, Groh, & Allen, 2001). Moreover, it is necessary to achieve high motivation in students, as well as stimulate the dynamics of their thinking process (toward developing abstract thinking) (Prince, 2004; Sawyer, 2006).

Problem-based biology teaching involves several successive stages: posing the problem, finding solution principles (choosing rational hypotheses), analyzing the problem, solving the problem and drawing conclusions (with possible verification of the drawn conclusions in new situations). Interpolation problems (when the facts of the initial situation and the goal are known) or extrapolation problems (when either the goal or the facts are known, or when neither is known) can be presented. Several studies have confirmed the efficiency of implementing a problem-based approach in the teaching of biology (Chin & Chia, 2000, 2006), environmental protection (Ying, 2003), and a computer-supported learning environment in population ecology (Ergazaki & Zogza, 2008).

In considering specific ecology education programme material in biology for the seventh grade in Serbia, and taking into account the students' ages, it might be concluded that implementation of the problem-based interpolation is appropriate for carrying out this type of instruction. However, it is necessary to analyze the efficiency of this didactic model and compare it with the traditional informative-illustrative model in teaching these ecology contents.

2. Research design and method

2.1 Aims and objectives

The main task of this research is to experimentally verify the effectiveness of problem-based biology teaching, as a special didactic model, in accomplishing the ecology curriculum (teaching) goals for biology in elementary school. 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 problem-based instruction) in the experimental group.

The alternative hypothesis is that there is a statistically significant difference when teaching ecology material (sea-living communities–problems and solutions) between the experimental and control groups, after introducing the experimental factor, which is problem-based biology teaching, in the 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 177 students [seventh-grade (13 to 14 years old)] from four elementary schools: "Sisters Ilić", "The first primary school", "Miloš Marković" and "Milovan Glišić", in the municipality of Valjevo (western Serbia). To achieve the aims of this research, the model of pedagogical experiment with parallel groups [experimental (E) and control (C)] was applied (Killermann, 1998). Students were grouped into one E and one C group. Before the introduction of the experimental factor, the groups were made uniform in number of students, gender, and general knowledge of ecology as determined by distributing a pre-test of knowledge.

The pre-test was composed of ten 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 ecology programme material (for seventh-grade students) that had been taught before the material related to sea-life communities (teaching areas: basic concepts of ecology, living conditions in the water, and marine ecosystems). The maximum number of points in the pre-test was 100.

After equalizing the E and C groups of students, group E began covering the prepared ecology material (marine-life communities–problems and solutions) by applying the problem-based teaching method, while group C applied the informative-illustrative teaching method. Both groups realized the same ecology programme (teaching) contents, from the same textbook.

The informative-illustrative teaching method (classical model of instruction) in group C was implemented by presenting the above teaching content using classical teaching methods: oral presentations, illustrations and demonstrations. Students did not have the opportunity to discuss, either individually or in groups, the given material or to draw their own conclusions by solving the presented problems.

The problem-based biology instruction in group E was implemented in several stages (setting the problem, analysing the problem, finding solutions, solving the problems and drawing conclusions). Students considered the problems faced by different living organisms on the basis of previously prepared materials–teaching/instruction sheets, and images, photos, charts and text in textbooks. Students worked in groups and determined the problems faced by marine organisms living in different ecosystems. Then they analyzed these issues, found the principles and solutions for the survival of organisms under the given conditions, and drew conclusions related to the given topics. All of the steps in the realization of this type of problem-based instruction were conducted and implemented with the help of teaching-instructive working papers, which had defined problem questions for consideration (by each particular group of students). By solving given problem questions, students successively passed through all stages of the problem-based instruction in terms of ecology programme content.

To determine the knowledge acquired by the students using the problem-based and classical, informative-instructional biology teaching approaches, we applied a post-test of knowledge. This measured the quantity and quality of the students' acquired knowledge in the specific area (sea-living communities) for both groups of students. The post-test (see Appendix) was composed of nine tasks (classified into three levels, as with the pre-test) which, in terms of their content, were suited to the given teaching field. As in the pre-test, the maximum number of points that students could achieve in the post-test was 100.

For this research, aside from the pre- and post-tests, other documents were analysed: school documentation, teaching sheets, adequate text materials and drawings. Data and result processing was performed by applying basic statistical methods/table-descriptive statistics (sum, percentage frequency, mean, standard deviation, coefficient of variation, Chi-square test and paired sample t-test for testing differences between similar statistical indicators). All statistical analyses were performed using the software package STATISTICA 6 (StatSoft, 2001).

3. Results and discussion

To verify gender uniformity, the Chi-square test (Fisher, 1922) was applied, with the values obtained for the gender relation between E and C groups: Chi^2=1.015, df=1, p=0.314. Since the obtained value of Chi^2 does not exceed the value limits of 3,841 for one degree of freedom and a probability of 5%, this unequivocally shows that the groups were equal in this parameter.

The results of the pre-test are presented in Tables 1, 2 and 3. Table 1 presents student performance in the pre-test as expressed by the total number of points achieved and the percentage of points achieved in the different ranks and as a whole. On the basis of these results, we observed differences in the number of points achieved (insignificant percentage difference of achieved points), which were further examined by their significance (Table 2).

Table 1
Performance of students in the pre-test

		Rank I		Rank II		Rank III		Total	
Group	No. of students	No. of points	%	No. of points	%	No. of points	%	No. of points	%
E	97	2287	76.06	2457	76.76	2356	67.47	7100	73.20
C	80	2073	83.59	1970	74.62	1812	62.92	5855	73.19

Table 2
Basic statistical data for the pre-test

	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	23.58	6.07	25.73	25.33	8.53	33.67	24.29	6.84	28.15	73.20	16.91	23.10
C	25.91	4.46	17.23	24.63	7.94	32.25	22.65	8.61	38.01	73.19	13.30	18.18

$\overline{X}$, mean number of achieved points; S, standard deviation; V, coefficient of variation.

Based on the results presented for the pre-test for the E and C student groups, we can conclude, using Student's t-test for a significance 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 the second- and third-level tasks, or in the test as a whole (Table 3), and that these two groups were balanced in terms of general knowledge of ecology before the introduction of the experimental factor.

Table 3
Testing group uniformity in terms of the pre-test, using the t-test
Critical value **t=2.58 for p=0.01

Relation	Rank I	Rank II	Rank III	Total
E:C	2.86**	0.56	1.41	0.01

The results of the post-test are presented in Tables 4, 5 and 6. Table 4 shows the students' performance in the post-test of knowledge, expressed as total number of points achieved and as percentage of points achieved by levels and as a whole. There are differences in the number of points achieved between the E and C groups, favouring the former, in all three levels of tasks on the test and on the test as a whole.

Table 4
Performance of students on the post-test

		Rank I		Rank II		Rank III		Total	
Group	**No. of students**	**No. of points**	**%**	**No. of points**	**%**	**No. of points**	**%**	**No. of points**	**%**
E	96	2299	77.25	2058	64.96	1945	56.28	6302	65.65
C	81	1842	73.36	1701	63.64	1293	44.34	4836	59.70

However, a t-test was still needed to show whether these differences are statistically significant. 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 (Tables 5 and 6).

Table 5
Basic statistical indicators for the post-test

	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	24.20	6.03	24.91	21.66	8.76	40.46	20.47	9.89	48.32	66.34	22.08	33.28
C	22.74	6.10	26.81	21.00	7.24	34.48	15.96	9.80	61.39	59.70	18.78	31.45

$\overline{X}$, mean number of achieved points; S, standard deviation; V, coefficient of variation

Table 6
Testing group uniformity in the post-test, using t-test.
Critical value *t =1.96 for significance level p =0.05 and **t=2.58 for p= 0.01)

Relation	Rank I	Rank II	Rank III	Total
E:C	1.63	0.51	3.00**	2.12*

On the basis of the presented results for the post-test of knowledge for E and C groups, we can conclude that there are statistically significant differences in the number of points achieved in the level III tasks and in the test as a whole, in favour of the E group (Rank I: t=1.63<1.96; Rank II: t=0:51<1.96; Rank III: t=3.00**>1.96; a total of t=2.12*>1.96).

The obtained t-coefficient values (marked with an asterisk) are significantly greater than the critical value (by levels 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 students can be explained by differences in the way of teaching the ecology material in the field of sea-living communities, i.e. by application of the didactic model of problem-based biology instruction.

4. Conclusions

The research was conducted with the same teaching content (marine-life communities, seventh grade of primary school), by applying problem-based instruction in the E group and informative-illustrative instruction in the C group. E and C groups showed uniform knowledge on the pre-test (in terms of general knowledge of ecology) in task levels 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 ecology before the introduction of the experimental factor.

After introduction of the experimental factor–problem-based biology instruction–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 marine-life communities), 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 problem-based biology instruction), is confirmed.

It can therefore be concluded that the application of problem-based biology teaching directly contributed to better learning and knowledge acquisition in the teaching of ecology contents (the field of marine-life communities). 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 processes, especially of ecology curricula, should involve the model of problem-based teaching, which was explicitly proven to be of high efficiency.

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Appendix

Example of a questionnaire used as an indicator of Ranks I, II and III.

Rank I
I Circle the letter of the correct answer:

1. The octopus is a resident of the:
a) Abyssal zone
b) Bathyal zone
c) Supralitoral zone

2. The dolphin is a resident of the:
a) Pelagial zone
b) Tidal zone
c) Bathyal zone

3. The goose barnacle is a resident of the:
a) Tidal zone
b) Supralitoral zone
c) Bathyal zone

4. The sea cucumber is a resident of the:
a) Bathyal zone
b) Tidal zone
c) Abyssal zone

5. The red sea anemone is a resident of the:
a) Tidal zone
b) Supralitoral zone
c) Bathyal zone

II If the statement is true circle "T", or "F" if the statement is false:
6.
a) The tidal zone is a habitat where conditions are favourable for life. T F
b) The living world in the intertidal zone is richer and more diverse than the living world in the supralitoral zone. T F
c) The sea bottom to depths of 50 m is the best place to live. T F
d) Many benthic organisms live in the pelagial zone. T F
e) Temperature in the deep sea is high, and pressure is low. T F
f) Many unicellular and multicellular species of floating plankton live in the bathyal zone. T F
g) The pelagial zone, from the surface to depths of 50 m, is a suitable place for life. T F
h) Plants and animals that make up biocenoses of free water have developed different ways of active and passive swimming. T F

Rank II

III Connect the terms with their matching statements (in brackets in front of the statements, write the letter marking the appropriate term):

7.

A. Benthos

B. Plankton

C. Phytoplankton

D. Zooplankton

E. Nekton

( ) Life community comprised only of animals that float passively in the water.

( ) Life community consisting only of plants that float passively in the water.

( ) Life community consisting of all organisms that float passively in the water.

( ) Life community of organisms that actively swim.

( ) Life community of organisms that are active at the bottom of aquatic ecosystems.

8.

A. Supralitoral zone

B. Tidal zone

V. Bathyal zone

G. Abyssal zone

( ) Complete rhythmic drying

( ) A constant threat for the organisms of detaching from the ground and being carried into the sea depths

( ) Exposure to constant water currents

( ) Exposure to extremely high pressure

( ) Exposure to low temperature

( ) Exposure to strong sunlight

Rank III

IV Connect the main types of habitats in the marine ecosystems with the most common solutions for ecological problems that their inhabitants have found (in the cell where the habitat type and ecological problem intersect write an X).

9.

Marine zone / **Characteristics of organisms**	**Suprali-toral zone**	**Tidal zone**	**Bathyal zone**	**Pelagial zone**	**Abyssal zone**
Development of extremely large mouth					
Body growth and expansion					
Appearance of illuminated organs on the body					
Development of a calcareous nipple-shaped shell					
Development of various swimming techniques					
Development of extremely large teeth					
Emergence of lung development					
Permanent coalescence of bodies of males and females					
Body is slimy, slippery and elastic					
Good camouflage in the underwater meadows					
Water retention in special parts of the body					
In the body there are oils, fats, mucus, or gases					

13 ANIMAL SURVIVAL: LEARNING BY INQUIRY AND DESIGN IN PRIMARY SCIENCE EDUCATION

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Abstract

Learning outcomes of learning by inquiry and design (LIND) have been studied in primary education, with particular attention to the development of science concepts and 'scientific attitudes'. A series of lessons with these aims was carried out in upper primary education, on how wild animals survive in their environment and what this means for their survival in a zoo shelter. The underlying concept developed further by the pupils in these lessons was 'form-function'. Pupils investigated the natural behaviour and build of some wild animals, their properties ('form') in relation to how they survive ('function') in their environment and subsequently, how that translates to the design of a zoo shelter, which they were then asked to build for the animal they had investigated. Both the development of the concept 'form-function' and pupils' 'scientific attitudes' were studied and pupils were assessed for their ideas about 'form-function', as well as inquiry and design. The results suggest that LIND contributes to the use of the concept 'form-function' by pupils in a practical way. As we observed several dispositions of scientific attitudes in pupils' activities, we can also preliminarily conclude that LIND gives pupils the opportunity to develop their scientific attitudes.

Keywords: animal survival; form-function; scientific attitude; learning by inquiry and design; primary education

1. Introduction

For the last four years, the Dutch Ministry of Education and Science Education has focused on a scientific way of learning for pupils in primary school. Thus, the intention is not only to introduce science concepts, but also to contribute to scientific reasoning (Russ, Coffey, Hammer, & Hutchison, 2008), with an important focus on the development of pupils' 'scientific' attitudes. To achieve this, a learning and teaching strategy for 'learning by inquiry and design' (LIND strategy) was developed (Duschl, Schweingruber, & Shouse, 2007). One of the main problems in teaching practices is that due to the lack of a scientific way of learning in the preparatory as well as teacher-training curricula, primary teachers do not have any knowledge or experience with this approach. The attitude of becoming curious about, or amazed by scientific phenomena and technological problems is not well developed by many primary school teachers. Besides, many teachers lack the competencies to facilitate dialogic reasoning and to stimulate pupils' questioning behaviour, both considered important teacher competencies in the LIND strategy. Another problem concerning the LIND strategy is how teachers determine pupils' learning outcomes, in particular concerning their learning processes, their scientific attitudes and their conceptual development. It is therefore difficult to create a 'class as a scientific community' in which inquiry, including dialogic reasoning, is a way of teaching, resulting in substantial learning outcomes that can be objectively determined. Overcoming these problems will take several years. However, in the period 2008-2010, the Dutch government offered 5000 teachers and 5000 students at teacher training centres an initial course for the development of their own scientific attitudes in the domain of science education.

We acquired some preliminary experience with the LIND strategy in primary schools. First we described the basic elements of this strategy, which teacher trainers can adopt in their in-service training as well as in their teacher development courses (Van Graft & Kemmers, 2007). Preliminary results from studies with pupils aged 6 to 10 years showed that interactions between teacher and pupils, as well as among pupils, are an important element of the LIND strategy, in particular when guiding the process and discussing the concepts (Kirschner, Sweller, & Clark, 2006). Nevertheless, further study is required to deal with the aforementioned problems with the LIND strategy and to develop support for teachers in incorporating this strategy into their repertoire. Therefore, a series of lessons was developed on animal survival with 'form-function' as the underlying key concept (Boerwinkel, 2003; Boerwinkel, Waarlo, & Boersma, 2008). Within this context, the following research question was formulated:

How can the learning and teaching strategy of 'learning by inquiry and design' contribute to the development of pupils' concept of 'form-function' and to the development of pupils' 'scientific attitudes'?

2. Design of the study

Based on the description of Boerwinkel (2003, p. 239), we first elaborated the form-function relationship between the needs of an animal species and their environment. Worksheets were prepared that enabled pupils to look for this information. This series of lessons concerned information about the need of an animal to survive in a zoo shelter. The learning and teaching strategy of LIND consists of seven steps (Van Graft & Kemmers, 2007). To carry out the LIND strategy in the intended way and to support and guide the teachers, the lessons were elaborated into scenarios that contained learning and teaching activities. For the characterization of the pupils' scientific attitudes, an observation instrument was developed based on Van der Rijst, Van Driel, Kijne and Verloop (2007). To assess the pupils' knowledge of form-function, they were tested 4 months after the lessons had been carried out.

2.1 Form-function relationship

In the lessons about the relationship between animal survival and demands of a zoo shelter, the idea of Boerwinkel (2003, p. 239) on the concept of form-function was used as a starting point. Thus, the focus is on the aspect 'function as a contribution to the survival value' of the feature 'animal'. This was further specified in four main functions – the environment, food, enemies and reproduction, as well as other categories. The main functions were used to categorise questions that the pupils formulate to look for information about their animal (feature), e.g. properties such as build and behaviour. With the outcome of this inquiry, pupils formulated demands of the zoo shelter.

2.2 Learning by inquiry and learning by design: the LIND strategy

To determine whether the LIND strategy is appropriate for contributing to pupils' conceptual development, as well as to their scientific attitude, the strategy was split into seven steps, with slight differences between learning by inquiry and learning by design (Table 1).

Table 1
Seven steps in learning by inquiry and design in science education

LEARNING by INQUIRY	LEARNING by DESIGN
Exploring a phenomenon	Exploring a problem or need
Formulating a research question(s)	Formulating design demands
Designing an experiment(s)	Developing a design
Performing an experiment(s) and collecting data	Making the product
Drawing conclusions	Testing the product
Communicating conclusions	Communicating about products
Reflecting on conclusions	Reflecting on the product

These seven steps were provided with goals and teaching activities to guide the learning activities of the pupils which would ultimately lead to conclusions or products (Tang, Coffey, Elby, & Levin, 2010). However, we do not expect this to be a linear process. Therefore, during the learning and teaching processes, teachers have to make clear to the pupils that they may go back and forth between the successive activities. Other important teacher activities are: talking with pupils about their observations, findings and the problems they encounter during their inquiry or design activities. They have to cope with pupils' different ideas and to connect these with the aims of the lesson.

In this study, the LIND strategy was further developed into a scenario in which learning and teaching activities were described (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). First, in the 'inquiry' part of the lessons, pupils chose a wild animal and then investigated its behaviour and properties for survival in its natural environment. They were asked to describe how the animal survives in the environment in terms of its behaviour and properties. Subsequently, they divided these terms for behaviour and properties into survival categories (Boerwinkel, 2003): e.g. to eat, to defend against environmental factors, to defend against enemies and to reproduce. In the second part, the 'design' part of the lessons, pupils were asked to design a shelter for their animal. To do this, they were asked to take into account the behaviour and properties of their animal.

Our earlier pilot studies with pupils aged 6 to 10 years led us to expect content-specific discussions between pupils and the teacher on the concept 'form-function', in fact a kind of dialogic reasoning. In lessons 1 through 3, the discussions were to focus on the properties and behaviour of animals in relation to survival in a zoo shelter, whereas in lessons 4 and 5, discussions were to focus on articulating a set of requirements for the shelter. The teachers were expected to have the competency to guide these discussions and to promote exchange of pupils' ideas.

2.3 The scientific attitude of pupils

According to the seven steps in the LIND strategy, pupils have the opportunity to carry out different learning activities. Examples are:

- Searching for and interpreting information
- 'If...then' reasoning about questions and results, problems and solutions
- Using their creativity in solving problems and answering questions
- Voicing criticism

Although these activities are expected to contribute to the development of their scientific attitude, the question of which aspects of a scientific attitude pupils might develop by following the LIND strategy should be answered. Moreover, what kind of aspects of the 'scientific attitude' may we expect from pupils in upper primary education? To answer these questions, we used the categories of scientific attitudes described by Van der Rijst et al. (2007), who categorized the scientific research disposition into the following six, qualitatively distinct 'inclinations': to know, to be critical, to understand, to be innovative, to achieve and to share knowledge. In order to determine which and to what extent these inclinations can be observed in practice, an observation scheme was devised that exemplified the aspects underlying the inclinations as indicated by Van der Rijst et al. (2007). The meaning of each inclination was described and specified by means of examples that might be given by the pupils. Table 2 shows examples of three elaborated inclinations: to be critical, to be innovative and to share knowledge, the three inclinations that were observed most frequently during the lessons. The other three inclinations were specified in a similar way.

Table 2
Excerpt from the observation scheme on the inclination to be critical, the inclination to be innovative and the inclination to share knowledge

Inclination	Consists of:	Including:	Specification of behaviour, for example exhibited by pupils when they:
To be critical	observing	tracking phenomena, being attentive	assess observations
			connect observations with expectations
		exploring, manipulating circumstances	discuss results when circumstances change
	fairness	handling work in a fair, honest way	repeat measurements
			calibrate equipment
	precision	working with precision	take meticulous notes
			check reliability of data or equipment
		working conscientiously	focus attention on project
			work with care with materials or organisms
	being critical of others' work	having a critical attitude toward existing ideas, including the teacher's ideas	ask others questions
			discuss correctness of definitions or arguments

	being critical of own work	having a critical attitude toward own ideas and work	ask themselves questions
			correct research or design when necessary
	being auto-nomous	showing independence	work independently on their tasks
		setting one's own course	suggest which activities they have to fulfil next
	being uncon-ventional	having the nerve to be different	imagine about reality
		thinking outside the box	show an original approach to the problem with a certain naivety
To be innovative	having new ideas	having original thoughts, novel ideas	come up with new reasoning
			make connections with other subjects
		being innovative	want to invent things
			present inventive solutions
	being associative	showing creativity and an associative capacity	recognise patterns
			look at relationships with comparable problems
			use insights and skills from different disciplines
To share knowledge	being open to others	being open to others' ideas	share information with others
			ask for advice
		readiness to learn from others	are open to others' opinions
	explaining and convincing	willingness to explain problems to others	explain their research or design
			involve others in the research or design process
			share their problems with others
		winning over others	convince others to accept their ideas, or solutions
	being social	being cooperative	focus on cooperation with others
		being social	respect values of others
			ask for help if things fail
		keeping up social contacts	maintain good relationship with co-workers
			activate and stimulate others

To enable a characterization of pupils' scientific attitudes by means of this instrument, video and audio recordings were made. For the subsequent analysis, audio recordings were transcribed and the transcriptions were analysed. As a unit of analysis we used an uninterrupted sentence or line of reasoning from one pupil. One unit could include one or more specifications of behaviour of one or more inclinations. Video recordings were used in case of doubt. The inter-rater reliability among the three researchers was over 75%.

2.4 Participants and the series of lessons

Teachers from three primary schools, involved in a course to develop their own scientific attitude, were instructed to give the zoo lessons. In this course, the LIND strategy was used as the leading learning and teaching strategy to develop pupils' scientific attitude. The lessons were elaborated into a scenario with instructions for the teachers. The scenarios of these lessons were discussed with the teachers and modified on the basis of their suggestions. We also provided a tool to facilitate the interaction between pupils and between pupils and the teacher (Damhuis, De Blauw, & Brandenbarg, 2004). Over a period of 5 weeks, the teachers carried out five 2- to 3-hour lessons. The series of lessons consisted of six parts (Table 3).

Table 3
Overview of the series of lessons, including a test

To design and build a zoo shelter

Series of lessons about animal survival

1. Collecting and answering research questions about wild animals
2. Formulating a set of demands for the shelter
3. Designing the shelter
4. Building the shelter
5. Presentation of the shelter
6. Testing the concept and the process of inquiry and design

Finally, four teachers from the three different schools put the lessons into practice. The lessons that were carried out in these four classes provided a general picture of the way the teachers used the scenarios, how pupils were involved in the learning and teaching activities, and what they might learn. One of the teachers was selected for a detailed study of all of the activities. This class was comprised of 22 pupils, aged 11-12 years. During the lessons, video and audio recordings were made of whole-class activities and of two groups of four pupils (all female and chosen by the teacher) when they worked in groups. Four months after the lessons had been given, pupils were tested for their understanding of the concept 'form-function'.

3. Results

The results presented here on scientific attitude were obtained from the first three lessons. In these lessons, pupils had thorough discussions in their group to determine the requirements for the shelter. They also had to draw a draft and a final model of the shelter and select the materials and constructions of the buildings. Although the pupils were eager to start with the building activities, in general, in the three schools, the pupils were also enthusiastic about the subject. Enthusiasm (or involvement) was not measured as such, but subsequent activities evidenced it. In one of the schools where no recordings were made, the day following the first lesson one pupil came up with a scale model she had made for her group's animal. The teacher instructed her group to improve the scale model during the following lessons. Results in the analysed class showed that the fact that pupils first had to investigate the needs of their chosen animal (steps 1 and 2 in the LIND strategy) did not decrease their motivation. In this class, after the first lesson, many pupils brought in materials from home that they thought might be useful during the building of the shelter. Furthermore, the teacher of this class reported that during the breaks, pupils frequently worked on the computer looking for answers to their questions. In most groups, although there were sometimes lively but serious discussions about the needs of the animals, visitors and caretakers in relation to the shelter, pupils collaborated well and focused on their individual and collaborative tasks.

In the first lesson, pupils had to formulate questions about the life of their animal. After they had discussed these questions in their group, they had to categorize them into five categories: questions about food, factors the animals have to deal with in their environment, defence against enemies, reproduction, and other features. Figure 1 shows an example of the worksheet with answers to questions in the cheetah group.

Our animal is a: cheetah.	**Our group consists of: Ferdy, Mark, Jin and Marloes.**
These are answers to the questions [we had] about food	Hares, impalas, gazelles and young swine and antelopes. The cheetah weighs 21 to 72 kg and can eat that amount too. It puts its head down and then jumps on the animal [its prey].
These are the answers to the questions about defence against surroundings	A warm climate. It needs bushes and savannah. Yes, it needs a lot of space to run.
These are the answers to the questions about defence against enemies	Yes, it is threatened by humans (its biggest enemy). It does not get sick easily.
These are the answers to the questions about reproduction	It can have 2 to 5 young. It can have young at 2 years of age. It takes care of its young. They are [like] birds that stay in the nest. It lives up to 12 years, in captivity 17 years.
These are the answers to the questions about other features	Its maximum speed is 200 km per hour. It is related to the house cat. There are no [visible] differences between males and females.

Figure 1
Worksheet with information pupils collected about their animal [translated from Dutch]

The pupils took the information they collected on their chosen animal very seriously and used it in the discussions about the design of the shelter. In lesson 3 (step 3 in the LIND strategy), they used the information to formulate requirements for the design of the zoo shelter for the animal (Figure 2, column 1). Subsequently, they define requirements of the caretakers and visitors (Figure 2, column 2). Before pupils could start building the zoo shelter, they had to find a compromise between the requirements of the animal and those of the caretakers and visitors. These definitive requirements are described in Figure 2, column 3.

Concerning the scientific attitude of the two groups of pupils studied, video recordings and the transcripts of the audio recordings were analysed. The following results were obtained from lessons 1 to 3 (Table 4).

Nearly all categories of inclinations were observed. From lesson 1 to 3, pupils showed an increase in the inclinations to *share knowledge* and *be critical.* For instance, there was a critical ‘form-function’ discussion in the rhino group about the construction of the gate. The pupils argued that the gate must be strong enough to keep the rhino inside the shelter. From the visitors' point of view, they decided that the gate had to have an open construction, otherwise they would not be able to see the rhino. However, they realised that an open construction could damage the horns of the rhino. Finally, after discussion with the teacher, they chose to make a heavy wall of bricks with thick glass on top of it. Thus, the wall was strong enough to keep the animals inside, and visitors could see the rhinos.

Our animal is an: elephant.	**Our group consists of: Eline, Janine, Marjolein and Lianne.**	
1. What does the animal want?	**3. What are the requirements for the shelter?**	**2a. What does the caretaker want?**
<u>Food:</u> straw, pond, a piece of tree bark to eat <u>Defence against environment:</u> rocks, gates, bushes, trees <u>Defence against enemies:</u> no jaguar [in or near the enclosure] <u>Reproduction:</u> males, females <u>Further info:</u> iron balls on chain, branches, sprinklers	Gates > how? > glass very thick Sprinklers > how and where? 15 cm, on the ceiling Good view > how? Trees > Why? To play with and to eat from Space Pen 6 m below the ground, special pen for sick elephants 6.5 m^2 to 7 m^2 Outside a ditch with water with a brick wall 1 m [high around it] and a gate in front of it, rocks, waterfall [etc.]	Gates, shovels, cleaning materials, sprinklers **2b. What do the visitors want?** Gates, a good view, not too many trees, space, benches

Figure 2
Worksheet to formulate requirements for the animal shelter [translated from Dutch].
The arrows indicate that the information described in columns 1, 2a and 2b is used in column 3 to determine the requirements for the animal shelter.

From lesson 1 to lessons 2 and 3, a shift was observed from the inclination to *know* to the inclination to *understand*. At the same time, pupils showed an increase in the inclination to be *innovative*, in particular to be original and creative. The inclination to *achieve* was less prominent in lessons 1 to 3 than in lessons 4 and 5, when pupils were building their animal's shelter.

When tested 4 months after the final lesson, 12 out of 23 pupils in the investigated class could describe all four categories of information on animals' properties (form-function), while 11 pupils could describe three categories; 16 pupils could use form-function reasoning to explain how a specific part of their shelter suited their animal (Figure 3), while the other 7 pupils could do this to a lesser extent.

Build and behaviour[...]
Describe why this [part of the shelter] is especially well suited to the build or behaviour of your animal.

Question on the test	Pupil's answer
An important part of our shelter was:	*the rocks*
In making this part, we took the build or behaviour of the animal into consideration, because:	*rhinos like to be alone (sometimes) and then they hide. The rhino is an aggressive animal, and it can bang on the rock when angry.*

Figure 3
An example of form-function reasoning in the test [translated from Dutch]

Table 4
Scientific attitudes of two groups of pupils observed during lessons 1, 2 and 3.
Every black square (■) indicates 1-5 observations as a mean of two observers;
■■ means 6-10 observations, and so on

Inclination to:	Consists of:	Lesson 1	Lesson 2	Lesson 3
know	Curiosity	■	■	
	motivation	■	■■	
	enthusiasm	■		
be critical	Observing			
	fairness			
	precision	■■		■
	being critical of others' work	■	■■■	■■■■
	being critical of own work	■	■	■
understand	understanding (in general)		■■	■■
	surveying		■■	
be innovative	being autonomous	■	■	■
	being unconventional		■	■
	having new ideas		■	■■
	being associative	■	■■	
achieve	Initiating			■
	persisting		■	
	being patient	■		
	ambition			■
	being energetic	■		
	passion	■		■
share knowledge	being open to others	■	■	■■
	explaining and convincing	■	■■	■■■■
	being social	■■	■■	■■■■

4. Conclusions and discussion

Pupils were enthusiastic about the subject, and their involvement increased during the series of lessons, in particular as they started constructing the zoo shelter for their own wild animal.
The preliminary results from the analysed class indicate that after the series of lessons about animal survival according to the LIND strategy, pupils could reproduce the relationship between the properties of an animal ('feature' or form of their properties and behaviour) and the requirements of the shelter (the 'functions' for the survival of the animal) reasonably well. From the requirements that they remembered during the test, they could explain their function in relation to the animal's survival. This result shows that these lessons, carried out according to the LIND strategy, may contribute to the development of pupils' insight into the

relationship between animal behaviour and the environment they live in. Many science methods only explore the properties of the animals (their features), without paying attention to the relationship between these features and their functions in the animals' surroundings. The elaboration of the concept form-function in the well-known context of a zoo appears to have made the lessons more attractive to the pupils.

During the lessons, all six inclinations of the scientific attitude described by Van der Rijst et al. (2007) were exhibited by the pupils. The increase in the inclinations to *share knowledge* and *be critical* coincided with the shift from mostly teacher-driven work to more pupil-driven collaboration within groups. The first two lessons in the analysed class were rather teacher-driven, whereas in the following lessons, pupils could collaborate more autonomously. The teacher visited the groups of pupils one by one and they could call the teacher for support if necessary. The low prominence of the inclination to *achieve* could be due to the teacher's role of structuring the research and design process and assisting in problems that were encountered by the groups. Therefore, shifts in the inclinations can be contributed by the teacher's role, as the development experienced by both teacher and pupils during the lessons might contribute to a change in the inclinations. This means that the teachers' role in the learning and teaching strategy of LIND is of importance in the learning activities of the pupils, as well as in the learning outcomes of the pupils. Further research should concentrate on the role of teachers in this LIND strategy in relation to the learning outcome of pupils. In this study, we also tried to characterize the pupils' scientific attitude by analysing their conversations. However, it would be interesting for teachers to establish whether there is progress in the pupils' scientific attitude. Such an observation instrument could be based on these inclinations. However, the instrument that we used in this study is too complex to be used in teaching practice and should be optimized for teachers' use.

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14 CHILDREN'S ATTITUDES TOWARDS ANIMALS: EVIDENCE FROM THE RODENTIA PROJECT

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Abstract

The instructional use of animals is a popular strategy to engage students with science, enhance their motivation, and promote values such as respect, tolerance, and empathy for all living beings. Although these beneficial outcomes are widely acknowledged, research has not provided reliable indicators of their efficiency. Therefore, it is essential to broaden studies on the use of animals in education. In this regard, it becomes necessary to understand the students' attitudes towards animals.
This paper presents data on the attitudes of primary school children towards the humane treatment of animals. It follows the implementation of a longitudinal project based on the concept of classroom pet aimed at fostering the development of scientific-reasoning competencies and positive attitudes towards animals. To assess the project's efficacy, a methodology combining quantitative and qualitative assessment approaches was outlined. The study involved 43 students, aged 8 to 10, from two fourth-grade classes in the same school. Findings concerning how children's attitudes towards different animals and animal uses are modulated as the result of an animal-based educational intervention and naturally, throughout their maturation, are discussed. This study provides relevant information for the development and evaluation of humane educational programs.

Keywords: animal; assessment; attitude; primary school; science education

1. Introduction

The didactic resources used to scaffold children's understanding of biology impact their knowledge and attitudes towards living organisms (Prokop, Prokop, & Tunnicliffe, 2008). Animal use for instructional purposes has become a popular strategy, acknowledged to produce positive educational outcomes, such as the development of reasoning and observational skills, enhancement of students' motivation and improvement of social inter-relational competencies (Ascione & Weber, 1996; Daly & Morton, 2006; Zasloff, Hart, & DeArmond, 1999). By promoting positive attitudes, respect and kindness, the use of animals in education is also thought to foster the development of empathy, moral values and pro-social behaviour among children (Daly & Suggs, 2010; Faver, 2010). However, in spite of being widely acknowledged, these beneficial outcomes are not fully consolidated (Arbour, Signal, & Taylor, 2009; Ascione & Weber, 1996; Faver, 2010; Thompson & Gullone, 2003b).

There are four main categories of educational interventions in which animals can be used (Zasloff et al., 1999): traditional instruction of science curriculum topics; transdiciplinary instruction for the development of general competencies; motivational development; humane education. From these general interventions, humane education has been receiving increased attention (Thompson & Gullone, 2003b). Humane education programs (HEPs) are formalized character education interventions in which animals are directly or indirectly used to promote social awareness and respect for life, and encourage children to be compassionate, caring and tolerant in their relationships with all living creatures (Daly & Suggs, 2010; Faver, 2010; Phillips & McCulloch, 2005; Thompson & Gullone, 2003b). Nevertheless, although the effectiveness of HEPs is empirically endorsed, only a few studies have assessed their outcomes, usually measuring empathy levels (Arbour et al., 2009; Ascione & Weber, 1996; Faver, 2010; Taylor & Signal, 2005; Thompson & Gullone, 2003b). However, empathy may not be the most adequate indicator of HEP efficiency. In fact, since empathy develops according to a normative path during childhood, it may be difficult to assess an intervention's effects in children who already possess normative levels of the construct (Faver, 2010; Thompson & Gullone, 2003a). Moreover, animal-directed empathy has not been shown to necessarily transfer to human-directed empathy (McPhedran, 2009; Patterson-Kane & Piper, 2009). Therefore, instead of empathy, several authors have analyzed children's attitudes towards animals to understand these programs' effects (Ascione & Weber, 1996; Nicoll, Trifone, & Samuels, 2008; Thompson & Gullone, 2003a).

In addition to the motivational benefits that underlie the introduction of animals in the classroom, under a more instruction-oriented perspective, live animals and non-living animal materials are reportedly efficient tools to address ecological, physiological and ethological contents (Abate, 2005; Tomkins, 2000; Zasloff et al., 1999). The instructional use of animals has also been shown to contribute to the development of scientific-reasoning competencies, such as observation and critical-thinking skills (Hull, 2003). Furthermore, emotional engagement with animals has been linked to the enhancement of positive attitudes towards science (Daly & Suggs, 2010; Sorge, 2008), which has obvious implications for science education, particularly considering the reported decrease in young people's interest in science and technology studies and careers (Sjøberg & Schreiner, 2006). Given the increasing demand for public participation in democratic decision-making processes regarding countless socio-scientific issues, including animal welfare, it is important to understand whether animals can be used to improve students' scientific knowledge and reasoning from an early developmental stage. Surprisingly, in spite of numerous reports of animal use in elementary classrooms (Sorge, 2008; Zasloff et al., 1999), this remains an open question.

1.1 The RODENTIA project

The work presented here is within the scope of the RODENTIA project (http://www.rodentia.ibmc.up.pt/), a longitudinal interventional program based on the concept of *classroom pet* aimed at promoting the development of scientific-reasoning competencies and positive attitudes towards animals in primary school. During a full school year, a small group of female laboratory rats (*Rattus norvegicus*) are kept in a specifically designed habitat in the classroom, and are used to engage students in multiple self-planned inquiry-based activities surrounding diverse curriculum-driven requirements. The children are also made responsible for tasks related to the maintenance and well being of the animals. RODENTIA aims to acquaint children with science and its methods and to promote positive attitudes towards animals and respect for animal life, while creating opportunities for high-quality social interactions. With the purpose of understanding the effectiveness of the RODENTIA project, an assessment methodology was defined, combining quantitative and qualitative approaches to assessing the evolution of students' reasoning skills and attitudes towards animals. This study focuses on the effects of the RODENTIA project on the children's attitudes.

2. Research design and methodology

Considering that children tend to be inherently motivated and emotionally attached to animals, particularly when their socio-cultural environment is favourable (Prokop et al., 2008; Zasloff et al., 1999), the main research questions addressed were: (i) Are there significant changes in students' attitudes towards animals following the implementation of an educational program involving the use of animals? (ii) Are traditional assessment approaches combining quantitative and qualitative data analyses suitable for evaluating the effects of such programs?
The assessment of child-directed educational programs intended to promote positive attitudes and behaviours towards animals requires the application of diverse instruments and methodologies, which must take into account the children's developmental stage (Ascione & Weber, 1996; Thompson & Gullone, 2003a). Children's normal developmental process leads to expectable changes in maturity that will likely result in enhanced social awareness of the importance of humane treatment of animals (Ascione & Weber, 1996). Therefore, the evaluation of longitudinal educational interventions through attitude measurement should allow discriminating between the differences related with those interventions' effects, and the ones that stem from the children's maturation. Accordingly, to meet these requirements, an integrated assessment approach was implemented, combining a quantitative methodology based on a pre-/post-test design, and a qualitative strategy through group and pair interviews. The inclusion of a control group allowed the assessment of developmentally related outcomes.
The sample was comprised of 43 students from two fourth-grade classes in the same school. The experimental group (n=22) included 11 boys and 11 girls, and the control group (n=21) included 12 girls and 9 boys. The children's mean age ranged from 8.980 (SD=0.344) years, at the start of the project's implementation to 9.530 (SD=0.505) years, at the end.

2.1 Quantitative assessment

The questionnaire (available from the authors upon request) was developed by adjusting the Intermediate Attitude Scale (IAS) (©WIRE 1983) and the instrument used by Phillips and McCulloch (2005) according to the specificities of the target population. The produced instrument includes 43 statements scored on a five-point Likert-type scale (1–strongly disagree to 5–strongly agree) measuring attitudes towards: *companion animals* (10 items), *wild animals* (10 items), *laboratory animals* (5 items), *livestock animals* (6 items), and *animal sentience* (12 items). The questionnaire was used as a pre-test to identify the children's constitutive attitudes and address the following questions: (i) How positive are children's attitudes towards animals? (ii) Does companion animal ownership and familiarity with a species influence children's attitudes towards other animals? (iii) Does gender affect children's attitudes towards animals? The same questionnaire was used as a post-test, to investigate modifications in children's attitudes at the end of the school year.
The data were collected at the beginning and end of the 2009/2010 school year, codified, and recorded using the Statistical Package for the Social Sciences (SPSS) version 17.0. Mean scores were calculated for the whole set of items and for the items in each of the questionnaire's five sections. The items were codified so that higher mean values translated to more positive attitudes towards animals in each of the situations considered. Student's t-test was used to examine and compare the children's mean responses. Correlations between variables were assessed through the Pearson's correlation coefficient. Parametric test results were confirmed using non-parametric statistics.

2.2 Qualitative assessment

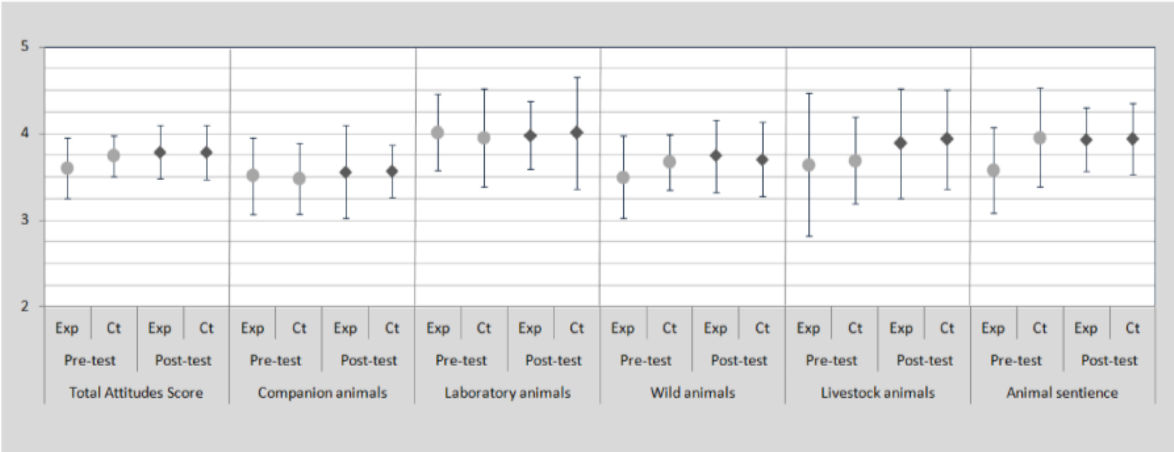
For the qualitative assessment, a multi-step interview-based inquiry strategy was developed. An initial group interview was organized to engage the children from the experimental group in a discussion of ethical implications of animal use and different human-animal interactions. The gathered data were used to design a script for two series of five semi-structured pair interviews involving 10 students from the experimental group and 10 from the control group. These interviews focused on two main issues: (i) the use of various animals in different types of scientific research, and (ii) the affective determinants of human engagement with animals, namely the children's positioning towards unpopular animals, such as invertebrates (Prokop et al., 2008), and their *belief in animal mind* (Hills, 1995), i.e., their assessment of non-human animals' reasoning and emotional capacities. To consolidate the appraisal of the children's positioning during these interviews, the experimental group and a randomly selected subgroup of controls were asked to participate in another group discussion. The outcomes of the interviews were integrated with the information provided by the quantitative analyses.

3. Results and discussion

Overall, the participants (n=43) displayed positive attitudes towards animals, both at the beginning (M=3.672, SD=0.305, $t(42)$=14.646, p=0.000) and end (M=3.787, SD=0.304, $t(42)$=16.961, p=0.000) of the school year, which is consistent with previous reports on children's interest and motivation towards interaction with animals (Bjerke, Ostdahl, & Kleiven, 2003; Zasloff et al., 1999). Although in the pre-test the children in the control group scored significantly higher (p=0.026) than their counterparts in the experimental group for the *animal sentience* section, there were no other significant differences between the groups (p>0.05) with respect to their pre-test and post-test scores (Figure 1). However, in contrast to the control group, for which the only significant pre-/post-test difference occurred for the attitudes towards *livestock animals* (p=0.047), the experimental groups' attitudinal scores were significantly increased in the post-test globally (p=0.007) and for the *animal sentience* section (p=0.001) (Figure 1).

3.1 Types of animals and animal uses

Human attitudes towards animals are influenced by the species and type of animal considered (Driscoll, 1995; Prokop & Tunnicliffe, 2009). People tend to identify themselves with appealing and companion animals (Driscoll, 1995; Knight, 2008; Serpell, 2009), and to be less sympathetic to unpopular animals such as insects or reptiles (Prokop & Tunnicliffe, 2010). In this study, children seemed to be more affectionate towards specific animals, particularly dogs and chimps. For example, when asked to decide which animals should be used in scientific research from a list comprising rats, fish, snails, horses, dogs, rabbits, cows, and chimps, students excluded dogs because "[they] liked them".



Note. All means are significantly different from 3, for α=0.01. Exp – experimental group, Ct – control group

Differences between the groups' mean scores in the pre-test and in the post-test:

		Total Attitudes Score	Companion animals	Laboratory animals	Wild animals	Livestock animals	Animal sentience
Pre-test	***t*(41)**	-1.486	0.252	0.424	-1.369	-0.223	-2.318
	p	0.145	0.802	0.674	0.178	0.825	0.026
Post-test	***t*(41)**	0.036	-0.057	-0.169	0.318	-0.270	-0.040
	p	0.971	0.955	0.867	0.752	0.788	0.969

Note. Independent samples *t*-test, for a 95% confidence interval.

Pre-/post-test scores variations for the experimental and control groups:

	Experimental group				Control group			
	M	***SD***	***t*(21)**	***p***	***M***	***SD***	***t*(20)**	***p***
Total Attitudes Score	-0.183	0.284	-3.019	0.007	-0.043	0.218	-0.906	0.376
Companion animals	-0.045	0.655	-0.325	0.748	-0.086	0.486	-0.808	0.429
Laboratory animals	0.036	0.464	0.367	0.717	-0.057	0.762	-0.344	0.735
Wild animals	-0.245	0.600	-1.919	0.069	-0.033	0.501	-0.305	0.764
Livestock animals	-0.242	0.798	-1.425	0.169	-0.246	0.534	-2.112	0.047
Animal sentience	-0.352	0.430	-3.847	0.001	0.020	0.431	0.211	0.835

Note. Paired-samples *t*-test, for a 95% confidence interval. *M* – difference between pre-/pos-test mean scores, *SD* – standard deviation.

Figure 1
Children's attitudes towards animals

The use of chimps was also excluded: even though they were recognized as phylogenetically similar to us and, arguably "the ones that provide better results", the children felt that "they are close to us". Concerning their thoughts about spiders and insects such as mosquitoes, their answers demonstrated a rational assessment of their importance. Although a few children admitted they would "call an adult to kill [a spider]" if it was in their home, most of them agreed that "they must exist for some reason" and that "all animals are somehow important". Furthermore, when asked if animals used in biomedical research that are usually considered companion animals, such as cats, dogs and rabbits, should receive better treatment than animals such as rats or fish, only one child from the control group thought they should. The pre- and post-test scores also showed that children's familiarity with animals was not a determining factor in their attitudes towards them. For example, the mean value for children's attitudes towards companion animals was actually lower than the mean values obtained for laboratory and livestock animals (Figure 1). Interestingly, regardless of the group considered (p>0.05), the children appeared to be particularly aware of the need to guarantee the welfare of laboratory animals, as suggested by the fact that the score for the *laboratory animals* section was highest in both the pre- and post-test (Figure 1). Moreover, when asked about the acceptability of animal experimentation, the children's initial reaction was to oppose it under all conditions. They considered that "it is bad to conduct experiments on animals", because "it can be dangerous to the animals".

Besides animal type, there are other factors affecting people's support for the use of animals, including the relevance of the manipulation and the conditions in which the animal is kept (Phillips & McCulloch, 2005; Saucier & Cain, 2006; Serpell, 2009). Accordingly, the children showed considerable concern for the importance of the purpose for which animals are used in scientific research. In fact, consistent with previous reports (Saucier & Cain, 2006), most of the children in both groups conveyed the belief that it is more acceptable to use animals in medical product testing than in cosmetics testing, because "medicines are more important". In addition, they recurrently emphasized the importance of assuring that the animals were being treated adequately. Most of them feared that caged animals in laboratories, farms or zoos might not have sufficient space and would suffer from stress.

To a certain extent, these outcomes indicate that kinship and self-identification with the animals influence children's opinions, thus suggesting a *relational view* of animal use (Anthony, 2010), in light of which an attitudinal pattern surfaces that has been defined as *humanistic* (Kellert, 1985). Nevertheless, although this *humanistic* value has been reported as most common among children (Bjerke, Odegardstuen, & Kaltenborn,1998; Eagles & Miuffitt, 1990), in this study it was combined with a tendency towards an instrumental view of animals, consistent with a pragmatic evaluation of animal use that converges towards the attitudinal response described by Kellert (1985) as *utilitarian*. This tendency is clearly illustrated by the participants' concerns about the need to consider the validity and feasibility of experimental procedures when deciding which animals to use in research. Arguments such as reproductive rate and manageability were used by many students to select the most suitable laboratory animals. For instance, rats were the most frequently selected because "they reproduce a lot" and "are similar to us", while cows and horses were dismissed because "they require too much space" and "they are big and it is difficult [to manipulate them]". Children were also aware that, whichever animal was used, "the results can be different [when the test is conducted in humans]". When asked about the possibility of using abandoned animals in research, children, particularly in the experimental group, questioned the option's viability, as it does not allow control over variables that can affect the efficiency of the experimental procedures. In fact, most of them thought that animals should be purposely raised as laboratory specimens. However, some eventually admitted that in the impossibility of finding owners for young and healthy abandoned animals, these could be used in research, since "at least they would be useful in some way". This is interesting considering that, when transposed to human-human interactions, the underlying representation of this perspective evokes an ideological concept of social usefulness. The implications of these findings will be presented in a future study.

Hence, the children's moral decisions on laboratory animal use were comprised of both rational and intuitive elements (Herzog & Golden, 2009). Not surprisingly, given that the animals used in RODENTIA are presented and used by the children not as pets, but as instructional resources, the tendency for instrumentalization was predominantly manifested within the experimental group (50% vs. 30% in the pair interviews). This, together with the lack of significant pre-/post-test differences within each group and between the groups in their pre- and post-test scores for the *laboratory animals* section (p>0.05) (Figure 1), suggests that the project raised the participants' attention towards procedural factors that are essential in scientific research without negatively impacting their attitudes towards the humane treatment of the animals used. The project fostered an increased reasoning sophistication that left students divided between *humanistic* impulses pertaining to their relationships with animals, and the need to efficiently use them for investigation purposes. By considering it more acceptable to experiment on animals they least identify themselves with, children looked for an emotional constriction that would relieve the pressure placed on their affective engagement with them.

3.2 Animal sentience

The ongoing debate about the moral status of animals and how this might influence the ways in which it is acceptable to exploit them considers the animals' levels of consciousness and self-awareness (Burghardt, 2009; Knight, Vrij, Cherryman, & Nunkoosing, 2004). People's beliefs about animals' ability to think, feel and communicate determine their interactions with them and their willingness to accept the uses made of them (Burghardt, 2009; Driscoll, 1995). Arguably, the conceptualization of animals as unintelligent and insentient, mechanically reacting creatures relieves some of the ethical and moral impediments regarding their use for purposes that might otherwise be considered unacceptable (Knight et al., 2004). However, this study indicates that this relationship is not straightforward. Although the control group scored significantly higher than the experimental group for the *animal sentience* section in the pre-test (p=0.026), this difference was not observed during the post-test (p=0.969) (Figure 1). The fact that the experimental group's post-test score was significantly increased (p=0.001), whereas there were no significant pre-/post-test differences (p=0.835) in this section's score for the control group (Figure 1), indicates that the RODENTIA project enhanced the participants' perception of animal sentience. Since this occurred solely within the experimental group, in which a more *utilitarian*-oriented positioning was more pervasive, it appears that the *belief in animal mind* does not antagonize a pragmatic and worth-related evaluation of animal use, or the opposite. Interestingly, although all of the interviewees considered that animals have feelings, they were uncertain about whether or not they are conscious of themselves and what happens around them, and about their ability to think, reporting that "it depends on their evolution and on the animal itself". Mammals, particularly dogs and wild animals, and birds were indicated as most likely to have the ability to reason. It has been argued that children may not distinguish between human and animal sentience (Phillips & McCulloch, 2005). Given that this relationship was not directly assessed in this study, this premise cannot be dismissed. However, regardless of this element's influence on the participants' attitudes, they distinguished between the value of human and animal life. In spite of stressing that "people should care about the animals that die", the children mentioned that "animals are different from people, and humans are more important than animals".

3.3 Companion animal ownership

Companion animal ownership has been associated with empathic behaviour (Daly & Morton, 2006), although there is equivocal evidence that owning animals affects attitudes towards other animals (Nicoll et al., 2008; Prokop & Tunnicliffe, 2010). Most of the participants (over 68% in the experimental group and 62% in the control) indicated that they owned animals and/or that they had had contact with other people's animals (over 59% in the experimental group and 76% in the control). However, these features were not significantly associated with their attitudes, at either the beginning or end of the school year (p>0.05). As expected (Bjerke et al., 1998), children referred to their companion animals as friends or family members, and used them to illustrate animals' ability to experience feelings, namely when they want to play or avoid going to the veterinarian. However, these reactions were not associated with these children's reactions to other animals. Therefore, companion animal ownership does not necessarily imply a positive impact on children's attitudes towards other animals. Nevertheless, it is important to bear in mind that these children held positive attitudes towards a wide range of animals, including a few they might not be familiar with, which does not dismiss the possibility that this element enhances affection towards other animals in children who are intrinsically less motivated towards the humane treatment of animals.

3.4 Gender significance

Several studies have shown that females tend to nurture more positive attitudes towards animals than males (Heleski, Mertig, & Zanella, 2004; Herzog & Golden, 2009; Knight et al., 2004; Phillips & McCulloch, 2005). However, the few gender-related differences identified in this study do not definitively reinforce these findings. In fact, although in the pre-test the girls in the experimental group (M=3.718, SD=0.389, $t(10)$=6.117, p=0.000) displayed significantly more positive attitudes towards *wild animals* ($t(20)$=2.350, p=0.029) than the boys (M=3.282, SD=0.477, $t(10)$=1.959, p=0.079), there were no other significant gender-related differences within either of the groups (p>0.05). The analysis of the pre-/post-test scores revealed significant increases in the global attitudinal score (M=-0.100, SD=0.151, $t(11)$=-2.310, p=0.041) and in the *livestock animals* section score (M=-0.319, SD=0.429, $t(11)$=-2.579, p=0.026) for the girls in the control group, and no significant differences for the boys (p>0.05). The girls in the experimental group also revealed significantly more positive attitudes globally (M=-0.152, SD=0.194, $t(10)$=-2.605, p=0.026) and towards *livestock animals* (M=-0.409, SD=0.584, $t(10)$=-2.324, p=0.042). In addition, both the boys (M=-0.295, SD=0.405, $t(10)$=-2.417, p=0.036) and the girls (M=-0.409, SD=0.465, $t(10)$=-2.920, p=0.015) in the experimental group scored significantly higher in the *animal sentience* section in the post-test. The qualitative data analyses revealed no conspicuous differences between the boys' and girls' answers.

Attitudes are formed early in life through direct and indirect contact with objects (Bjerke et al., 1998; Knight et al., 2004; Millar & Millar, 1996). Whereas indirect experience is thought to lead to cognitively driven attitudinal patterns, direct experience expectably leads to affectively based attitudinal responses (Millar & Millar, 1996). However, this study demonstrates that this depends on the type of experience considered. The children engaged in direct interaction with the laboratory rats used in RODENTIA increased their perception of animal sentience while simultaneously displaying a tendency towards animal instrumentalization and *utilitarian*-driven attitudinal responses, which are more influenced by conscious, rational and controlled processes (Greene, Morelli, Lowenberg, Nystrom, & Cohen, 2008; Herzog & Golden, 2009). Hence, by providing the children with positive experiences with the animals used, and giving them the opportunity to learn more about and from them, the RODENTIA project contributed to a more nuanced and complex picture of animal use in science, according to which the children can add practical elements into the equation without losing respect for the intrinsic value of animals.

4. Conclusions

This study confirms that children are intrinsically motivated to treat animals well and to respect animal life. Furthermore, it demonstrates that the RODENTIA project promotes the development of a rationalized and complexified appraisal of animal use in science, compatible with the nurturing of positive attitudes towards those and other animals. These findings contribute to a more reliable evaluation and understanding of the effects of educational interventions that rely on the use of animals. By demonstrating that children hold solid beliefs concerning human responsibilities towards animals, these outcomes have evident consequences for the optimization of strategies aimed at evaluating the efficacy of these interventions. The assessment of changes in attitudinal patterns characterized by robust constitutive levels requires instruments with high discriminative power to account for subtle variations. In this study, only the combination of quantitative and qualitative assessment methods and the use of a control group allowed documenting the effects of the RODENTIA project on children's attitudes towards animals, and distinguishing them from changes associated with their normal developmental process.

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Section 4

Reasoning and argumentation: The use of socio-scientific issues

15 DEVELOPING A PEDAGOGY OF RISK IN SOCIO-SCIENTIFIC ISSUES

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Abstract

The aim of this research is to develop principles for a pedagogy of risk in socio-scientific issues. Risk is challenging to teach because of its contested conceptual basis incorporating epistemic and non-epistemic values, its situated nature and its mathematical basis in probability and statistics. In our project–Promoting Teachers' Understanding of Risk in Socio-scientific Issues (TURS)–we have built a set of mature software tools designed through an epistemological analysis of risk and consideration of teaching and learning, as reflected in discussions with teachers. This software provides teachers with tools that enable them to express what they see as the significant issues, giving feedback for them to redraft their models in light of the consequences of their decisions. Pairs of science and mathematics teachers modelled a scenario based on personal decision-making for a surgical intervention. Inductive analysis of teacher dialogue generated four key findings: teaching risk lends itself to a multidisciplinary approach; recognition of the multidimensional nature of risk can be elicited through engagement with contextualised biological dilemmas; use of executable models promotes discussion of the complexity of risk, and expressive tools can be designed which support coordinated analysis of the multidimensional nature of risk.

Keywords: risk; socio-scientific issues; modelling; pedagogy; decision-making

1. Introduction

The importance of understanding risk in terms of public engagement with science and in critical support of science policy is summarised in the House of Lords Science & Technology report on Science and Society (House of Lords, 2000, Para 4.2): 'When science and society cross swords, it is often over the question of risk…'. Socio-scientific issues, such as those that arise in the media, can only be rationalised through an appreciation of risk as a multidimensional organising idea incorporating epistemological, psychological, sociological and cultural, and pedagogical perspectives.

The concept of risk commonly used today in the context of science and technology has its roots in the theory of decision-making, in the form of the 'subjective expected utility' (SEU) model: for every hazardous event there is both a likelihood of that event happening, and a numerical utility (also called dis-utility) measure which expresses the impact that the hazard would have on an individual or organisation involved should it occur (Edwards & Tversky, 1967). The arithmetical product of the likelihood and utility is defined as the 'risk' of the event. Hazardous events usually consist of many different interconnected hazards, and so

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there exists a 'total risk' for an event which is the sum of all individual risks. The SEU model then supposes that for someone faced with a hazardous situation, they can identify a comprehensive set of different possible courses of action, analyse those into sets of hazard events, give values for the likelihood and dis-utility of every hazard, compute the total risk of each course of action, and conclude with an optimal decision by selecting the course of action with minimum 'total risk'.

In contemporary technological societies, such a characterisation of risk is limited; there is debate on how risk is conceptualised (Wilensky, 1997): traditionally as the product of probability and impact around a particular event, but these variables are themselves subject to conditions of trust (O'Neill, 2002) and interpretations of lay and expert rationalities and context (Stilgoe, 2007). The psychological aspect arises from subjectivities and perceptions associated with risk (people are often willing to accept high risks with a low element of dread or a high element of familiarity, such as car accidents, but not low risks with a high element of dread such as airline accidents (Slovic, Flynn, & Layman, 1991)). In the sociological aspect, risk is seen in the context of institutional and cultural contexts (Douglas & Wildavsky, 1983), including the type of socio-political relations which make some risks either acceptable or unacceptable, for example, the use of vaccinations for the Human Papilloma Virus. The pedagogic aspect relates to the skills and confidence essential for teaching risk in the context of socio-scientific issues (Levinson & Turner, 2001; Ratcliffe & Grace, 2003).

Risk in issues in biology include the privatisation of genetic testing kits in which the healthy have now become the genetically unwell (Bennett, 2006) thereby imposing an artificial strain on health services, the causes of heart disease, screening practices, uncertainty about the epidemiology of cancer from new technologies such as mobile phone use and the emissions from base stations, and the international multi-party debate about risk and action on climate change.

Notwithstanding the global socio-political discourse on risk in science and technology, it has only recently begun to be incorporated into science curricula, most notably in England in Twenty First Century Science (Millar, 2006) and in Science in Society A2 level (www.scienceinsocietyadvanced.org). Despite an increasing emphasis on teaching risk, there is very little empirical research on its pedagogy. In this research project, funded by The Wellcome Trust's Society Awards research programme, we start from the assumption that risk is multidimensional and interdisciplinary, involving ideas which span a range of domains including science and mathematics. In so doing, two factors underlie the research design:

- To perturb teachers' thinking to gain a window on their thinking-in-change about risk and its pedagogy
- To embed conjectures about pedagogy into new tool designs.

Our research question, therefore, is twofold: To what extent can teachers' thinking-in-change about risk be captured through a structured microworld based on a utility approach? What are the implications for the design of new tools?

2. Methodology

2.1 Tool design and participants

We built a set of mature software tools designed through an analysis of the epistemology and the teaching and learning of risk, as reflected through research and in discussions with teachers of science and mathematics. These software tools embody emergent design ideas: the need to (i) involve the teachers in complex decision-making scenarios which draw on interdisciplinary knowledge; (ii) provide them with expressive tools to capture significant factors in decision-making; and (iii) provide feedback on the consequences of decisions made to enable redrafting of their models. By interacting more deeply with interdisciplinary knowledge, the aim is that mathematics and science teachers can be empowered to develop meaningful activities around the concept of risk. A key component of the research was that three pairs of teachers (one mathematics, one science) from the same school work together to explore the possibilities of cross-curricular working in their school, and become involved with the design work of the project.

2.2 Scenario

This research reports on findings from the personal decision-making scenario called 'Deborah's Dilemma' (accessed at www.riskatioe.org) in which teachers input probabilities for the success and side effects of a surgical intervention based on their interpretations of advice given by various medical authorities, and taking into consideration the possible consequences based on Deborah's lifestyle.

Teachers are invited to put themselves in the position of a fictitious person, Deborah, on whether to have an operation that could cure a spinal condition that is causing her considerable pain. The operation would entail certain hazards with risks that need to be inferred from various authentic sources of information, such as doctors, back pain specialists, internet searches, and anecdotes from patients who have had surgery or who are considering having surgery. There is also a short presentation with pictures and cross-sections of lumbar intervertebral discs to identify the regions and procedures for intervention. Ambiguities in the data are deliberately set up in order to provoke discussion and debate; for example a "spine expert in London" and "a surgeon in a regional hospital", give conflicting opinions–who should one trust? Choosing not to have the operation would entail a lifestyle choice to manage the ongoing pain resulting from the spinal condition. Two software tools accompany the information about the condition. The first ("Operation Outcomes") is a probability simulator in which users model the possible consequences of having the operation (Figure 1). Numbers of operations can be varied so participants can look at the probability of success/failure for just one operation or, for example, for a million operations. The likelihoods for various complications (i.e. side effects of the surgery, ranging from minor to serious, such as superbug infection, or death through general anaesthetic) are represented on the simulator once teachers have inputted a range of probabilities related to outcomes and side effects.
The second tool, the "Painometer", attempts to give a rough estimate of Deborah's pain and how different activities may cause it to increase or decrease, relative to a "tolerable" level. Pain defies objective measurement; hence the personal perception of pain is a potentially interesting but problematic context for probing people's personal models of risk. Users are required to decide what everyday and leisure activities Deborah should or should not do if they were in her position, and in what amounts, and to infer from the information the effect of those activities on Deborah's pain level (as expressed through the dynamically varying height of a vertical bar as a "painometer"). The intention is for the tools to promote quantification of risk in a real context, allowing for personal interpretation, while not being constrained by formal models of risk such as exist in statistical decision theory, and which are conventionally used in risk assessment.

Figure 1
The probability simulator

2.3 Data collection

The three pairs of teachers (one science and one mathematics practitioner from the same school in each pair) worked through Deborah's Dilemma to arrive at a specific decision about what to recommend to Deborah. A researcher sat with each group but only intervened to demonstrate relevant aspects of the software, to address any technical points and to ask questions for clarification. Having arrived at a decision, each pair of teachers wrote a report explaining their reasoning. Video screen capture software recorded the process of inference-making through the teachers' dialogues and manipulation of the simulators. The session lasted approximately 2 hours.

Data for the analysis consisted of an audio transcript for each pair of teachers, a video record of their interactions with the software, their written account of the reasoning behind their final decision, and notes from each researcher, including observations from a 'floating' researcher who was able to compare the inference-making of each pair.

3. Results

The following points emerged from thematic analysis and inductive coding of the data. The pairs of teachers responded to the data and Deborah's storyline in the following ways.

3.1 Analysis of the statistical data favoured having the operation

After creating models with probabilities (see Figure 1), the teachers concluded that the operation was safe, i.e. low risk, with failures being relatively rare and complications even more so. They tended to agree that it was worthwhile having the operation. The following extract is part of a discussion between Tim (a mathematics teacher) and Nathan (a science teacher) as to what action they would take based on the statistical data.

Episode 1

N: So really, the complications that are likely to happen aren't really going to be a problem. She might feel a bit rough.

T: Yeah.

N: The trachea and the nerve roots are possibly serious.

T: Yeah they could leave her worse than what she was in the first place.

N: In our simulation that was four out of 51 wasn't it?

T: What–four out of 1000 operations?

N: Four out of 1000.

T: Out of the failures it was four out of 51. But you've got 51 failures which means 47 operations just didn't work, it just didn't do what it was supposed to do. And out of those four there were possibly serious complications, so that's, you know, point less than half of a seventh.

N: We've got to decide if we write that. If we're recommending the surgery then we'll write that, and if we're not recommending the surgery then we'll say four people (laughs)…

N: I think I'm for having the operation actually. Personally I was always for having the operation. I don't know, nothing there has made me change my mind.

T: At the moment we're having about half a percent big problems, and it looks like the failure rate is about what you'd expect, so I think anybody…oh sorry five percent failure rate…so out of those five percent there's only about half a percent overall and out of the failures only about 10% of the failures could be quite serious. Overall it's only a half percent that could be serious problems; I presume the other failures would just be called a failure that doesn't cause you any problems. That's what I'm thinking, that's my perception of it.

All three pairs of teachers supported having the operation based upon modelling the statistical data. However, there were a number of mediating factors. First, the teachers frequently referred to personal experiences of either being in hospital or having operations. Secondly, they questioned the provenance of the data: they wanted, for example, to know how many operations the back surgeon had carried out; if the quoted figures were for the UK only, for certain regions, or for other countries. The source of the data was always important to them, and occasionally the amount of data. In the face of uncertainty, the teachers saw the data from the most authoritative source as being the most reliable. Thirdly, they occasionally came across problems in translating the data from one form to another, as emerges from the dialogue between Tim and Nathan and, for example, between Linda (a biology teacher) and Adrian (a mathematics teacher).

Episode 2

[The surgical operation]

L: It must be pretty bad pain to consider…

A: If you're going to consider the surgery it's got to be.

A: 'Unwanted after effects' (laughs). So 95 to 98% successful. So that's…is that 95 to 98% of the time the pain is relieved? Or 95 to 98% of the time there are no complications?

L: That's a good question.

...

L: Complication three…oh ok so you don't need to…more risky than what's going on. 'This was helpful…I asked my doctor for a second consultation…' Yeah, major surgery; general anaesthetic is another risk, and the superbug.

A: 'Currently about 0.00025%', 25 in 100,000.

L: See that's what we were thinking; '…developing my lifestyle to support long term management of the pain'. '…Yes, I can live with the pain and I have adjusted my lifestyle successfully'. It's more of a lifestyle operation; it's not something that's going to save her life is it?

A: Well she'll still be alive but it's got implications right through doesn't it? I suppose if it does deteriorate you set yourself up for…

L: Well if anything did deteriorate you'd be in a different position but if you lived slightly different then…Do you want to look at the other two options?

A: One in 1000 for general anaesthetic.

L: That's one in 10,000.

A: One in 4000 for the superbug.

A probability of 0.00025% of contracting a superbug is mistranslated as 25 in 100,000, or 1 in 4000. In fact this is far too high for the current prevalence of superbug infections in UK hospitals. In paired dialogue, it was easy for teachers to miscalculate small figure percentage values into the more prevalent discourse and numbers of chance and probability. This illustrates a common problem in which people find large numbers and low probabilities very hard to comprehend and deal with. It reflects the need to take care in the design of materials about risk, possibly highlighting the need to support consumers in negotiating and interpreting the ways in which probabilities are represented.

3.2 Attention to the focus of the problem influenced teachers' decision-making in terms of risk

The shifting of position seemed to relate to where the teachers' attention was directed, often by affective reactions to the context of the scenario at any particular point in time. This resulted in fluctuating decision-making in the dialogue between the two teachers as reflected in this exchange between Linda and Adrian.

Episode 3

A: I'd have the operation, give it a go. That's my lifestyle.

L: If someone said you couldn't play football, that would be important? You wouldn't be prepared.

A: Not only that, it's self-sufficiency as well. You need someone to do your shopping for you, already at 38.

L: Well she can use a trolley.

A: No, she can't lift a shopping bag–doing shopping would make you worse. Everything you chose to do for yourself would make you worse, leading to a more serious condition.

L: If you're recommending it purely on the odds, right...

A: No, not purely, I'm recommending it possibly against the odds, you know 3... over here [looking at written notes] complications or failure is 5%.

L: If you were saying it for yourself, you would be prepared, but say you were making it for her–then you'd be saying, well actually.

A: Right, we have to come down on one side or the other, we can't just re-present the evidence, we've got to say 'we recommend you do this', we can't sit on the fence.

L: Do you think if you were the doctor, if you were someone close to Deborah...

A: You might have a different opinion.

L: ...it's going to come down to the relationship with the patient as well. What are we, we're just people looking at statistics, if the computer says no, because at the moment to me the computer is saying no.

A: 3 in 1000 serious complications.

L: That's serious, you are 38 your life could–

A: Yeh!

L: Because the computer...[laughs] Who are we??

A: That's the question isn't it?

L: All these things, is lack of sleep, nausea, even depression…

A: That can ruin your life.

A key overall observation about Adrian and Linda's exploration is that there was a regular switching of positions which depended on the information immediately in front of them (the 'availability' heuristic), and their shifting estimations of impact. Initial exploration of the "outcomes" tool suggested a likelihood of serious complication arising from the surgery on the order of several cases in 1000, and they initially talked about this as a "reasonable risk". However as they explored with the Painometer tool, they began to favour a non-surgical approach and to reassess the reasonableness of the surgical risks. Our interpretation is that they were left in an ambiguous position between the two "sets of evidence" and in the end rationalised their position by appealing to the authority of the "specialist in London". Linda comments:

'I think the fact she's gone to the person who knows more about it, spends his life looking at risk, he says no there are better things out there for you, other options… As a scientist I would go with the specialist spine doctor who knows more about it, I would go with what he says'.

It would seem that Adrian (the mathematics teacher) brings in the probabilities to make the choice; this is mediated by Linda (the science teacher) who brings in social issues, stressing the impact (minor and major complications); Adrian changes his mind, as illustrated in the final recommendation that the pair produce, presented as a personal letter and reproduced below. It should be noted that this happened with just one pair of teachers and illustrates the importance of collaboration and discussion between teachers from (different) disciplines. Such subtle distinctions between science and mathematics teachers were observed in the other two groups as well. The approach taken by the project enabled effective cross-curricular working in an aspect of pedagogy which is often absent from classrooms, the discussion of issues beyond the quantitative or scientific evidence.

> '….We have looked at the probabilities of failure and complications during surgery and whilst the likelihood of severe complications is around 0.4%–possibly quite low–we are unsure as to the exact chance of success as the study quoted by your first doctor referred to arm pain only and we are inclined to take the opinion of the spine specialist that managing your condition is the best course of action.'

3.3 The problematic interactions of likelihood and impact

Standard risk theory involves a coordination of the likelihood of an event with its impact. That such a coordination is problematic and difficult to integrate can be seen from episode 3, in which Adrian and Linda have difficulty linking these two dimensions, not surprisingly given the complexity of the dilemma, its situated and affective nature. Impact is both difficult to quantify, even in relatively simple contexts, and to compare between contexts. To support teachers in coordinating these factors and rough estimations of risk, we designed a mapping tool which allows early reflections in linking likelihoods to impacts (Figure 2). This tool allows participants to combine likelihood with impact and arrange their estimates of risk across the screen. This tool was subsequently used with 14- and 15-year-old science students in a secondary school who were able to discuss these two factors together and compare risk situations across the screen.

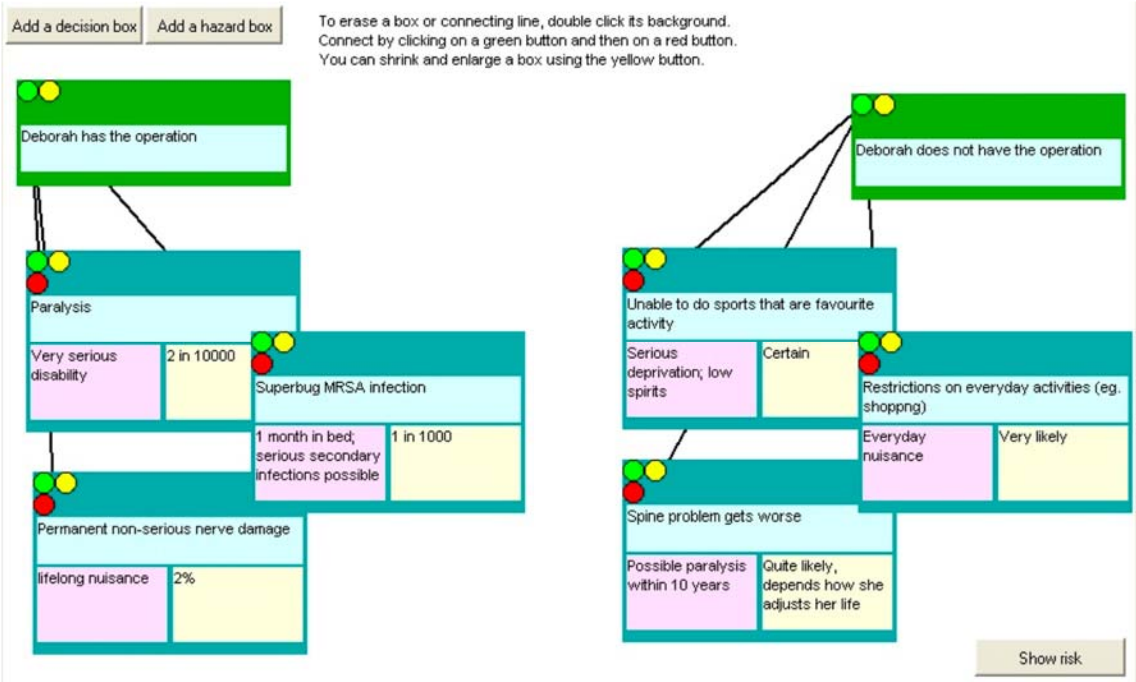

Figure 2
The mapping tool

4. Conclusions

Section 3 presents only a snapshot of the diverse themes discussed by the pairs of teachers, but focuses on the commonalities between them. While teachers are able to draw informal inferences given sufficient knowledge of context (Pratt et al., 2010), empathic and affective responses mediate decision-making about risk, and executable models make the various dimensions of risk-taking explicit. From the evidence of teachers' interactions with a co-designed flexible model of a risk-taking scenario, we have devised four pedagogic theory components which incorporate our findings.

- Risk is a multidisciplinary subject that can be addressed within conventional school structures.
- Risk is multidimensional, embracing at least the elements of likelihood, impact and value-laden ethical considerations. Recognition of the various dimensions can be stimulated by engaging with specific contextualised socio-scientific dilemmas and discussing the multifaceted nature of the dilemma.
- A modelling approach that encourages making the dimensions of specific contextualised socio-scientific dilemmas explicit in executable models supports recognition of and discussion about those dimensions, as well as awareness of the consequences of their characterisation of the dilemma: building and evaluating computer-based models renders the knowledge captured by those models more open to reflection, discussion and evaluation (Hoyles & Noss, 1992).
- Expressive tools can be designed that support the coordination of the dimensions of risk.

5. Implications

Personally oriented executable models which include tools for dialogue around taking risks in scientific issues offer the possibilities of interdisciplinary planning to teaching about risk for tasks which are framed in specific decision-making contexts. Incorporating value components from personal and social heuristics demonstrates how quantification is mediated in decision-making. While expressive tools can be designed which coordinate the multidimensional aspects of risk, it is still not clear how these dimensions are coordinated. Nonetheless, these tools provide a potential starting point for research in other contexts, such as genetic testing and nanotechnology.

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16 ARGUMENTATION STRATEGIES USED BY TEACHERS TO PROMOTE ARGUMENTATION SKILLS ABOUT A GENETICS SOCIOSCIENTIFIC ISSUE

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Abstract

The ability to justify and defend a decision using a rational and well-constructed argument is an important outcome of science education. Since 2006, the authors have conducted research in science classrooms on argumentation about socioscientific issues. Using a mixed-methods research design, seven teachers participated in professional learning sessions on argumentation and then explicitly taught argumentation skills using socioscientific issues in a genetics context. Grade 10 students (n=193) participated in small-group and/or teacher-led whole-class discussions and used writing frames to assist in constructing arguments about socioscientific issues. The students' argumentation ability and informal reasoning types for a socioscientific issue were measured with a pre- and post-test. Qualitative data sources included classroom observations, lesson transcripts, teacher and student interviews, writing frames and teaching programs. The students who were explicitly taught about argumentation showed significant improvement in their argumentation skills and ability to use rational informal reasoning compared to a control group of students (n=186) who studied the same genetics topic but did not learn about argumentation. The teachers whose students developed argumentation skills were found to have emphasised the use of scientific evidence, encouraged questioning of the validity of evidence and promoted rebutting claims and evidence.

Keywords: genetics; socioscientific issues; argumentation; informal reasoning; high school

1. Introduction

Internationally, an accepted aim of science education is to enable all students to develop a deeper understanding of the world around them, and to use their understanding of science to contribute to public debate and make informed and balanced decisions about scientific issues that impact their lives (Millar & Osborne, 1998).

1.1 Socioscientific issues

Our research is focused on problems that are not only scientific, but are important to human society in some way and, therefore, are referred to as socioscientific issues (SSIs). A multitude of scientific issues can be considered socioscientific, such as energy consumption, stem cell research and gene technology. SSIs are a central aspect of our research because they provide a context for student argumentation.

1.2 Informal reasoning

The process of thinking about and considering different aspects of a complex SSI, such as embryonic stem cell research, is referred to as informal reasoning (Sadler & Zeidler, 2005). Informal reasoning can be of different types, including intuitive, emotive, and rational (Sadler & Zeidler, 2005). Intuitive informal reasoning is evident when people respond to SSIs with immediate ideas based on their gut instincts (Sadler & Zeidler, 2005). In emotive informal reasoning, people respond based on their feelings and concerns for their own or others' well being. Informal reasoning can also be rational, that is, the person expressing their thinking demonstrates that they have drawn on logical, scientific concepts and ideas.

1.3 Argumentation

In our work, we follow the tradition of Toulmin (1958) by using the term argumentation to refer to a process of debate and structured discussion in order to reason about problems and issues, including SSIs. According to Sampson and Clarke (2008) argumentation describes the complex process in which people participate when they generate, justify and explain claims. ‘Good’ argumentation skills include being able to make strong and clear connections between claims and evidence and being able to rebut and create counter arguments to alternative ideas. Toulmin (1958) developed a model of the different aspects of an argument that can be used to analyse the structure and complexity of what has been said or written (Dawson & Venville, 2009; Osborne, Erduran, & Simon, 2004a). Toulmin’s model has also been used to teach teachers and students about how to improve their argumentation skills (Osborne et al., 2004a). Toulmin’s model begins with claims, which are a conclusion, proposition, or assertion about the issue. The next aspect is data, which includes any evidence provided by the arguer that supports the claim. Toulmin’s model then describes warrants, which involve an explanation of the relationship between the claim and the data. The next component of an argument is backings, which are the basic assumptions that support the warrants, data, and claim. A further component of an argument, according to Toulmin, is the qualifiers, which provide conditions under which the person considers a claim to be true. Finally, Toulmin describes rebuttals, which are the conditions under which the claim can be discarded.

1.4 Our research

Since 2006, we have been conducting a program of research that examines the impact of argumentation on high-school students’ argumentation skills, informal reasoning, and understanding of the science about which they have argued. Our previous research revealed that without instruction on argumentation, Australian high-school students use almost no or only simple data to justify their arguments. Further, they use predominantly intuitive (33%) and emotive reasoning (28.5%), rather than rational reasoning (18%), when making arguments about biotechnology (Dawson & Venville, 2009). As part of our previous research, we developed a useful method for analysing students’ argumentation using both Toulmin’s model of arguments to determine the degree of complexity of the argument structure, and a second method, based on work by Sadler and Zeidler (2005), that characterizes the nature of the informal reasoning employed by the students while creating their arguments. This dual approach contributes to addressing the problem that only measuring the degree of complexity of the argument does not determine the quality of the science used to make the argument.

The next stage in our research involved working with one case-study school to pilot-test a professional learning program for teachers on the instruction and practice of argumentation in a naturalistic high-school classroom setting (Venville & Dawson, 2010). Argumentation was introduced to the 14- and 15-year-old high-school students through SSIs in the context of gene technology. The intervention included one 50-minute lesson specifically about the structure of an argument and two lessons in which students themselves were involved in whole-class argumentation. We worked with the teacher and collected pre- and post-instruction data on students' argumentation skills and type of informal reasoning used. Findings were very encouraging as the results indicated that the students involved in the argumentation intervention showed statistically significant improvements in argumentation and informal reasoning compared with students not involved in the argumentation intervention. In evaluating the argumentation strategies used by the teacher, four factors appeared to promote argumentation: the role of the teacher in facilitating a whole-class discussion, the use of writing frames, the context of the SSI and the role of the students (Dawson & Venville, 2010). As this part of the research was a pilot case study, the findings were limited in their generalisability, particularly because only one teacher was involved in delivering the argumentation intervention (Venville & Dawson, 2010). We wanted to know to what degree these positive results could be generated in other classrooms, with other teachers, in a broader range of school types.

The research questions addressed in this paper are:

1. How does an intervention based on argumentation impact the structure of high-school students' argumentation and type of informal reasoning about a genetics SSI?
2. What argumentation strategies are used by teachers who effectively introduce argumentation skills into their genetics classes?

2. Research design and method

The research reported here followed a mixed-methods approach (Creswell, 2003), utilising both quantitative and qualitative approaches to provide a broad and diverse data base allowing triangulation of the findings. We implemented a quasi-experimental design with pre- and post-instruction assessments of students' argumentation skills and informal reasoning type. In addition, comprehensive qualitative data were collected from teachers and their students. Seven teachers and their Grade 9 or 10 students from four schools were involved in this research. Hence the generalisability of the findings compared with our previous case study (Venville & Dawson, 2010) is greatly enhanced. The findings presented in this paper are part of this larger study and relate to the nature and impact of the argumentation intervention in the experimental classes.

2.1 Sample

Information about the type of school, teacher and number of students is summarised in Table 1. Seven teachers from four schools in metropolitan Perth, Western Australia, participated in professional learning sessions and subsequently taught argumentation skills to their Grade 9 or 10 students. Eight classes, comprising 193 students, participated in the intervention on argumentation and formed the experimental group. Eight classes, comprising 186 students, did not participate in the intervention and formed the control group. Seven teachers taught the experimental classes and seven teachers taught the control classes (Table 1). All students were in either Grade 9 or 10 (age 13-15 years). The schools included a coeducational (girls and boys) Catholic school, a fully government-funded, coeducational school, an independent girls-only school and an independent coeducational school.

Table 1
Information about the schools, teachers, and experimental and control classes

School Type	Group	Teacher	Grade	Number of students who completed both pre- and post-test
A Catholic (coed)	Experimental	Teacher 1 – male, biology major, 19 years experience	Grade 10	46 (2 classes)
	Experimental	Teacher 2 – female, biology major, 7 years experience	Grade 9	26
	Control	Male, biology major, 10 years experience	Grade 10	46 (2 classes)
	Control	Male, biology major, 11 years experience	Grade 9	50 (2 classes)
B Government (coed)	Experimental	Teacher 3 – female, non-biology major, 15 years experience	Grade 10	29
	Experimental	Teacher 4 – female, biology major, 7 years experience	Grade 10	27
	Control	Female, biology major, 1 year experience	Grade 10	21
C Independent (girls)	Experimental	Teacher 5 – male, biology major, 20 years experience	Grade 10	20
	Experimental	Teacher 6 – male, biology major, 15 years experience	Grade 10	20
	Control	Teacher 5	Grade 10	22
	Control	Teacher 6	Grade 10	20
D Independent (coed)	Experimental	Teacher 7 – male, biology major, 27 years experience	Grade 10	25
	Control	Teacher 7	Grade 10	27

2.2 Quantitative data

A quasi-experimental design with a pre- and post-test (Cohen, Manion, & Morrison, 2000) was used to examine the effect of teaching argumentation on students' argumentation skills and informal reasoning type as pertaining to a SSI on designer babies. It was not possible to randomly assign the students into experimental and control groups because the schools had already completed their class allocations. As an alternative, we randomly assigned classes to experimental and control groups. To improve the validity of our research, we attempted to match a number of variables between experimental and control classes so that the two non-equivalent groups were as similar as possible. For example, classes were matched as much as possible for their school socioeconomic status, whether they were homogeneous or streamed according to ability classes, single sex or coeducational, and degree of teacher experience. In schools C and D, the three teachers (5, 6 and 7) taught both the experimental and control classes.

2.3 Intervention

All experimental and control classes were taught an 8- to 10-week unit on genetics that is a standard part of the Western Australian science curriculum (Curriculum Council of Western Australia, 1998). The intervention involved the seven teachers who taught experimental classes participating in professional learning sessions on argumentation and subsequently teaching argumentation skills. The professional learning sessions were of approximately 90 minutes duration and usually occurred at the teachers' school. The teachers were given a briefing sheet that explained the rationale of argumentation, informal reasoning, decision-making and SSIs. The Ideas, evidence and argument in science (IDEAS) materials (Osborne, Erduran, & Simon, 2004b) were used to define argument and provide exemplars.

The session began with a discussion of what an argument is and how scientists argue and debate with their peers in many contexts, such as within journals and at conferences. For example, scientists argue and debate about the type of data to be collected, data validity and reliability, data interpretation and suitability of models. Resource sheets from the IDEAS training pack (Teaching argument) were used to introduce Toulmin's (1958) model of arguments, examples of arguments and their parts (i.e., claim, data, warrant, backing, qualifier and rebuttal) and the use of argument prompts. Video excerpts showing two teachers introducing and modelling argumentation were viewed and critiqued. The professional learning sessions were conducted as an interactive discussion, with the teachers having significant input as they discussed their ideas on how best to teach argumentation.

The teachers were provided with writing frames about two SSIs to support the implementation of the intervention in their classes. The teachers of experimental classes explicitly modelled and taught argumentation skills to their students over two or three 50- to 60-minute lessons within the genetics unit. The teachers introduced students to the parts of an argument, including claims, data, warrants, backings, qualifiers and rebuttals. Working individually, the students then used writing frames to develop arguments about two SSIs on genetically modified foods and cystic fibrosis. The writing frames contained prompt questions designed to scaffold the structure of an argument. Students also participated in whole-class discussion and/or small-group work to voice their arguments about the two SSIs (Dawson & Venville, 2010). Control classes did not participate in argumentation but had the same total teaching/learning time during their genetics unit.

All students completed a written survey before and after completing the genetics unit. Part of the student survey, developed in our previous investigation (Venville & Dawson, 2010), was made up of a genetics-based SSI about designer babies which was originally developed by Lewis (2000) (Figure 1).

A Sydney IVF clinic has recently been offering to produce 'designer babies' for parents. For just $10,000 the clinic will check and, if necessary, change the parent's genes in order to produce the baby of their choice. Once selected, the baby develops normally inside the mother. The choice at the moment is limited to sex, intelligence, height and hair colour but a spokesperson said that several other features would soon be available. All 'designer babies' are guaranteed free from identifiable genetic diseases.
Do you think this use of gene technology should be allowed?
Write as many reasons as you can to support your answer.

Figure 1
Designer baby scenario

The students' written responses were analysed using two methods. To determine the complexity of the argument used by each student, a classification scheme based on Toulmin's argumentation pattern (TAP) was used (Dawson & Venville, 2009). Students' written arguments were assigned a level or score from 0 to 4 depending on the presence of claims (decision only), data (evidence to support claim), warrants (relating data to claim), backings (assumptions to support data/warrant) and qualifiers (conditions under which claims or data are true). Level 1 arguments consisted of a claim only; level 2 arguments comprised a claim, data and/or warrant; level 3 arguments included a claim, data, warrant, backing or qualifier, and level 4 arguments included a claim, data, warrant, backing and qualifier. No response was scored as a 0.

To determine the type of informal reasoning used by the students, a method previously employed by Sadler and Zeidler (2005) and Dawson and Venville (2009) was used. Students' responses were classified as rational (logical, using correct scientific language, evaluating risk), emotive (care, empathy, concern for others) or intuitive (gut response, personal). The responses were scored as 3 (rational), 2 (emotive) or 1 (intuitive). Sixty percent of the student responses were coded independently by the two authors and an inter-rater reliability of 79% was achieved. The remaining sample was coded blind by the first author. Pre- and post-test scores for all students were entered into an SPSS database and analysed statistically. Differences in pre- and post-test scores for argumentation and informal reasoning were analysed statistically using Wilcoxon Signed Rank Test, while differences between the experimental and control groups were analysed using Mann-Whitney U Test.

2.4 Qualitative data

Qualitative data included field notes from the professional learning sessions and classroom lessons, argumentation lesson transcripts, post-unit teacher and student interviews, writing frames and teaching programs. Because of school constraints, it was not possible to collect qualitative data from School B or student interviews from School C. However, a total of 19 students (10 from Teacher 1's class, 4 from Teacher 2's class and 5 from Teachers 7's class) were interviewed at the end of the genetics topic about their perceptions of the argumentation classes. The students were interviewed in groups of two or three at their school. For each class, the students were selected by their teacher to represent high, medium and low achievement in science. In the post-unit interview, the students were asked what they thought of the argumentation lessons and what they had learned, and why. The interviews were fully transcribed.

A total of 10 audiotaped lessons and classroom observation field notes were fully transcribed and classroom observation field notes were written up as soon as possible after the lessons. To analyse the types of argumentation strategies used by the teachers to implement various argumentation skills, we used a framework developed by Simon, Erduran and Osborne (2006). They developed their framework by analysing lesson transcripts from teachers who had successfully introduced argumentation. They found that these teachers consistently used particular strategies to promote students' argumentation skills.

The argumentation process and accompanying strategies were:

1. Talking and listening
2. Knowing the meaning of argument
3. Positioning
4. Justifying with evidence
5. Constructing arguments
6. Evaluating arguments
7. Counter-arguing/debating
8. Reflecting on the argument process

The degree to which the teachers in this study used each of the strategies was determined by examining the lesson transcripts and classroom observation field notes for instances in which the teacher explicitly used the strategy. The student interview transcripts were also examined for examples in which a student or students explicitly described the strategy used by the teacher. The extent to which the strategy was used was scored from 0 (not used) to +++ (used by teacher on more than two occasions, mentioned in student interviews).

3. Results

3.1 Argumentation quality

The Wilcoxon Signed Rank Test showed a statistically significant difference in the complexity of the experimental group's levels of argumentation compared with their pre-instruction levels of argumentation ($p<0.001$, medium effect size $r=0.36$). A similar difference was not found in the control group. Further, the Mann-Whitney U test showed that while the pre-instruction levels of argumentation in the experimental and control groups were not significantly different prior to instruction, the experimental group's post-instruction levels of argumentation were significantly different from the control group's post-instruction levels of argumentation ($p<0.05$, medium effect size $r=0.36$). Figure 2 presents graphs of the percentage of students displaying the levels of argumentation in both experimental and control groups pre and post-instruction.

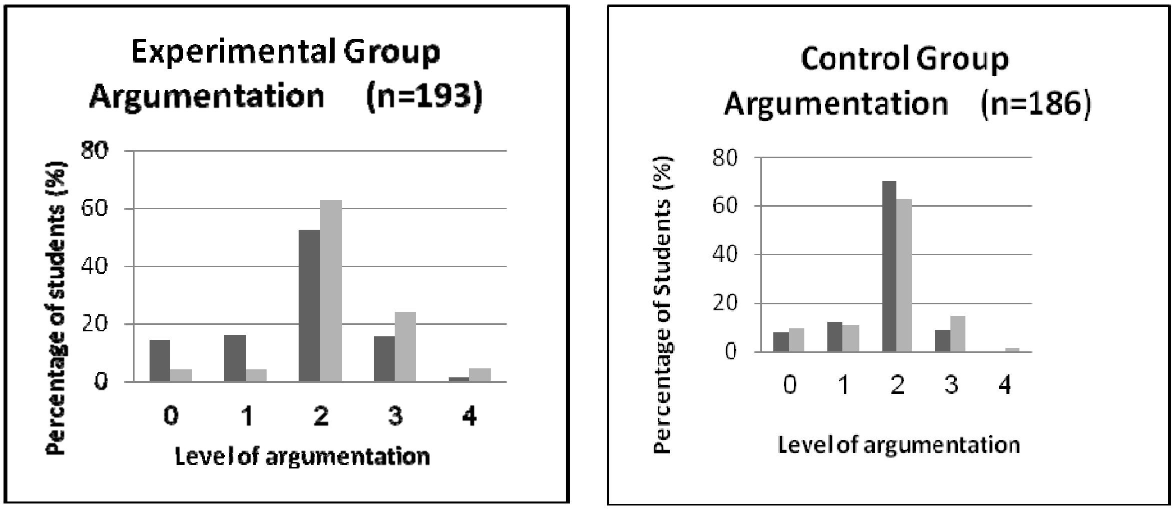

Figure 2
Numbers of students showing each level of argumentation in the experimental and control groups pre (left column) and post (right column) instruction

The following examples illustrate the level of argumentation demonstrated by students.

Student 4293 – I don't think it is right to design a baby the way you want it. (Level 1)

Student 4282 – This is not a good idea because if everyone could choose exactly how their child would be then the following generation would be very similar as people have a very set idea of what is valued, attractive, etc. (Level 2)

Student 4280 – No. I think it shouldn't happen because a baby is designed naturally and it should be a surprise to see what the child grows up to be like. It would be a waste of money and the only reason I can see it happening is if the child were going to have a life-threatening disease. (Level 3)

Student 74 – I don't know because in some ways it is right in being able to take out genes for genetic disorders because it will save the parents and child a lot of pain. I think you shouldn't be able to change things such as sex, intelligence, height and hair colour because it shouldn't be the parent's decision and is interfering with nature. If everyone had designer babies then a lot of people's hair colour, height, etc. would be the same and not unique to a person and special. (Level 4)

3.2 Informal reasoning

The Wilcoxon Signed Rank Test showed a significant change in informal reasoning in the experimental group from pre-instruction to post-instruction ($p<0.05$, medium effect size $r=0.34$). No significant change was observed in the control group from pre- to post-instruction. The Mann-Whitney U Test showed that while there was no significant differences between the experimental and control groups pre-instruction, post-instruction types of informal reasoning for the experimental group were significantly different from the control group ($p<0.05$, small effect size $r=0.12$). Figure 3 presents graphs of the percentage of students who demonstrated the various types of informal reasoning for both the experimental and control groups pre- and post-instruction.

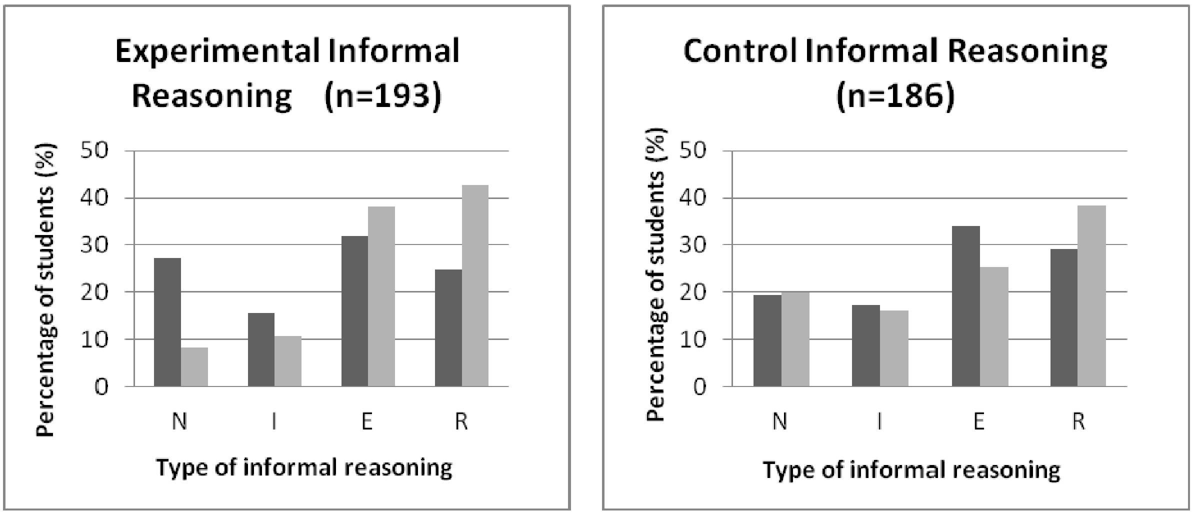

Figure 3
Numbers of students showing different types of informal reasoning in the experimental and control groups pre (left column) and post (right column) instruction. N – none, I – Intuitive, E – Emotive, and R – Rational informal reasoning

The following three examples illustrate the types of informal reasoning demonstrated by students.

Student 4280 – No. it's just wrong. There is no need to. It's selfish and just stupid. (Intuitive)

Student 4297 – No. If this went through, there would be a huge chance that everyone would look like each other. All parents would want their children to be intelligent and ideal looking. Even though this experimental breakthrough could change the way of how everyone looked, no one would be unique or have individual characteristics anymore. (Emotive)

Student 4198 – I don't know. It may stop abortions but it could change the population into mainly one sex and this would upset the balance. It could affect other genes and cause unknown diseases. (Rational)

3.3 Argumentation strategies

The quantitative data indicate that the students in the experimental group significantly improved their ability to construct a quality argument and use rational informal reasoning as compared to a control group of similar students. The teachers of the experimental group explicitly taught argumentation skills to their students. In this section, the argumentation strategies used by the teachers are examined. As described in the methods, 10 lesson transcripts, classroom observation field notes and 19 student interviews were examined to determine the strategies used by teachers in this study. Table 2 summarises the extent to which the teachers used particular argumentation strategies in their lessons.

4. Conclusion

The results of this research demonstrate that an intervention that included teachers' professional learning about argumentation, SSIs and decision-making followed by explicit instruction on argumentation in students' genetics classes resulted in students significantly improving their quality of argumentation and using a rational type of informal reasoning about a genetics SSI. These findings are significant as they indicate that a targeted professional development session and a brief classroom intervention can improve students' argumentation skills and change their informal reasoning type from intuitive and emotive to rational. However, we were somewhat disappointed with the results: the students in the experimental classes were given direct instruction on the structure of an argument and practice in a whole-class setting or small groups on developing arguments, but only 28% of the students constructed level 3 and level 4 arguments in the post-test survey compared to 16% in the pre-test survey. However, the results can also be viewed positively given the comparatively large scale of this study, with seven different teachers taking the intervention classes and nearly 200 students participating in pre and post-instruction surveys.

Table 2
Argumentation strategies used by teachers

Argumentation strategy	Teacher 1	Teacher 2	Teacher 5	Teacher 6	Teacher 7
Encourages discussion and listening	+++	+++	+++	+	+++
Defines and exemplifies argument	+++	+++	+++	++	+++
Encourages ideas, positioning and values different positions	+++	++	+	+++	+++
Checks evidence, provides evidence, prompts justification, emphasises justification and plays devil's advocate	+++	+	+++	+	++
Uses writing frames or written work, prepares presentations, assigns roles	+++	+	++	++	+
Encourages evaluation of argument, argument process and the nature of evidence	+++	-	-	++	+
Encourages anticipating counter argument and debate (through role play)	+++	+	+	-	+++
Encourages reflection and asks about change of mind	+++	+	+++	+	+++

Key: - not demonstrated; + demonstrated once, ++ demonstrated a few times, +++ demonstrated on numerous occasions

Figure 3 shows that for both the experimental and control classes, the students generally used more rational types of arguments in the post-instruction survey than in the pre-instruction survey. This is not surprising since all students had been involved in an 8- to 10-week genetics unit and as a result, they improved their understanding of genetics. Therefore, the students would have had more scientific information about genetics available to them and it seems that they were able to use that scientific information to make their arguments. The statistical testing showed that post-instruction, the students in the experimental classes, on average, had significantly different informal reasoning types compared with the students in the control classes. The shifts evident in Figure 3 in the types of informal reasoning show that the students in the experimental classes were more likely to produce emotive and rational arguments than the students in the control classes. The shift to rational informal reasoning is more apparent for the students in the experimental group. This result is encouraging as emotive and rational types of informal reasoning are more desirable from a science education perspective, because they require more thought than intuitive informal reasoning as well as consideration of scientific information.

In our earlier work with a case-study teacher, the role of the teacher in facilitating whole-class discussion, the use of writing frames, the context of the SSI and the role of the students all appeared to be important factors in developing students' argumentation skills (Dawson & Venville, 2010). The findings of this study support the important role of the teacher in facilitating either whole-class or small-group discussion. The use of writing frames to scaffold argument structure does seem to enable students to plan individually before they voice their arguments.

It would appear that all teachers did encourage their students to engage in whole-class and/or small-group discussion and also to listen to the arguments of their peers. The teachers also explicitly defined the parts of an argument (claim, data, warrants, backings, qualifier and rebuttal) and provided at least one detailed example of an argument with all components. The teachers prompted students to provide evidence to support their claims and played devil's advocate. All teachers required students to use writing frames to practice constructing arguments. However, the extent to which the teachers prompted students for evidence and further justification of their claims was variable. Evaluation of whether a student's evidence was correct or not was variable (and absent in some classes). Some students used emotive or intuitive responses and were not encouraged to use scientific evidence. With the exception of Teachers 1 and 7, students were not encouraged to debate or evaluate each others' answers or anticipate counter arguments. It is suggested that it is the development of these latter skills that promote the higher level arguments and the rational informal reasoning that so few students demonstrated. It is recommended that teachers' professional learning focus on emphasising the importance of encouraging students to use sound scientific evidence, question the source and validity of evidence, and anticipate and rebut claims and evidence.

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17 ARGUMENTATION, NORMS AND NORMATIVITY: DISCOURSE ANALYSIS CONCERNING HUMAN EMBRYONIC STEM CELLS

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Abstract

The use of human embryonic stem cells (hESCs) is under French bioethics law revision. In 2009, the French government organized a citizen forum and a variety of players expressed their opinions.

The main theoretical framework used in this study was the didactics of controversial socioscientific issues together with communication sciences' theoretical framework of science "sociodiffusion", which focuses on the rewording of scientific concepts during their social circulation. I performed a comparative sociolinguistic analysis of three discourses: scientific, media-related and religious, focusing on argumentation and on the scientific and social norms used.

I observed that some researchers who participated in the citizen forum did not always clarify their own opinions. In particular, scientific norms concerning ontogenesis of the nervous system were rarely clarified. In contrast, Christian church instructors expressed social norms concerning a human embryo's status. Their argumentation was mainly based on the embryo's personification. An analysis of media reports revealed a different framing of hESC uses in each newspaper. Press articles introduced several of the players' discourses, but did not report on the entire diversity of the public discourses.

This research should help science educators evaluate their own scientific and social norms when planning debates with their students.

Keywords: socioscientific issue; embryonic stem cells; media; church; researcher; discourse analysis

1. Introduction

The use of human embryonic stem cells (hESCs) for research and for the treatment of diseases raises many controversial societal issues. In the French context, a revision of bioethics laws, including the uses of hESCs, is planned for 2010.

This study is the first step in elaborating a protocol for the organization of students' debates concerning hESCs, in parallel with the law revisions. These debates, organized by the science center "Tous chercheurs", will take place in schools in Marseille's working-class district in 2010-2011.

I analysed the points of view of the main social players in the controversy and their arguments, to identify all relevant players for the students to consult and the most relevant types of information to analyse (and how) with the students.

To explore a corpus of discourses produced by several social players and the press, I used the rationale of both socioscientific issue (SSI) didactics and communication sciences (sociological approach to the mediation of science and controversies).

2. Biological topic

The use of hESCs for research or treatment of degenerative diseases deals with scientific knowledge, such as stages of ontogenesis, as well as personal opinions or values. A variety of players have formulated opinions on hESC use.

Since the 1990s, controversy has existed within the scientific community on how to obtain and store hESCs (issues of proliferation and differentiation) and on their therapeutic use (feasibility, therapeutic efficiency, risks of tumour development in the patients). Use of the human embryo as a source of totipotent cells is influenced by social representations and value systems due to the fact that isolation of hESCs requires embryo destruction and consequently raises the question of the embryo's status. Therefore, it is a highly controversial social issue. The benefit-to-risk ratio for patients treated by cell therapy is debated in society and at the time of this study, the ethical framework for therapeutic use of stem cells in France was provided by a restrictive legislation on hESC use (Biomedical Agency). An additional controversial point concerns therapeutic cloning, by which scientists create human embryos through nuclear transfer and extract stem cells for cell therapy, thus avoiding immunocompatibility problems.

3. Rationale

This study fits in a theoretical framework where techno-sciences are viewed as including important social dimensions (STS education). Didactics of controversial socioscientific issues (SSIs) is the main rationale used (Sadler, Chambers, & Zeidler, 2004; Simonneaux & Simonneaux, 2008). In France, SSIs are also termed "socially live", which means that they involve uncertain knowledge in the scientific area, raise debates in the social arena and feed topical items in the media (Legardez & Alpe, 2001). As Simonneaux (2003, p. 189) points out, developing the abilities to debate those SSIs has a major educational purpose: *"to train individuals in research methods, their applications and potential impact and to develop their ability to participate in debates and to make reasoned decisions when the facts are uncertain"*.

According to Sadler (2004), the main research using this rationale focuses on skills, understanding of the nature of science, relationships between scientific knowledge comprehension and SSI decision-making, and various, sometimes contradictory sources of information analysis. I focus in this study on socioscientific argumentation skills (Jiménez-Aleixandre, 2002; Jiménez-Aleixandre & Federico-Agraso, 2009; Sadler & Donnelly, 2006; Simonneaux & Simonneaux, 2004; Zohar & Nemet, 2002) and on the ways of evaluating information (Kolsto, 2001).

For this purpose, I also use the theoretical communication sciences framework of science "sociodiffusion" proposed by Jacobi (1999), which focuses on the rewording of scientific concepts during their social circulation (Memmi, 1989; Moscovici, 1976). Discourses relating to sciences are analysed to comprehend "*transformations and sense changes in which scientist discourse becomes a more common and less legitimate discourse"* (Jacobi, 1984).

According to the "deficit model" criticized by Irwin (2001), I focus on experts' discourses, considering, with Levy-Leblond (2001), the importance of developing a symmetrical analysis of scientists' and non-specialists' conceptions of a SSI.

This social approach is also inspired from probation sociology ("sociologie des épreuves"), in which controversy is studied per se or *sui generis* as a condition in which the players modify their reciprocal social links (Callon & Latour, 1991). In this way, the controversies are seen as systems of players and arguments within a context (Chateauraynaud, 2007), characterized by the dynamics (advertising, confinement) of the disagreements between peers in front of a public (Lemieux, 2007).

Finally, because SSIs deal with scientific knowledge and values, I consider, with the epistemologist Canguilhem, the sciences in society by considering the scientific and social norm interconnections and their process of normativity, meaning that which institutes norms. According to Canguilhem (1994, [1943]), norms are at the same time facts and values because they are defined as "*the result which gives a value to any object, event or act*".

This is why I used an epistemological model of continuity for interactions between scientific and social norms. This model modifies the classical opposition between scientific knowledge and values (objective facts vs. subjective opinions or *episteme* vs. *doxa*) as science-demarcating criteria.

4. Research problem and key objectives

This study is aimed at comparing the discourses concerning hESC research of the different players participating in the public debate to identify their opinions and arguments. An attempt was also made to identify the scientific and social norms used within the discourses. Are these norms clear? What are their dynamics and their interconnections?

Indeed, clarifying the implicit scientific and social norms involved in the debates, their dynamics and interplay appear as a necessary condition to empower students to develop their own social norms when they debate on SSIs (and they can also help teachers assist them).

5. Methodology: methods and data sources

I performed a historical comparative sociolinguistic analysis of three types of discourses concerning hESC uses: those of researchers and religious representatives (particularly of the Christian and Apostolic church communities), and media reports.

5.1 Contexts and data sources

Researchers' discourses (n=6) were taped during the public debates of the "Etats généraux de la bioéthique". This citizen forum on bioethics was aimed at developing informed opinions and shared values concerning scientific progress in the perspective of the bioethical laws revision planned for 2010. The first bioethics laws (1994) banned research on human embryos and the first revision (2004) maintained the ban with a 5-year moratorium of allowing exemptions for a few research projects. The forum protocol included the presence of 17 citizens over a 6-month period (January 14th to July 1st). They were informed during a three-step formation:

1) formation with experts (1 MD, 2 lawyers, 2 philosophers);

2) public hearing of "important people" (2 MDs from INSERM, 1 Professor of health law, 1

biologist from INSERM, 1 Professor of paediatrics and ethics, previously secretary of health);

3) these citizens had to deliver a report of consensual advice.

The researchers' discourses were compared with a previous analysis of students' debates, led in 2005 during the last bioethics law revision, in which the students consulted with researchers.

The analysed media reports consisted of media coverage of the controversy in the general interest national press during the period of the citizen forum. I chose five daily newspapers, with a diversity of political opinions (Babou & Le Marec, 2010): *Le Monde* (center-left), *Libération* (left), *Le Figaro* (conservative right), *L'Humanité* (official newspaper of the French communist party) and *La Croix* (Catholic traditionalist newspaper). I collected 48 articles from a numerical database with the software "Factiva" using the keywords "cellule" (cell), "souche" (stem) and "embryon" (embryo) from January 1st to August 1st 2009.

The analysed church discourses were the instructions of the official voice of the Christian and Apostolic church (Holy See from the roman curia) *Dignitas personae on certain bioethical questions* (Benedict XVI, September 2008), and the instruction *Donum Vitae on Respect for Human Life in Its Origins and on the Dignity of Procreation* (John Paul II, February 1987).

5.2 Methods

Concerning the researcher and church discourses, I used sociological principles of discourse analysis (Kerbrat-Orecchioni, 1998) and performed an argumentative analysis (Breton, 2003; Goffman, 1973); Perelman & Olbrecht-Tyteca, 1988) to categorize the different types of arguments and the argumentative frameworks. Argumentation is defined as a way of supporting a personal opinion (Breton, 2003). The quality of the arguments was analysed by counting claims without justification, simple arguments relying on only one justification, and multiple-level strategies involving several justifications that are linearly linked or interrelated, that is, with counterclaims or rebuttals, but is not presented here (Federico-Agraso & Jiménez-Aleixandre, 2006; Simonneaux, 2003; Toulmin, 1958). I also studied the *modalisation* of the discourses, which consists of the semantic method used by the speakers to reveal their level of adhesion to their arguments (Bronckart, 1996).

In this paper, I mention arguments as justifications used to connect information to claims. I also attempt to identify the social and scientific norms used and their putative clarification. Then I propose a comparative analysis between the norms used by the different players, their dynamics and their interconnections.

Concerning the media reports, I used Charaudeau's method (2008) of media discourse analysis. A corpus of 48 articles was first analysed to eliminate those in which hESC use was not the central subject, and I defined different themes. Then, I identified the different frames of questioning: scientific, ethical (moral), political (power), judicial (law), social or economic. One article could contain more than one theme or frame of questioning. The identity of the author was also specified (researcher, MD, general or specialist journalist, politician, citizen…). Finally, I performed an analysis of the different types of texts: informative (without argumentation), analytical-commentary (explanatory argumentation), points of view (persuasive argumentation). The argumentative strategies of the media samples were analysed according to their focus on the problems (framing for legitimacy, credibility), on the points of view (made explicit for sincerity, talking as a specialist, witness, player, victim…) and on the evidence (resorting to the value of scientific knowledge or knowledge of "belief"). This analysis is in progress and only parts of it are presented here.

6. Results and discussion

6.1 Arguments and norms in the researchers' discourses

Two of the six researchers consulted during the 2009 citizen forum on bioethics expressed their personal opinions in an explicit way. They were researchers favourable to maintaining the law, i.e. favourable to the ban on research on human embryos with exemptions.

In a previous study (discourse analysis of seven researchers consulted by students during the last bioethics law revision in 2004-05), we observed that the researchers' personal opinions were not made explicit (Molinatti, Girault, & Hammond, 2010). Rewording processes occurred in their communication discourses reducing the human embryo to its cellular dimensions (embryo as a "*sphere, pile of cells*"). Their implicit purpose was to present the embryo as an object more than a subject so as to legitimize its use for research. Scientific norms, especially concerning ontogenesis of the nervous system, were also often not clarified. Nevertheless, the researchers used "framing arguments" (e.g. the embryo is frozen and not to be used for a parental project) but did not explain their own opinions. The major argument used by the researchers was the therapeutic perspectives offered by hESC research.

In the present study, the argument of secured uses of hESCs for therapy was rejected and potential therapeutic properties of hESCs were minimised "*because of unexpected results*" of the research. A scientist reminded: "*we appreciate the importance of a finding by the degree of surprise it provokes*" (Pr Ameisen).

Some rewording processes persisted in the argumentative discourses of the researchers. For example, Pr Mattei redefined the embryo as a "living human being" and claimed:

"*life must be respected as soon as it begins*" and evoked "*a window of vulnerability for*

this developing being", "*the living human*" (Pr Mattei).

However, the major arguments consisted of displacing the way in which the problem is considered (effects of "problematisation"). For example, several researchers (Pr Mattei, Dr Testart), unfavourable to the evolution of the laws, supported the notion that the question of embryo status was not appropriate. According to them, there should be no status for any one moment of life that would rank it higher than another: "*I think this question of a status for the embryo is totally archaic…we should not define the embryonic being but our duty as human beings towards the embryo*" (Pr Mattei).

A researcher (Dr Testart) underlined the confusion between research "on" the embryo and research "with" the embryo to denounce the use of the embryo as an object.

In contrast, the researchers favouring the evolution of the laws pointed out the difference between the embryo considered as a whole and the stem cells separated from the embryo. According to a scientist, the main question becomes: "*What is the problem? The destruction of the embryo, or once the embryo is destroyed to do research on the cells that have been isolated?"* (Pr Ameisen).

When I compared this study to the one in 2005, I found that the most important changes concerned clarification of scientific norms about the embryo. During the more recent debates, some scientific norms were made explicit by the researchers. However I noted that these concerned contexts other than the French one or another period in judicial history.

For example, a scientist explained the scientific norm (nervous system ontogenesis) used in

Great Britain to allow research on the embryo before 14 days of gestation: "*This delay of 14 days in England…it is because, at a given time, one had defined death as* ***brain death*** *this is* *why one can take subjects which still have a heart which beats but which are considered as brain dead, what authorizes the sampling of the organs. By reason of symmetry, it has been considered that* ***life was the functioning of the brain, of a nervous system****, and it is what occurs around the 14th day in the human being*" (Pr Menaché).

Another researcher pointed out the relativity of these norms which depend on our scientific knowledge. He took the example of the vote, in France, of the law permitting voluntary interruption of pregnancy (1975): "*At that time the presence of an embryo was found after three weeks of pregnancy and thus it was not threatened before because one was unaware of its presence and, in addition, the last three months it was inaccessible to medicine because we did not have the techniques which we have today. In other words between three weeks and three months there was a window of vulnerability for this developing being*" (Pr Mattei).

6.2 Arguments and norms in the official voice of the Christian and Apostolic churches

Christian and Apostolic church instructions (instructions *Donum Vitae*, 1987 and *Dignitas Personae*, 2008) expressed a very clear opinion against research on the embryo.

For the Christian church, the argumentative strategy consisted of the way of questioning, considering the embryo as a person, and an explicit point of view.

The strategy of evidence resorted to knowledge of "belief" from the value domain of ethics where the embryo is at the same time human and divine (biological and spiritual dualism); that is why he / it cannot be used as research material: "*primary and fundamental right to life…from the first moment of its existence, that is to say from the moment the zygote has formed…the purposes, rights and duties which are based upon the bodily and spiritual nature of the human person*" (Instruction *Donum Vitae*, 1987).

The argumentation related to the embryo's protection was based mainly on the embryo's personification using rhetorical processes such as effects of "nomination", where the embryo is presented as a: "*little unprotected human being*", an "*orphan*", the victim of a "*crime*"…

Risks of eugenics and the need for research to take care of the worst-off were also ethical values used as arguments to ban research on the embryo.

Compared to 1987, in 2008, the argumentative strategy of these theological discourses utilized some scientific terms more often (zygote, embryo, hESC, in vitro fecundation, oocyte, embryo stage, intracytoplasmic injection, germinal and somatic, genetic patrimony, human cloning, therapeutic and reproductive, asexual reproduction, nucleus transfer, hybridization…) or debates to disqualify hESC research (Instruction *Dignitas Personae*, 2008).

The therapeutic potential of adult stem cells was highlighted in comparison to that of embryonic stem cells: "*many of the cited works conclude with an indication of the great promise that adult stem cells offer for effective treatment of many pathologies*" (Pontifical Academy for Life, 2000).

Finally, these discourses were based on very stable social norms (dogma): *"the conclusions of science regarding the human embryo provide a valuable indication for discerning by the use of reason a personal presence at the moment of this first appearance of a human life: how could a human individual not be a human person? The Magisterium has not expressly committed itself to an affirmation of a philosophical nature, but it constantly reaffirms the moral condemnation of any kind of procured abortion. This teaching has not been changed and is unchangeable"* (Instruction *Donum Vitae*, 1987).

I found the dogma *"no gradation of the moral value during the development*" (Instruction

Dignitas Personae, 2008) interesting to study, as it provided a relevant statement to compare with other players' implicit norms.

6.3 Analysis of media reports

The quantitative analysis showed that 17 articles out of the 48 specifically concerned the hESC theme and the French bioethics law revision. Thirteen articles dealt with therapeutic or reproductive cloning, 10 with the evolution of US legislation, particularly when President Obama lifted the ban on ESC research (March 2009), 7 with bioethics generalities and 5 with the discovery of induced spermatozoa from ESCs. Three articles out of the 48 were outside the theme.

The number of articles for each daily newspaper (Table 1) and the monthly calendar of the publications (Table 2) showed that each national general interest press group has its own editorial policy. As an example, the traditionalist Catholic newspaper *La Croix* offered larger media coverage of the hESC theme than of the French bioethics law revision: a total of 13 articles out of 17, including a special series of reports (March 2009) concerning the bioethics law re-examination entitled "ABC de la bioéthique", with 10 articles dedicated to research on embryos.

In other words, the newspapers exhibited different editorial choices and despite the diversity of expressed opinions, their press coverage was not representative of that diversity. This phenomenon has been shown for other socioscientific controversies as well, such as that surrounding genetically modified organisms (Babou & Le Marec, 2010; Charaudeau, 2008).

For a more detailed qualitative analysis of the media discourses, I selected the 17 articles focusing on the hESC theme of the French bioethics law revision.

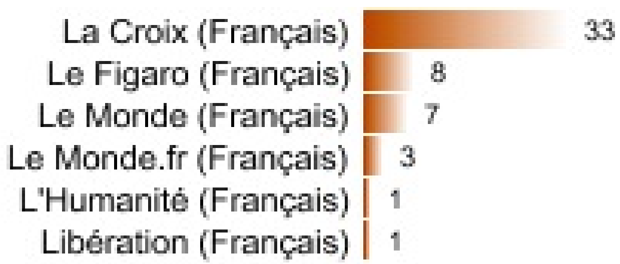

Figure 1
Number of articles containing the keywords stem cell and embryo for each French newspaper from the 1st of January to the 1st of August, 2009 (Factiva)

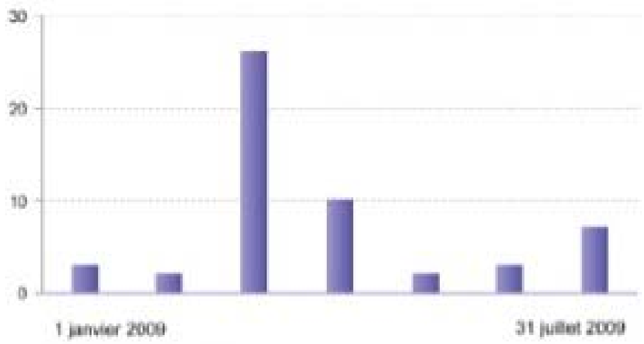

Figure 2
Number of articles containing the keywords stem cell and embryo. Monthly calendar from the 1st of January to the 1st of August, 2009 for all six newspapers considered (Factiva)

Concerning *La Croix*'s special series "ABC de la bioethique" (10 articles), the major frames of questioning were, in order of occurrence: ethical (6), judicial (5) and scientific (1). A generalist or specialist journalist wrote the great majority of the articles. Only one article consisted of an interview of a researcher working on human umbilical cord stem cells, and a philosopher wrote one other article. The types of texts were in majority points of view (persuasive argumentation) but also analytical-commentaries.

The argumentative strategies were based on:

- the frames of questioning, being the choice between types of hESC research that are free of ethical problems (adult stem cells or induced pluripotent cell research). Another question was "*Is it possible to destroy life in order to regenerate life?*" (researcher's interview).
- a clear and explicit point of view to maintain the ban on embryo research, even if the *La Croix* special series presented arguments of other churches agreeing on the uses of hESC (Islam: therapeutic perspectives; Protestant: no consensus concerning supernumerary embryos; Jewish: embryos are considered only in the context of the parental project), and other national contexts (USA, Germany).
- the appeal to knowledge of "belief" from the value domain of ethics: *"the dignity due to a person from the beginning of life*" (extracted from the Instruction *Dignitas Personae*, 2008).

Thus, the used social and moral norms were made explicit and, similarly, scientific norms and definition of the embryo were also made explicit (zygote, morula, blastocyst from 5 to 7 days, embryo from 8 days to 8 weeks, foetus thereafter).

Concerning the other articles, the main frames of questioning were also ethical and judicial. However the authors were more diversified: a specialising journalist (*Le Monde*), a philosopher and a researcher (*Libération*), a generalist journalist and an archibishop (*La Croix,* outside of the special series). The types of texts were more often analytical-commentaries. For example, the article from *Le Monde* introduced the different points of view of several social players. The journalist made explicit the choice of law evolution between continuation of the ban on embryo research with exemptions and authorization with restricted conditions.

At the opposite end of the spectrum, the article from *Libération* was a point of view signed by a researcher, J. Testart, who asserted his strong disagreement with research on embryos. Qualifying the scientists as "conquistadors of the embryo", this researcher based his argument on the eugenics risks, the insufficient therapeutic perspectives and the alternative possibilities.

However, in those two main articles (from *Le Monde* and *Libération*), the scientific and social norms were not made explicit, whereas they were made explicit in the *La Croix* articles: an archbishop referred to human embryo destruction as an ethical transgression due to its human/divine nature and several researchers' negative points of view, particularly those of Pr Mattei's, were mentioned.

7. Conclusions and educational implications

This study of social communication in the domain of biological science pinpoints several aspects of the social discourses produced on a controversial SSI. In particular, its conclusions could help science educators deal with meetings with experts and/or use of the media when analysing a SSI with the students.

First, it was of pedagogical interest to analyse a SSI that has been controversial for a long time (nearly 20 years for hESCs) because: 1) the legitimacy of the players change with time, 2) the arguments evolve and 3) the discourse of a given player can change with the dynamics of the controversy. It is necessary to take into account the advertising or confinement movements of the controversy. It is also necessary to help students develop critical thinking, based on critical rationality. In this way, the school can be the place where students challenge their capacity of having a hold on reality (Jiménez-Aleixandre, Agraso, & Eirexas, 2004). In my opinion, constructing scientific citizens means that students will be able to be the social players in future controversial SSIs.

Second, the media coverage of a controversial SSI was a relevant pedagogical material because it presented contradictory discourses. Moreover, the media is the major source of science information for adults in everyday life. We noted that the media coverage did not reflect the diversity of opinions expressed within the public space. This is because national general interest press groups have their own editorial policies and interests. So it appears necessary to supplement an “internal” media coverage analysis with other sources, in order to respect a pluralism of opinions. Educators can diversify the sources of information, for example, using students’ free exploration of the Web content. I think that the analytical frame developed in science communication research (Williams, Kitzinger, & Henderson, 2003) is relevant to selecting a diverse media corpus for students.

Finally, when possible, I encourage educators to organize meetings in which students can consult scientific experts. The scientists express a diversity of points of view, and we showed in a previous study (Molinatti et al., 2010) that they are able to deal with unstable knowledge and to explain the nature of science (paradigms of their field of research, limits of validity, functioning of the peer community…). But we also noted that scientific and social norms are not always made explicit in the researchers’ discourses, meaning that the value given to a fact or to an object is not clearly explained and is dependent on the context of the scientist’s speech. In the informal educational context, the researchers chose to adopt a posture of neutrality, which they explained by “fear of” influencing young students. In contrast, they made their norms explicit in the public debates.

From that point of view, churches’ discourses are interesting to analyse with the students, to explicate what a social norm is and what norms are involved in the debates. Concerning hESCs, the Catholic church's position was interesting because the dogma was very stable. But in the interest of secularism, it appears necessary to analyse the debate within the other religions.

The analysis of the discourses produced by various social players on a given controversy could help science educators clarify the implicit scientific and social norms involved in the debates, their dynamics and interplay. This should help them conduct a reflexive work on their own norms, and assist students in challenging their own norms when debating a SSI, limiting the risk of influence.

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18

THE REASONED ARGUMENTS OF A GROUP OF FUTURE BIOTECHNOLOGY TECHNICIANS ON A CONTROVERSIAL SOCIO-SCIENTIFIC ISSUE: HUMAN GENE THERAPY

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Abstract

We explored the reasoning behind the stances taken by 19- to 21-year-old students in training at a biotechnology institute on the unsettled and controversial issue of feasibility and acceptability of human gene therapy. We organised debates in the class, punctuated by phases of epistemological "disturbances", during which we set up small discussion groups. We used a variety of resources and authentic gene-therapy cases combining gene therapy already undertaken and in progress. We also reconsidered Crick's model based on recent results in molecular genetics and genomics. By using authentic examples, the students were faced with a real picture of scientific practices in the knowledge-building phase and with the limits of this knowledge when applied to problem-solving. We used two analytical tools: Gauthier's (2005) categorisation to measure the intensity of the argumentation and determine its origins, and Habermas's (1987) theory of communicative action to identify the different types of action used by the students.

The presentation of texts on failed gene therapy stimulated critical analysis, and engaged the students in evaluating empirical evidence by mobilising current data in the field of molecular biology which challenges Crick's dogma.

Keywords: socioscientific issue; gene therapy; debate; argumentation; communicative action

1. Theoretical background

Generally speaking, the teaching of socioscientific issues (SSIs) aims at enabling students to identify, assess and form a reasoned opinion on a complex problem. We share the view with several other authors (Sadler, 2004; Simonneaux, 2010; Zeidler et al., 2002) that tools must be provided to help students master the SSIs which model their present-day world, even more so when that which is being taught is linked to their future profession. As Simonneaux (2010) points out *"each pupil is or will be faced with taking decisions on CSSIs, school must prepare them for this"* (p. 81). The challenge is thus *"to train individuals in research methods, their applications and potential impact and to develop their ability to participate in debates and to make reasoned decisions when the facts are uncertain"* (Simonneaux, 2003, p. 189).

It is therefore important to empower students to handle their choices and actions concerning the use of genetic technology in human gene therapy. This is, more specifically, a question of encouraging data interpretation, and evaluations of empirical evidence and of what the experts say. In the eyes of Lewis and Leach (2006), effective preparation for students' future involvement in SSIs can be achieved by developing explicit teaching of the nature of science. This allows them to see how scientific facts are accepted and understand the limits of science. Kolstø (2001) claims that what students lack is sufficient knowledge of scientific institutions. That author recommends placing more weight on providing more detailed background information. Along the same lines, Bingle and Gaskell (1994) suggest studying the context in which scientific knowledge is built (source of finance, personal prestige, etc.). Larochelle and Désautels (2006) think it is important to introduce students to the strategy of technosciences and to construct knowledge in multireferential situations.

In this study, we target student participation in evaluating technologies using a democratic style of expertise and authentic contexts, as emphasised by Kolstø 2001 or as Simonneaux (2010) suggests *"encouraging cognitive democracy and the examination of how information and expertise is evaluated. To develop participation in debates and the students' ability to produce a line of argument*" (p. 83). The challenge is to help students understand the temporary nature of empirical evidence and the uncertainties which are characteristic of what science produces, to develop their critical rationality (Jiménez-Aleixandre, 2006; Simonneaux & Simonneaux, 2009).

In this work and in light of our analyses, we attempt to answer the following questions: Do authentic contexts encourage students to become more involved in evaluating empirical evidence and what the experts say? Do authentic contexts improve students' reasoning?

2. Analytical frameworks

We use Gauthier's and Habermas's analytical frameworks. Gauthier (2005) defines argument *"as the articulation of a proposition and its justification"* (p. 132). According to this definition, argumentation amounts to presenting a certain point of view and justifying it. An opinion, on the other hand, is a proposition which is put forward without any justification. We chose Gauthier's definitions of argument and opinion because of their operative nature: they enable us to pinpoint the arguments in what the students say, by differentiating them from other discursive functions and from opinion. We previously completed this type of analysis with a finer study of modalisation (Chouchane & Simonneaux, 2009).

Habermas (1987) defines four types of action: strategic, normatively regulated, dramaturgical and communicative. Strategic action is a model of teleological action in which each participant calculates the ends and means to success, by anticipating the decisions which will be taken by the other participants, who are also pursuing their own goals. In this case the participants refer only to the objective world. Normatively regulated action is a system of rationality in which a group of individuals pursue common values and thus conform to a social norm, to the objective world and to the social world. Dramaturgical action is a system of rationality in which each participant presents his/her own intentions, thoughts, attitudes, desires and feelings; the player refers solely to the subjective world. Generally, the speaker is trying to affect the other person on an emotional level. Communicative action is the only sociological system of rationality that refers to all three worlds: objective, social and subjective. It takes the form of an interactive activity oriented towards reaching an understanding and is designed to coordinate the actions between participants. Based on Habermas's definitions, we used three criteria to identify these different types of action in the students' discourse: the type of rational behaviour, the communication aim and the reasoning model.

Table 1
Criteria to determine the different types of action identified by Habermas (1987)

	Comparison criteria		
Types of action	**Rational Behaviour**	**Communication aim**	**Reasoning model**
Strategic action	The student bases his/her assertions on the evidence. Claims of validity refer to the objective world: the logic of the proposition and/or the empirical effectiveness.	To achieve an objective and convince someone else	The student calculates the ends and the means involved in achieving his/her own goals, tries to anticipate the decisions of the other players and tries to influence them.
Normatively regulated	Actions are based on the values of the social group (norms internal and external to the group).	To quote and give grounds for the norms	The students attempt to impose a decision legitimated by the norms.
Dramaturgical	Actions are based on appealing to the feelings of the other person.	To gain support via emotions	The students use the affective to win support.
Communicative	Claims to validity refer to the objective (real) world, the social world (norms which are fair) and the subjective world (sincere subjective experiences). The student orients his/her actions in relation to the criteria of validity recognised intersubjectively.	To reach a goal and a mutual understanding	The students attempt to coordinate their actions by means of a common agreement which begins with the negotiation of their mutual interpretations.

3. Implementing the didactic strategy

To answer our questions, we organised reasoned debates punctuated by phases of epistemological "disturbances". In published writings, debate is accorded a predominant role in the treatment of controversial scientific issues. However, in our mind, the organisation of didactic games dealing with the question of confronting evidence and contradictory results seems appropriate. This should favour the epistemological disturbance and fuel the epistemic questioning because as Simonneaux and Simonneaux (2008) point out, *"this epistemic questioning is not automatically present in a debate"* (p. 2). We used five didactic situations combining debate and epistemological disturbances: 1) Ali's recovery thanks to gene therapy, 2) Jesse's death after undergoing gene therapy, 3) a strategy which challenges Crick's dogma, 4) the first recovery for the "bubble children" using gene therapy, and 5) gene therapies against cancer.

3.1 Presentation of the different situations

During the first situation, we presented a fictional scenario concerning a socioscientific controversy: Ali is suffering from a serious genetic disorder which obliges him to follow a very strict diet. A doctor proposes gene therapy treatment to cure him permanently of his condition. The parents are uncertain and decide to ask friends for a second opinion. This situation is followed up with a question which presents the issue to be debated. *Will the* *parents accept gene therapy treatment for their son? Why?* We asked the students, who had not yet been given any information, to explain where they stood on the issue. This was the first phase of the debate. The dilemma facing Ali's parents was the underlying theme of the whole strategy. The students discussed this dilemma during each situation.

In situations 2, 4 and 5, the students analysed texts describing authentic examples of gene therapies (the case of Jesse and the "bubble" children). The analysis focused on the conditions under which the clinical trials were carried out: the scientific aspects (characteristics of the disorder, types of vectors used, therapeutic approaches, scientific procedures, etc.), the economic factors (the laboratories and companies involved, the investors, conflicting interests, etc.), the ethical aspects (notion of informed consent, best clinical practices, etc.), and socio-epistemological factors (the nature of the sciences, information about the scientists, the epistemic nature of scientific proof, scientists' integrity, etc.). Situation 3 was dedicated to calling Crick's dogma (DNA→ mRNA→ protein) into question.

During situations 2, 4 and 5, each student studied texts or summaries of articles, which were accompanied by questions. At the end of each situation, the moderator launched a collective debate on the case studied in the text along with the dilemma facing Ali's parents.

Table 2 summarises situations 2, 4 and 5.

Table 2
The didactic strategy

Situations	Instructions or questions accompanying the texts	Epistemological disturbance targeted
Situation 2	Identify the nature of Jesse's illness. What form does the therapeutic approach to Jesse's condition take (the vector used, the gene used, where it is expressed, at what level it is expressed, the expected therapeutic effect)? What are the causes of Jesse's death? Does scientific knowledge lead to the success of this therapeutic trial? What is informed consent? What are the researchers' motives for conducting a clinical trial? Examine the nature of the relationships between the different players involved in a clinical trial concerning gene therapy. Are there any conflicts of interest involved in carrying out this clinical trial?	1. The image of the scientist: (conflicts of interest, motivation, credibility) 2. The context in which scientific knowledge is produced: the influence of society on science (problems of funding) 3. The influence of the researcher 4. The scientific method, the limits of the scientific enterprise and the notion of uncertainty
Debate on Jesse's case and on the dilemma facing Ali's parents		
Situation 3: Calling Crick's dogma into question		
Situation 4a	Identify the characteristics of the "bubble children's" disorder. What causes this disorder? What form does the therapeutic approach actually take in this case (the vector used, the gene used, where it is expressed, at what level it is expressed, the expected therapeutic effect)? To what do you attribute the success of this gene therapy?	5. The nature of knowledge: -the didactic games set up in situations 4a, 4b and 4c present the construction of scientific knowledge as a dynamic phenomenon -knowledge is temporal and relative; it is constantly evolving -the limits of models -the limits of empirical evidence

		-the notion of choice of experimental procedure and varying experimental conditions -the scientist does not work alone in the laboratory: the role of the bodies controlling scientific activity
Debate on the bubble children's recovery and on Ali's case		
Situation 4b	What happened to the two children? What name did researchers give to this complication? What is the cause of this complication? Can the cause be attributed to the therapeutic approach? Is there a conflict of interest in this case? Why did the AFSSAPS discontinue the therapeutic trials for this disorder? Which two hypotheses were put forward by researchers to reduce the risk of this complication and restart the protocol with other sick children?	Idem 4a
Debate on the fact that the two children developed leukaemia and on Ali's case		
Situation 4c	How old was the child treated by gene therapy, after trials were restarted? Have the two hypotheses put forward by the researchers been confirmed? Has the risk been reduced? What is the cause of this risk?	Idem 4a
Debate on the third case of leukaemia and on Ali's case		
Situation 5	Which therapeutic approaches are used? What is the aim of each approach? What are the characteristics of these approaches (types of vector, types of gene, where expressed and duration of the expression)?	6. The plurality of scientific methods Scientific knowledge construction is a process of transformation and complexification
Debate on transgenic cancer therapy and on Ali's case		

All of the exchanges were audio- or video-recorded and transcribed.

The arguments and opinions contained within the students' production were located using a two-stage procedure naturally resulting from Gauthier's (2005) definitions. In the first stage, we picked out all of the propositions expressed during the different phases of the debate, i.e. all of the instances in which a point of view is put forward. In the second stage, we determined whether or not each of these propositions is backed up by one or more justifications. The sets of proposition/justification(s) constitutes the arguments, and the solitary propositions, the opinions.

The discourse analysis of students' discussions, based on Habermas (1987), tries to identify specific indicators for each type of act (see Table 1). We followed the discourse dynamics to identify forms of repetition, transformation of proposals by students, evidence of full or partial agreement and signs of mutual understanding or protest. We also determined the type of information used by the students (scientific knowledge, practical experience related to the living world) and the mobilization of a common reference world (norms, values, affect). The search for the combination of these types of knowledge and reference worlds in the students' speech allowed us to determine the model of reasoning characterizing each type of action whose objective may be: to influence the other, to touch the other in an affective way, to carry membership or to reach a mutual agreement.

4. Results

Gauthier's categorisation enabled us to differentiate between opinions and arguments in the students' discourse and to measure the intensity of the argumentation. During the first situation, a large number of the students' propositions were opinions (21/44), and the arguments had only one justification. In their reasoned response, most students (15/21) declared themselves in favour of the use of gene transfer technology to cure Ali's disorder. Their justifications were based on Crick's dogma, faith in science and in scientists. These types of justification, illustrated in Table 3, demonstrate the significance of the empiricist perspective which informs the students' points of view on the use of genetic technology. During situations 2, 4 and 5, we observed very frequent changes in students' stances: 19/21 students changed their minds–two of them changed five times, seven of them four times and three of them three times. This demonstrates the impact of the didactic strategy on students' opinions. By monitoring the stances during all situations we were able to define five different profiles: *totally favourable* (1/21), *generally favourable* (4/21), *generally unfavourable* (1/21), *totally unsettled* (2/21) *and unsettled* (11/21). We notice that the *unsettled* profile was the dominant one.

Table 3
Examples of justifications based on the confidence certain students have in scientists and in Crick's dogma

Line	Discourse	Type of justification
60.	E3: the parents should accept the treatment of their child by gene therapy because *researchers today are able to cure this disorder*	Confidence in scientists
62.	E13: I think that scientists can cure the child *because they have the means to do so*	
64.	E15: from a scientific point of view, it has been demonstrated that *by changing the gene, one obtains a functional protein*	Gene-protein link: Crick's dogma
108.	E3: *the gene controls protein synthesis via mRNA* so it's true that the functional gene will cure Ali's genetic disorder	

We also observed that the students' argumentation was based on their scientific knowledge and empirical data taken from the texts and the article summaries analysed. They used mostly two, rarely three, justifications. We found that very few students stuck to Crick's dogma in their line of argument during situations 4 (2 students) and 5 (3 students). Note that during situation 1, Crick's dogma was widely called upon (9 students) to justify the feasibility of the gene therapies. This change may be explained by the strategy of challenging Crick's dogma. Furthermore, we noted that certain students drew on current data in molecular biology to justify their reasoning. As an example, E13 and E18 referred to the complexity of gene regulation to justify their points of view, others (E2, E7, E11 and E16) mentioned the role of introns in gene regulation. E5 and E19 highlighted the importance of interaction between genes. Finally, E16 added the idea of possible multi-gene control of tumoral cells.

Certain students' discourses showed systemic reasoning of gene therapy. These students realised the difficulty involved in successful human gene therapy. They emphasised the uncertainties (E2, E13, E16, E19). Others identified the need for further research (E13, E16, E18). We also noticed that nine students (E1, E2, E6, E8, E10, E11, E16, E18, E19) were sceptical about the information presented to patients by the researchers. In Jesse's case, six students (E1, E2, E6, E8, E11, E19) explicitly or implicitly contested the very integrity of the researchers (example 1); others (E12, E14, E16, E20) questioned the validity of the expertise (example 2). Finally, five students (E2, E6, E7, E9, E19) considered the researchers' interests (concerning their scientific, personal economic prestige) in carrying out a clinical trial (example 3). We also saw that in certain cases, the same empirical evidence could be assessed differently by different students (example 4).

To evaluate the intensity of the argumentation during a debate, we determined the $\frac{Arguments}{Opinions}$ ratio. The values–1.09, 1.65, 2.67 and 2.79 for situations 1, 2, 4 and 5, respectively–showed that the intensity of the argument increases progressively from one situation to the next.

We used Habermas's (1987) theory to identify the four types of action in the students' discourse. They were firstly strategic, then normatively regulated, dramaturgical and finally communicative. In all of the didactic situations, forms of communicative action were used the least, forms of strategic action the most. However, during situation 5, the students' discourse is more in line with communicative action than in the other situations. Table 5 offers a comparison between the different types of action identified by Habermas and some extracts from the analysed discourse corresponding to these types of action.

Table 4

Students' excerpts

Example	Line Discourse
Example 1 (situation 2)	126. E6: according to Jesse's parents the risks were played down 127. E11: the advantages for Jesse are exaggerated 132. E2: the researchers hid other information, the same vector caused the death of two monkeys 145. E1: no it's dishonest, Jesse's illness is only part of it. If his father has all this information I don't think he will agree to the treatment
Example 2 (situation 4b)	40. E16: I think, when testing the effectiveness of a protocol, it's impossible to reproduce all the aspects of a human disorder in mice and the fact that the two small children developed cancer is proof of this
Example 3 (situation 2)	163. E6: no there's not the whole story. The researchers might be motivated by the desire to make a name for themselves. I agree with Jesse's father 165. E19: I believe personal circumstances may also play a part. A researcher could have someone in his family who is suffering from the same disorder, his son for instance. So he will try anything in an attempt to find a solution for his son 168. E7: in Jesse's case it's the money. The person in charge of this therapy is the founder and director of the hospital, and at the same time a scientific consultant for a company who pays money to carry out these therapies
Example 4 (situation 5)	110. E13: I think it could be a cure for cancer because in the text it says that the tumours regressed in size after treatment in mice 112. E15: no the tumour is not completely eradicated

Table 5
Illustrations of types of action in the discourse

Type of action	Illustration	Description
Strategic	E13: I don't think it's reasonable to interrupt this type of treatment because it is a new treatment. There are risks involved as with all other treatments so, researchers should be given time to reduce these risks as much as possible. With Pasteur there were risks and with kidney transplants too. E16: I agree with you. Gene therapy has saved 9 out of 11 children. There are huge advantages, especially in the case of an incurable disease. We mustn't stop there because it could be a solution for other genetic disorders.	To convince the participants that halting gene therapy trials is irrational, E13 puts gene therapies into the context of new therapeutic specialities which are still in the experimental phase and therefore susceptible to a confrontation with hazards of this sort. To justify the merits of continuing the trials, he bases his argument on therapeutic history, in particular the works of Pasteur and kidney transplants which were not accomplished without taking risks.
Communica-tive	E16: do the researchers have any idea of the risk of insertional mutagenesis? E11: I think insertional mutagenesis is known to the researchers but the risk was very low in mice and had only been observed once. E9: according to the text, insertional mutagenesis had never been observed either in experiments on mice or in other clinical trials using retroviruses. E12: I think experiments need to be carried out on animals which are physiologically similar to humans because the mice didn't allow the researchers to prevent the insertional mutagenesis.	The extract begins with a request for information. Afterwards we observe an exchange based on the knowledge of each of the students with the aim of gaining a mutual understanding in order to predict the risk of this phenomenon. E12 proposes a solution to achieve this.
Normatively regulated	E16: in principle, a therapy should only be envisaged for Ali if the results on animals prove satisfactory. E2: experiments should be carried out on dogs and monkeys before moving on to man. E6: yes we must be certain that gene therapy works on large animals.	Experimentation on animals, to justify the validity of a therapeutic protocol, is a norm shared by most biotechnology students. This common value could be an ethical norm. Indeed, other work in the Tunisian context (Kacem & Simonneaux, 2007) has shown that animal experimentation is ethically acceptable. Both authors have demonstrated that students holding the CAPES teaching diploma in biology accept the use of oncogenic mice in medical biotechnological applications.

Type of action	Illustration	Description
Dramaturgical	E12: in my opinion, acting on genes using retroviruses is a form of transgression. It's obvious, even if you are sure of the technique, the risks are immeasurable. Just look at Jesse's case and the cancers developed by those three poor little children. E3: yes unfortunately the little ones were unlucky. E4: if the poor children leave their bubble to undergo chemotherapy, we can be really anxious about their future. That's why I think the right decision is to stop the treatment.	Dramaturgical argumentation tries to affect the other person's feelings as E12 illustrates. In his discourse, E12 denounces an act of violence (a "transgression") and he wants to denounce the injustice using the qualifier "poor". The utterance stirs up feelings and introduces emotion into rationality. The expression "poor little children" doesn't state indignation but aims at arousing it in the other students. In the same way, E4 uses his discourse to generate feelings and tries to emotionally affect the person he's talking to.

5. Conclusion

The fictional scenario presented at the beginning of the didactic strategy showed that most of the students were in favour of gene therapy. Analysis of their argumentation demonstrates the significance of empirico-realist epistemology. This epistemology does not enable the students to address the inevitable uncertainties and risks which underlie the application of this technology on humans, nor does it help them to adequately factor in the current socio-technical risk. The fictional scenario did not appear to be conducive to the problematisation of the controversy surrounding the use of this genetic technology. However, it did motivate and encourage the students to question some concepts and notions connected to gene therapies.

The authentic contexts, presented in the texts, stirred up the debate. We observed very frequent changes in the students' stances during situations 2, 4 and 5: 19/21 students changed their minds at least once; 11/21 were unsettled. Scientific evidence (success or failure of gene therapy) seems to be the key factor enabling students to take a stance on an issue. It appears that the focus of most of the students on the results of gene therapy trials (Jesse's case, the case of the bubble children, the onset of leukaemia) reinforced their search for scientific evidence. The students seemed to be confined to an empirico-realist repertoire which obliged them to use scientific evidence to back up their positions. In situations 2, 4b and 4c, the students were faced with the failure of gene therapy and this really encouraged them to get involved in the debate. It was particularly during these situations that the students submitted, to a much greater extent, the empirical evidence to verification, evaluation and criticism. They used current data in the field of molecular biology (the role of introns, the complexity of interaction between genes, multi-gene control, etc.) to strengthen their assessments. This could be the impact of the strategy of challenging Crick's dogma and introducing epistemological disturbances.

These situations encouraged recognition of the complexity inherent in successful gene therapy, a consideration of the issue from multiple perspectives (scientific, ethical, social and economic), an understanding that gene therapy experiments are on the research front. We observed, in the situation involving Jesse, that some students adopted a sceptical attitude when confronted with information on gene therapies. In situations 4b and 4c, characterised by the appearance of cases of leukaemia and the death of a child treated by gene transfer, some students focused on the emotional dimension. This idea is similar to that put forward by

Simonneaux and Simonneaux (2008) in their work on the effectiveness of authentic contexts in the treatment of SSIs: *"context reintroduces affective and axiological dimensions into the learning process; these dimensions can act as a support or become a barrier to learning"* (p. 17). In our research, we found that leukaemia and a child's death increased the intensity of the controversy; concerning this, Simonneaux and Simonneaux (2008) indicated that *"a strong social controversy surrounding the question may block or distort the reasoning and therefore prevent access to the scientific dimension of the issue"* (p. 17).

Regarding the arguments, we observed that the intensity of the argumentation and the number of justifications increased progressively from situation to situation. The use of authentic contexts seems to be a means of intensifying argumentation. We therefore concur with other works' reflections on the importance of authenticity of the SSIs in encouraging students to deepen their arguments (Jiménez-Aleixandre, 2006; Kolstø, 2004; Simonneaux & Simonneaux, 2009). In those studies, dealing with environmental issues, elements of contextualization allowed students to consider the practical significance of the discussed problems. Contextualization and anchoring in reality gave more meaning to scientific knowledge. Students in authentic contextualized situations feel more invested in a collective reflection on more concrete issues. Our results regarding the effect of authentic contextualization on the argument agree in part with those of Molinatti (2007) who, in a study on cellular therapies with bioethical implications, examined the impact of students consulting a representative of patients and a scientist. He showed that this contextualisation of the debates impacted a greater variety of arguments, in particular on scientific uncertainties and risks to patients. The students' concern for patients here and in Molinatti's research related to the discovery of treatment failures and permitted development of individuals' questioning and argumentation. Our study therefore confirms the importance of presenting issues in a socioscientific context, especially when authenticity is about epistemological disturbances, to renew students' images of science, scientists and scientific activity. Our study also shows the limits of using a fictitious situation.

The analysis according to Habermas's (1987) categorisation demonstrated the students' use of different types of action. Strategic action was dominant at the beginning of the experiment, but more in line with communicative action in situation 5. To what extent do the proposed didactic games encourage critical thinking? We consider it impossible to evaluate this in the short term. However, the use of communicative action in situation 5 hints at the interest of the teaching strategy employed.

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Section 5

Students' conceptions and conceptual change: Focus on evolution

19 SITUATIONAL INTEREST IN EVOLUTIONARY TOPICS, CONTEXTS AND ACTIVITIES

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Abstract

Situational interest is defined as a short-lived and context-dependent subject-object relationship. Thus, situational interest is different from personal interest, which is stable and content-specific. We investigated which recent evolutionary topics, contexts and activities meet students' situational interest: 740 students from grades 9 to 13 were asked to rate their level of interest using a 4-point rating scale. Taking into account that situational interest depends upon the context in which the topic is placed, and the activity that the students are asked to perform, we developed items by systematically combining evolutionary topics with contexts and activities. Students showed the highest situational interest in evolutionary phenomena that relate to humans (evolution of HIV, avian flu, antibiotic resistance, lactose tolerance and adaptation to high altitudes). On the other hand, situational interest in activities proved largely independent of the topic investigated–with watching films and doing computer simulations as the students' favourite activities. The situational interest in contexts varied with the topic.

Keywords: situational interest; evolution; context; activity

1. Theoretical background

From a theoretical perspective, one can distinguish between two kinds of interest: personal and situational (Krapp, Hidi, & Renninger, 1992). Personal interest is defined as a long-term subject-object relationship: it is stable, content-specific and develops over a long period of time during which a person constantly and consistently interacts with the object of interest (Schiefele, 1999). Situational interest, on the other hand, is often spontaneous, depends upon the context, emerges in response to the features of the environment and precedes the development of personal interest (Krapp et al., 1992). Mitchell (1993) considers interest a multi-faceted construct and distinguishes between capturing and holding a person's interest. According to Krapp (2002, 2003), the transition from capturing to holding is predicated upon whether or not the learning environment makes the content meaningful, personally relevant and emotionally satisfying. Thus, research into situational interest has focused on the features of the learning environment (e.g., Schraw, Flowerday, & Leman, 2001), but also on the specific context in which the content is placed, as well as on the specific activities the students are allowed to engage in (Häußler, 1985; Häußler & Hoffmann, 1998).

Summarizing these approaches, Krapp and Prenzel (2011) differentiate between three main dimensions of interest: interest in a particular topic, interest in a particular context in which a topic is presented, and interest in the particular activity a student is allowed to engage in, in conjunction with the topic. They also point out that in the PISA study interest in scientific topics was measured in combination with the contexts in which the topics were placed (embedded items).

The design of a study by Häußler (1985) and Häußler and Hoffmann (1998)–assessing situational interest by using a questionnaire in which students are asked to rate their interest in different topics placed in different contexts and combined with different activities–was successfully transferred from physics education to biology education (Bayrhuber et al., 2003). In the study presented here, the format of that questionnaire, i.e. topics placed in different contexts and topics combined with different activities, was used to assess situational interest in evolutionary topics. Our aim was to give teachers guidance for designing interesting learning environments in evolutionary biology. In particular, we investigated the students' situational interest in eight evolutionary phenomena, which were chosen because they are topical, and recent research has provided enough information to teach the examples in the classroom. We also selected eight contexts which allow for different perspectives on the topic, to determine which topic-context combinations are perceived as interesting by the students. In addition, we investigated the situational interest of eight typical classroom activities, which provide different possibilities for engaging students with the topic.

2. Research questions

- Which evolutionary topics, contexts and activities are perceived as interesting by students (situational interest)?
- Which topic-context combinations and which topic-activity combinations are perceived as interesting by students (situational interest)?

3. Research design and method

3.1 Description of the questionnaire

Rating scales are most commonly used to assess situational interest (Krapp & Prenzel, 2011). Alternatively, situational interest can be measured by asking students to formulate questions, which can be clustered and analysed as an indicator of their interest (e.g., Baram-Tsabasi & Yarden, 2009). Building on Häußler (1985) and Krapp and Prenzel (2011), we developed a multi-dimensional questionnaire to assess students' interest in evolutionary topics, contexts and activities. The questionnaire consisted of 123 items.

The questionnaire was organized in two parts. The first contained eight sections devoted to eight evolutionary topics (Table 1). Each of these sections began with a short stimulus text, introducing the topic. Then the students were asked to indicate their interest in the specific topic by rating the eight items, systematically combining each of the eight evolutionary topics with eight contexts (Tables 1, 2). However, due to inner constraints, it was impossible to formulate items for five topic-context combinations, i.e., T1xC8, T7xC8, T8xC8, T7xC3 and T8xC3.

The second part of the questionnaire consisted of eight sections devoted to different activities, (Table 1). For each of the activities, we asked the students to indicate their interest in specific topic-activity combinations. As in the first part of the questionnaire, the topics were systematically combined with the eight activities. In contrast to part one, however, the groups of items were organized by activity (Table 3).

Table 1
Evolutionary topics, contexts and activities included in the study

Topics	Contexts	Activities
T1 Evolution of HIV	C1 History of the evolutionary phenomenon	A1 Doing a computer simulation
T2 Evolution of the avian flu virus	C2 Impact on humans	A2 Watching an interview with a scientist
T3 Evolution of antibiotic resistance in bacteria	C3 Responsibility of humans	A3 Engaging in a discussion with classmates
T4 Evolutionary impact of trophy hunting on elephants	C4 Causes of the evolutionary phenomenon	A4 Doing internet research and presenting the findings
T5 Evolutionary impact of trophy hunting on bighorn sheep	C5 Application of knowledge about the evolutionary phenomenon in medicine and science	A5 working with scientific texts
T6 Evolutionary impact of size-selective harvesting on cod	C6 Methods of scientific inquiry	A6 Watching a film
T7 Evolution of lactose tolerance in humans	C7 Actions of individuals in response to the phenomenon	A7 Analysing authentic data
T8 Evolution of the ability in humans to live at high altitudes	C8 Impact on the environment	A8 Making comparisons

In both parts, the participants were instructed to rate their level of interest in each item using a 4-point rating scale (4=very high interest; 1=no interest).

Table 2
Sample items for the topic ‘Evolution of the avian flu virus’ (T2) combined with eight contexts (C1-C8)

Topic-context combination	Item Item-stem: I would like to find out more about…
T2xC1	…how long the H5N1 virus has been around and when it succeeded in crossing the species barrier between birds and humans.
T2xC2	…what the consequences of an outbreak of avian flu among humans would be like.
T2xC3	…what responsibility humans have for spreading the disease, for example, by keeping birds on farms.
T2xC4	…why the virus is able to change so rapidly.
T2xC5	…how the knowledge about the virus is used in order to develop vaccinations and medications.
T2xC6	…how scientists proceed to find out about changes in the virus and how they keep an eye on the virus crossing the border to other species.
T2xC7	…what I can do in order to protect myself against the virus.
T2xC8	…what the consequences for the environment would look like if the virus crossed the border to other species.

Table 3
Sample items for the activity 'Engaging in a discussion with classmates' (A3) combined with eight evolutionary topics (T1-T8)

Topic-activity combination	Item Item-stem: I would like to engage in a discussion with my classmates about...
A3xT1	...the influence of HIV on people's lives.
A3xT2	...the influence of the avian flu virus on people's lives.
A3xT3	...the influence of antibiotic resistance in bacteria on people's lives.
A3xT4	...the influence of humans on changes in elephants' tusks.
A3xT5	...the influence of humans on changes in the horns of bighorn sheep.
A3xT6	...the influence of humans on changes in cod body size.
A3xT7	...the selection pressure on humans, when they developed the ability to digest lactose.
A3xT8	...the selection pressure on humans, when they developed the ability to live at high altitudes.

3.2 Description of the sample

A total of 740 students took part in this study. The sample consisted of 417 students from grades 9-10 (female: 192, male: 224, gender not given: 1; average age: 15 years) and 323 students from grades 11-13 (female: 204, male: 117, gender not given: 2; average age: 18 years). The study was conducted in two states of Germany, North-Rhine-Westphalia and Lower Saxony.

3.3 Description of the statistical analyses

We calculated means (M) and standard deviations (SD) to describe the students' situational interest. To report on aggregated data, we calculated reliability coefficients (Cronbach's alphas) for the scales "situational interest in evolutionary topics" (calculated across all contexts), "situational interest in evolutionary topics" (calculated across all activities), "situational interest in contexts" (calculated across all topics) and "situational interest in activities" (calculated across all topics). All 32 scales proved reliable with Cronbach's alpha above 0.70. In addition, we tested the significance of differences between males and females and between age groups (grades 9-10 vs. grades 11-13) by t-test.

4. Findings

4.1 Students' situational interest in evolutionary topics

To investigate students' situational interest in evolutionary topics, we calculated mean scores for each evolutionary topic over all topic-context combinations (last row in Table 4). Students showed the highest situational interest in 'evolution of HIV' and 'evolution of the avian flu virus'. Slightly less interesting were 'evolution of antibiotic resistance in bacteria', 'evolution of lactose tolerance in humans' and 'evolution of the ability in humans to live at high altitudes'. Still above average, though slightly less interesting, were 'evolutionary impact of size-selective harvesting on cod' and 'evolutionary impact of trophy hunting on elephants'. The least situational interest was found for 'evolutionary impact of trophy hunting on bighorn sheep' (Table 4).

We used t-tests to compare the means of grades 9-10 and grades 11-13. No significant differences were found for most topics, but significant differences were found for 'evolution of antibiotic resistance in bacteria' (grades 9-10: M 2.80, SD 0.56; grades 11-13, M 2.91, SD 0.55; $p \leq 0.01$) and for 'evolutionary impact of trophy hunting on bighorn sheep' (grades 9-10: M 2.43, SD 0.75; grades 11-13: M 2.32; SD 0.75; $p \leq 0.05$). Additional independent sample t-tests indicated no statistically significant gender differences, except for the topic T8, 'evolution of the ability in humans to live at high altitudes' (male: M 2.77, SD 0.62; female: M 2.67, SD 0.64; $p \leq 0.05$; total sample).

Different results were observed when we calculated mean scores for each evolutionary topic over all topic-activity combinations (last row in Table 5). Interestingly, t-tests revealed that all mean scores for situational interest in evolutionary topics calculated over all activities are significantly lower ($p \leq 0.001$) than the mean scores for situational interest in evolutionary topics calculated over all contexts. The only exception was the mean score for situational interest in the evolution of HIV, where no significant differences were found. In addition, significant differences between the grade groups were found for 'evolution of antibiotic resistance in bacteria' (grades 9-10: M 2.58, SD 0.79; grades 11-13: M 2.70, SD 0.79; $p \leq 0.05$), 'evolutionary impact of trophy hunting on elephants (grades 9-10: M 2.42, SD 0.82; grades 11-13: M 2.22; SD 0.80; $p \leq 0.01$), 'evolutionary impact of trophy hunting on bighorn sheep' (grades 9-10: M 2.10, SD 0.77; grades 11-13: M 1.94; SD 0.75; $p \leq 0.01$), 'evolutionary impact of size-selective harvesting on cod' (grades 9-10: M 2.17, SD 0.79; grades 11-13: M 1.99; SD 0.75; $p \leq 0.01$) and 'evolution of the ability in humans to live at high altitudes' (grades 9-10: M 2.54, SD 0.79; grades 11-13: M 2.39; SD 0.77; $p \leq 0.01$). Independent sample t-tests also indicated statistically significant gender differences for 'evolution of the ability in humans to live at high altitudes' (male: M 2.60, SD 0.75; female: M 2.38, SD 0.80; $p \leq 0.01$; total sample), 'evolutionary impact of trophy hunting on bighorn sheep' (male: M 2.11, SD 0.74; female: M 1.96, SD 0.77; $p \leq 0.01$; total sample) and 'evolutionary impact of size-selective harvesting on cod' (male: M 2.21, SD 0.74; female: M 1.99, SD 0.79; $p \leq 0.01$; total sample).

4.2 Students' situational interest in evolutionary contexts

We also investigated the students' expressed situational interest for the eight contexts. We calculated mean scores for each of the eight evolutionary contexts over all topic-context combinations (last column in Table 4). With respect to contexts, students showed the highest situational interest in 'causes of the evolutionary phenomenon', 'application of knowledge about the evolutionary knowledge in medicine and science' and 'impact of the evolutionary phenomenon on the environment' and 'on humans'. The least situational interest was found for 'methods of scientific inquiry', i.e. the ways in which scientists proceed to find out about a phenomenon. Information on the other contexts can be found in Table 4. Separate analyses were performed for grades 9-10 and grades 11-13, but no significant differences were found. Nor were any significant gender differences found, except for the context 'history of the evolutionary phenomenon' (males: M 2.68, SD 0.65; females: M 2.60, SD 0.53; $p \leq 0.05$; total sample).

4.3 Students' situational interest in activities

To investigate the students' situational interest in activities, we proceeded in analogy to section 4.2 and calculated mean scores per activity over all topic-activity combinations (last column in Table 5). Students signalled the highest situational interest in 'watching a film'.

Table 4

Situational interest in topic-context combinations (total sample, n=740)

Columns: mean scores M, standard deviation *(SD)* and ranking (in brackets) of the situational interest in topic-context combinations in one row. (If two means differ by 0.02 or less, they share the same rank). Last row: mean score M and standard deviation *(SD)* for situational interest in one topic (calculated over all topic-context combinations). Last column: mean score M and standard deviation *(SD)* for situational interest in one context (calculated over all evolutionary topics).

	T1 Evol. of HIV	T2 Evol. of avian flu virus	T3 Evol. of antibiotic resistance in bacteria	T7 Evol. of lactose tole-rance in humans	T8 Evol. of ability in humans to live at high alt.	T6 Evol. impact of size-selective harvest. on cod	T4 Evol. impact of trophy hunting on elephants	T5 Evol. impact of trophy hunting on bighorn sheep	Mean score for situational interest in the context
C4 Causes of the evol. phenom.	3.14 *(.87)* (4)	3.10 *(.88)* (3)	2.89 *(.89)* (3)	3.17 *(.87)* (1)	3.07 *(.90)* (1)	2.77 *(1.00)* (1)	2.88 *(.98)* (1)	2.62 *(1.03)* (1)	2.95 *(.57)* (1)
C5 Appl. of knowl.	3.48 *(.71)* (1)	3.00 *(.87)* (5)	2.91 *(.85)* (3)	2.81 *(.92)* (2)	3.02 *(.90)* (2)	2.66 *(.97)* (3)	2.74 *(1.00)* (3)	2.53 *(1.01)* (2)	2.89 *(.57)* (2)
C8 Impact on environ.	No item	3.14 *(.79)* (2)	2.91 *(.87)* (3)	No item	No item	2.79 *(.97)* (1)	2.79 *(.99)* (2)	2.52 *(1.02)* (2)	2.83 *(.65)* (3)
C2 Impact on humans	3.26 *(.73)* (2)	3.24 *(.79)* (1)	2.99 *(.81)* (1)	2.79 *(.94)* (2)	2.81 *(.89)* (3)	2.61 *(.94)* (5)	2.44 *(.98)* (7)	2.26 *(.96)* (6)	2.80 *(.49)* (4)
C3 Responsi-bility of humans	3.21 *(.77)* (3)	2.95 *(.85)* (6)	2.89 *(.83)* (3)	No item	No item	2.67 *(.94)* (3)	2.59 *(.98)* (4)	2.28 *(.94)* (6)	2.76 *(.56)* (5)
C7 Actions in response to phenom.	3.13 *(.91)* (4)	3.11 *(.87)* (3)	2.98 *(.91)* (1)	2.5 *(.99)* (5)	2.24 *(.99)* (6)	2.47 *(1.00)* (7)	2.54 *(1.03)* (5)	2.31 *(1.01)* (4)	2.66 *(.55)* *(6)*
C1 History of the phenom.	2,89 *(.87)* (7)	2.75 *(.88)* (7)	2.65 *(.84)* (7)	2.69 *(.91)* (4)	2.71 *(.89)* (4)	2.60 *(.93)* (5)	2.53 *(.95)* (5)	2.30 *(.95)* (4)	2.64 *(.56)* (7)

C6 Methods of scientific inquiry	2.96 *(.89)* (6)	2.74 *(.90)* (7)	2.61 *(.90)* (8)	2.53 *(.90)* (5)	2.47 *(.88)* (5)	2.29 *(.91)* (8)	2.32 *(.89)* (8)	2.20 *(.88)* (8)	2.51 *(.59)* (8)
Mean score for situational interest in the topic	3.15 *(.51)* (1)	3.00 *(.57)* (2)	2.85 *(.56)* (3)	2.75 *(.65)* (4)	2.72 *(.63)* (5)	2.61 *(.71)* (6)	2.60 *(.72)* (6)	2.38 *(.75)* (8)	

‘doing a computer simulation’, and ‘making comparisons about evolutionary phenomena’. The least situational interest was found for ’doing/presenting internet research’, and ‘working with texts’ (Table 5). No significant differences were found between the two grade groups, except for situational interest in ‘doing a computer simulation’ (grades 9-10: M 2.70, SD 0.65; grades 11-13: M 2.57, SD 0.72; $p \leq 0.05$) and ‘doing internet research and presenting the findings’ (grades 9-10: M 2.38, SD 0.64; grades 11-13: M 2.20, SD 0.63; $p \leq 0.001$). Independent sample t-tests revealed statistically significant gender differences ‘for doing a computer simulation’ (males M 2.73, SD 0.67; females M 2.57, SD 0.9; $p \leq 0.01$; total sample), ‘watching a film’ (males: M 2.87, SD 0.66; females: M 2.70, SD 0.67; $p \leq 0.01$; total sample) and ‘analysing authentic data’ (males: M 2.59, SD 0.61; females M 2.41, SD 0.64; $p \leq 0.05$; total sample).

4.4 Students' situational interest in topic-context combinations

Here, in contrast to sections 4.1-4.3, we looked at individual items in order to analyse specific topic-context interactions, and ranked the means for situational interest in topic-context combinations per topic for all students (Table 4). Generally, the ranking shifted from topic to topic, as can be seen by comparing the ranking in one column to that in the other columns. For example, 'causes of the evolutionary phenomenon' (C4) is the most interesting context for 'evolution of lactose tolerance' (T7), 'evolution of the ability in humans to live at high altitudes' (T8), 'evolutionary impact of trophy hunting on elephants' (T4) and 'bighorn sheep' (T5), and 'evolutionary impact of size-selective harvesting on cod' (T6). In contrast, the most interesting context for 'evolution of HIV' is 'application of knowledge about the evolutionary phenomenon in medicine and science' (C5), whereas the students signalled the highest interest in 'evolution of the avian flu virus' (T2) in the context 'impact on humans' (C2). For 'evolution of antibiotic resistance in bacteria' (T3), two contexts are perceived as especially interesting, i.e. 'impact on humans' (C2) and 'actions of individuals in response to the phenomenon' (C7). The least interesting context for most topics proved to be 'methods of scientific inquiry' (C6).

4.5 Students' situational interest in topic-activity combinations

To investigate students' situational interest in topic-activity combinations, we proceeded in analogy to section 4.4. There was very little variation in the ranking of situational interest in topic-activity combinations, which indicates that the ranking of the means for situational interest in topic-activity interactions is largely independent of the choice of topic. For example, regardless of the topic, the activities of 'watching a film' (A6), 'doing a computer simulation' (A1) and 'making comparisons' (A8) meet the highest situational interest of the students. At the opposite end of the scale, students signalled the least situational interest in 'working with texts' (A5) and 'doing/presenting internet research' (A4), which was also true for all evolutionary topics investigated. Interestingly, however, the choice of topic determined the strength of the students' situational interest in the activities. This can be seen in Table 5 by comparing the means for the different topic-activity combinations in a row. For example, the means vary quite strongly from 'watching a film on the evolution of HIV' to 'watching a film on the evolutionary impact of trophy hunting on bighorn sheep'. Moreover, for an interesting topic such as 'the evolution of HIV', all topic-activity combinations are perceived with higher situational interest than any activity related to less interesting topics, for example, human-made evolution of cod, elephants and bighorn sheep (T4, T5, T6; Table 5).

Table 5

Situational interest in topic-activity combinations (total sample, n=740)

Mean scores M, standard deviation (*SD*) and ranking (in brackets) of the situational interest in different topic-activity combinations in one row (if two means differ by 0.02 or less, they share the same rank). Last column: mean scores for the situational interest in one activity calculated across different evolutionary topics. Last row: mean scores for the situational interest in one evolutionary topic (calculated across different activities).

	T1 Evol. of HIV	T2 Evol. of avian flu virus	T3 Evol. of antibiotic resistance in bacteria	T7 Evol. of lactose tolerance in humans	T8 Evol. of ability in humans to live at high altitudes)	T6 Evol. impact of size-selective harvesting on cod	T4 Evol. impact of trophy hunting on elephants	T5 Evol. impact of trophy hunting on bighorn sheep	Mean score for situational interest in the activity
A6 Watching a film	3.42 *(.79)* (1)	3.13 *(.91)* (1)	2.88 *(1.01)* (1)	2.74 *(1.03)* (1)	2.78 *(1.05)* (1)	2.35 *(1.09)* (1)	2.64 *(1.11)* (1)	2.29 *(1.09)* (1)	2.78 *(.67)* (1)
A1 Computer simulation	3.17 *(.89)* (3)	2.92 *(.93)* (2)	2.77 *(.97)* (2)	2.61 *(1.00)* (2)	2.64 *(1.00)* (2)	2.31 *(1.02)* (2)	2.52 *(1.03)* (2)	2.22 *(1.02)* (2)	2.64 *(.68)* (2)
A8 Making comparisons	3.24 *(.83)* (2)	2.88 *(.89)* (3)	2.74 *(.97)* (3)	2.59 *(.96)* (2)	2.58 *(.99)* (3)	2.15 *(.92)* (3)	2.41 *(1.04)* (3)	2.10 *(.99)* (3)	2.59 *(.61)* (3)
A7 Analysing authentic data	3.10 *(.89)* (4)	2.78 *(.92)* (4)	2.62 *(.99)* (4)	2.47 *(.94)* (4)	2.46 *(.97)* (4)	2.08 *(.94)* (4)	2.30 *(.98)* (4)	2.01 *(.91)* (4)	2.48 *(.63)* (4)
A2 Watching an interview	3.11 *(.92)* (4)	2.78 *(.91)* (4)	2.62 *(1.01)* (4)	2.48 *(.987)* (4)	2.44 *(1.00)* (5)	2.03 *(.95)* (5)	2.29 *(1.01)* (4)	1.99 *(.94)* (4)	2.47 *(.65)* (.4)
A3 Engaging in a discussion	3.13 *(.89)* (4)	2.79 *(.93)* (4)	2.59 *(1.0)* (6)	2.41 *(.98)* (6)	2.36 *(.98)* (6)	2.03 *(.95)* (5)	2.26 *(.98)* (6)	1.96 *(.91)* (6)	2.44 *(.61)* (6)
A4 Internet research	2.94 *(1.00)* (7)	2.59 *(.98)* (7)	2.42 *(1.02)* (7)	2.28 *(1.02)* (7)	2.30 *(1.03)* (7)	1.91 *(.95)* (7)	2.15 *(1.03)* (7)	1.83 *(.91)* (7)	2.30 *(.64)* (7)
A5 Working with scientific texts	2.81 *(1.00)* (8)	2.56 *(.96)* (8)	2.40 *(1.01)* (7)	2.27 *(.94)* (7)	2.25 *(.99)* (8)	1.87 *(.89)* (8)	2.08 *(.96)* (8)	1.83 *(.85)* (7)	2.26 *(.66)* (8)
Mean scores for situational interest in the topic	3.11 *(.66)* (1)	2.80 *(.71)* (2)	2.63 *(.79)* (3)	2.48 *(.77)* (4)	2.48 *(.79)* (4)	2.09 *(.78)* (7)	2.33 *(.82)* (6)	2.03 *(.77)* (8)	

4.6 Summary of the main findings

Evolutionary phenomena that relate to human health, i.e. the evolution of HIV, the evolution of the avian flu virus and the evolution of antibiotic resistance in bacteria, and phenomena that relate to human evolution in general, such as the evolution of lactose tolerance and of adaptation to high altitudes, are perceived with the highest situational interest. This is true regardless of whether scores are formed across all topic-context combinations (Table 4, last row) or across all topic-activity combinations (Table 5, last row). However, topic-activity combinations are generally perceived to be less interesting than topic-context combinations. Analysing topic-context combinations at the item level, we found that situational interest in the topic varies according to the context with which it is combined (Table 4). For example, situational interest in 'evolution of lactose tolerance' (T7), 'evolution of the ability in humans to live at high altitudes' (T8) and evolutionary impact of human activity on elephants, bighorn sheep and cod (T5, T6, T4) is highest if these topics are combined with the context 'causes of the evolutionary phenomenon' (C4). In contrast, a maximum situational interest in 'evolution of HIV' (T1) was found if this topic was placed in the context 'application of knowledge about the evolutionary phenomenon in medicine and science' (C5). For 'evolution of the avian flu virus' (T2), as well as for 'evolution of antibiotic resistance' (T3), the students indicated the highest situational interest when they were combined with the context 'impact on humans' (C2), whereas the latter topic was also perceived as very interesting in the context 'actions of individuals in response to the phenomenon' (C7). Among the least attractive contexts for all topics was 'methods of scientific inquiry' (C6).

The ranking of most interesting to least interesting activities proved largely independent of the topic investigated (Table 5). The activities 'watching a film' (A6) and 'doing a computer simulation' (A1) were met with the highest situational interest regardless of the topic-activity combination. On the other hand, the students indicated that 'working with texts' (A5) and 'doing/presenting internet research' (A4) are least interesting to them. However, situational interest in the same activity varies depending on whether it is combined with a more or less interesting topic. This is evident for all activity-topic combinations and can be seen, for example, by comparing A6xT1 and A6xT5 (Table 5).

5. Discussion and educational implications

The format of the questionnaire–the systematic combination of evolutionary topics and contexts as well as the combination of evolutionary topics and activities–yielded detailed insights into which combinations are most effective for science educators who would like to trigger students' situational interest in evolutionary biology. For example, for all topics included in this study, we can recommend the activities 'watching a film', 'doing a computer simulation' and 'making a comparison' to capture the students' interest.

In the literature, rather general recommendations can be found on how to trigger students' situational interest, for example, by explicitly pointing out the relevance of the phenomenon for humans. This holds true for some evolutionary phenomena investigated in this study, such as HIV, avian flu and antibiotic resistance, but not necessarily for others, for example the human-made evolution of cod. This is a surprising finding, because size-selective harvesting of cod has recently led to a reduction in fish body size and this phenomenon has an impact on consumers and fishermen alike.

Also, to our surprise, the students signalled low situational interest in the context of methods of scientific inquiry, whereas the inclusion of such contexts plays an important role in modern science education (e.g., Hunt & Millar, 2000). Because knowledge of the methods of scientific inquiry is an important component of scientific literacy, students need to understand how scientists proceed when they generate new knowledge, and special effort needs to be invested in making this type of context interesting. On the basis of this study, one way to do this is to choose effective topic-context combinations, for example, by combining the methods of scientific inquiry with the evolution of HIV or of the avian flu virus.

Interestingly, the choice of topic has a strong impact on the strength of the situational interest expressed by the students for certain activities. Although it may not strike science educators as an unusual finding that students like to watch films and do computer simulations, we observed that the means for less interesting activities, such as working with texts or doing internet research, increase if they are combined with interesting topics, such as the evolution of HIV, avian flu or antibiotic resistance. The opposite effect can be seen for the more interesting activities, whose means decrease when they are combined with less interesting topics, such as the human human-made evolution of bighorn sheep. Knowledge of these interactions can be helpful in making choices about specific topic-activity combinations in the classroom.

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20 LEARNING PROGRESS IN EVOLUTION THEORY: CLIMBING A LADDER OR ROAMING A LANDSCAPE?

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Abstract

The objective of this naturalistic study was to explore, model and visualize the learning progress of 13-year-old students in the domain of evolution theory. Data were collected under actual classroom conditions from a sample size of 107 learners, who followed a teaching unit on Darwin's Theory of Natural Selection. Before and after the teaching sequence, the students wrote texts that explained an evolutionary phenomenon. Their explanations for evolutionary change were analyzed and categorized into nine different patterns. In addition, we contrasted these explanation patterns with the corresponding scientific conceptions. This resulted in five conceptual frontiers, each of them marking one major learning task. The actual learning progress of the sample group was visualized as learning trajectories on a conceptual landscape. Our findings indicate that learning to explain evolution is a highly individual process in which the students depart from several distinct ideas and take different trajectories. The method of mapping content-specific learning progress within a mental landscape may be advantageous for other domains of science teaching as well.

Keywords: evolution; conceptual landscape; learning progression; design research; naturalistic study

1. Introduction

New curricula in many countries stress the importance of Darwin's theory as fundamental for biology education. Understanding evolution and diversity is no longer seen as one content domain out of many. Instead, evolutionary concepts such as diversity are introduced as early as grade 5 and continually developed. Evolution theory is expected to connect all major biological concepts in students' minds (e.g. Niedersächsisches Kultusministerium, 2007, p. 69). However, due to lack of evaluation, the impact of the new curriculum on students' knowledge is largely unknown. There are ongoing efforts to develop a content-oriented theory of learners' development in this domain, based on empirical data about the learning process. But although some progress has been made, we still lack a model of content-specific conceptual development in evolution theory that can easily be used in the classroom. Such a model should be able to visualize the learning demand as well as the actual learning progress. Furthermore, it should be based on both general and content-specific theories, but also be practicable under classroom conditions.

2. Theoretical background

2.1 Learning to explain evolutionary change

Learning difficulties in the field of evolution have been explored and described by several authors (Deadman & Kelly, 1978; Halldén, 1988; Olander, 2008; Wandersee, Good, & Demastes, 1995). Some of the recent studies (Baalmann, Frerichs, Weitzel, Gropengiesser, & Kattmann, 2004; Weitzel, 2006) have focused on the learner's perspective, using the Model of Educational Reconstruction (MER) as a framework (Duit, Gropengiesser, & Kattmann, 2005). Most authors concluded that conceptual change in favour of scientific explanations is difficult to achieve in this domain. Learners tend to make sense of species evolution and adaptation phenomena in their own, non-scientific way. These explanations cannot simply be replaced by scientific conceptions that are contradictory to the learner's experiential realism (Gropengiesser, 2003; Lakoff, 1990). Students tend to stick with their own, non-scientific explanations, especially teleological ones (e.g. Baalmann et al., 2004; Halldén, 1988; Wandersee et al., 1995).

2.2 Design research: modelling content-specific understanding

There is an ongoing debate about content standards and assessment in science education, which has some impact on the issue of teaching evolution as well. Science educators complain about benchmarks being implemented top-down, and “atomised” lists that are too superficial (Wilson, 2008). Instead, standards could represent a realistic model of the learners’ development in a specific domain (Wilson, 2009); this means developing a “construct” or content-oriented theory of the learners’ development in this domain, based on empirical data about the learning process. This idea is widely accepted and has fuelled different approaches and concepts in science education research that are more or less closely related to the notion of design research or design-based research. An important approach is that of content-specific learning progressions (LPs). LPs describe “successively more sophisticated ways of reasoning within a content domain that follow one another as students learn” (Smith, Wiser, Anderson, & Krajcik, 2006). Thus, they are hypothetical models of learning over time that can be used to track student progress. LPs are assumed to focus the science curriculum on a “smaller set of core ideas” and thus provide better alignment between curriculum, instruction, and assessment (Duncan & Hmelo-Silver, 2009).

A different idea is that of content-specific theories (CSTs). Andersson and Wallin (2006) see CSTs as situated between two poles: general theoretical platforms such as theories of understanding or learning on the one hand, and the specific teaching practice in a certain biological topic on the other. Thus, CSTs should be able to bridge the existing gap between research in science education and classroom practice. Andersson and Wallin argue that design research should develop “theories that promote learning with long-term understanding of given topics” (2006, p. 673). Referring to the example of Lijnse and Klaassen (2004), they characterize design research by some common elements, e.g. the iterative nature of the work, the contribution to the development of educational science, and the multiple roles of the researcher, which can include designer, teacher, and teacher trainer (Andersson & Wallin, 2006, p. 674).

2.3 Design research concerning evolution theory

A few models on the teaching and understanding of evolution theory already exist, based on design research. Catley, Lehrer, & Reiser (2005, pp. 8-11) have suggested a LP for evolution theory, based on data from natural history museums. Emphasizing the role that evolution plays in biological diversity, the authors present a “distillation” of six central concepts for evolution, e.g. “diversity”, “structure-function”, and “variation”. They add two methodical concepts, the “forms of argument” and “mathematical tools”. For three different age groups from grade 1 to 8, the authors specify standards for all eight concepts, interrelated and connected with learning activities. Their work represents a detailed model of how knowledge and skills around the big idea “evolution” can be developed with students. One strength of their approach lies in the tight connection between conceptual framework, age-specific standards, and the classroom practice associated with these goals. However, in their view, the evolution LP is tied to specific instructional interventions, which contrasts somewhat with the idea that LPs are essentially theoretical constructs that do not depend on an instructional setting (Duncan & Hmelo-Silver, 2009, p. 3).

Andersson and Wallin (2006) chose evolution as an example of a CST. Relying on international studies and their own teaching experiments, they explore nine different aspects of teaching evolution and give recommendations to teachers in the form of hypotheses: “If attention is paid to…the following aspects,…learning with understanding is promoted” (p. 678). Most of these aspects are content-specific, such as “Evolutionary time is made concrete”. Others, however, focus on the nature of science and general pedagogical aspects, such as the teacher’s role as a “bearer of culture” (p. 683). Compared to Catley et al. (2005), the work of Andersson and Wallin (2006) is more general and theoretical in its approach, and has a broader empirical foundation. On the other hand, their “aspects” do not form a consecutive model of a conceptual development or learning pathway, but rather shed light on different problems that are discussed separately.

3. Key objectives

The main objective of this investigation was to develop a method to assess learners’ preconceptions about evolution, as well as their actual learning progress during an evolution teaching unit, on a classroom scale. Our intent was to create a content-specific and empirically validated diagnostic tool to improve teaching and learning in the field of evolution theory, and to visualize learning progress. The development of the model includes the following research questions:

1) How do 13-year-old students explain evolutionary change before and after instruction in this field?
2) What are the essential achievements and frontiers to be crossed on the conceptual landscape of evolution theory?
3) What are the various learning trajectories of a large sample population? Are there patterns, and if so, can they be linked to specific interventions or teaching strategies?

4. Research design and method

4.1 The model of educational reconstruction

Our research design was inspired by the MER (Kattmann, Duit, Gropengiesser, & Komorek, 1995, 1997). The MER was designed primarily as a frame for science education research and development. However, it also provides significant guidance for planning science instruction in school practice. The MER consists of three closely interrelated components: (1) clarification and analysis of science content, (2) research on teaching and learning, and (3) design and evaluation of teaching and learning environments. The three components do not follow strictly one upon the other but influence each other mutually. In our study, the teaching sequence on evolution theory was designed beforehand, based on literature and practical experience. The study was carried out in 2005 and involved five classes from three different grammar schools (*Gymnasium*), all situated in small towns in northern Germany. The sample encompassed a total of 107 lower secondary students (grade 7, average age 13 years).

4.2 Instruction and data collection

All students followed a teaching sequence on evolution theory over a period of 5 weeks, about 10 lessons in all, designed according to the theory of conceptual change (Posner & Strike, 1992) and cognitive conflict (Duit & Treagust, 1998). The sequence was tested in school and ultimately published (Giffhorn & Langlet, 2006). During the present study, all students were taught by their usual biology teachers. In the initial phase, students were asked to explain whale evolution based only on their pre-instructional knowledge. Then, Lamarck's "natural laws" (Lamarck, 2002/1809) were presented to them without labelling this theory of evolution as historical. Most students felt that their preconceptions had been confirmed, conceiving evolution as a process of individual adaptation, initially triggered by environmental conditions and inherited by subsequent generations. The students were then confronted with Weismann's experimental findings (Weismann, 1902) in order to shatter their belief of the inheritance of acquired traits and make them actively search for a new explanation for adaptation phenomena. Then their attention was directed towards the breeding of domestic animals. Darwin's Theory of Natural Selection was introduced and applied to various evolution phenomena. The data were collected by a writing assignment at the beginning and end of a teaching sequence, in which the students were asked to explain the evolution of modern whales from their terrestrial ancestors (Zabel, 2009, pp. 126-128). The assignment was almost identical in the pre- and post-test and was illustrated with three naturalistic drawings: a contemporary blue whale and two extinct whale ancestors, one terrestrial and one semi-aquatic. In this way, we collected a total of 214 pre- and post-instructional texts from the 107 students of the sample group.

4.3 Data analysis

All texts were analysed for explanations of whale evolution, using Qualitative Content Analysis (Mayring, 2007). The students' explanations were condensed into nine explanation patterns and formulated.

According to the MER, the corresponding scientific conceptions are needed for a mutual comparison. In this case, we could rely on Weitzel's (2006, pp. 41-79) thorough clarification of the concept of "adaptation", based on the theories of evolution by Lamarck, Darwin and Mayr. Darwin (1872) and Mayr (1984) both explain adaptation phenomena predominantly by natural selection. The mutual comparison of student and scientific conceptions led to conceptual frontiers, each of them marking one major learning task on the way towards a Darwinian explanation. The conceptual development of all 107 participants was then assessed according to the explanations they used before and after the instruction. These longitudinal data were visualized as learning trajectories on a mental landscape.

5. Findings

5.1 The explanation patterns: how do 13-year-old learners explain evolutionary change?

The analysis of the students' texts by the method described above led to nine different patterns of explanations for evolutionary changes (Table 1). The pattern "Mere description of evolutionary change" is the only exclusive one and marks the absence of any causal mechanism in the text. Other explanation patterns occurred in different combinations within one text.

Table 1

Patterns of explanations for evolutionary change in learners' texts on whale evolution

Mere description of evolutionary change: Learners give no causal explanation whatsoever, but merely describe the steps of evolutionary change. *"Then I started going in the water more often, my hind legs turned into fins and a tail fin grew. (...) Then the hind fins disappeared, and the forelegs became small fins, too."*

Environment causes evolution: The environmental changes and/or long time spans are seen as sufficient explanations for evolutionary processes. *"The blue whale's ancestor lived close to the seaside. As he came in contact with the water quite often, he developed webbed feet and a tail fin."*

Evolution caused by need: The evolutionary changes are explained by necessity that arises from the environmental conditions of the whale ancestors. No physical mechanism is described. Change occurs because it is necessary. *"The animals developed to aquatic animals, because the sea spread more and more."*

Intentional adaptation of individuals: Evolutionary changes result from intentional and goal-directed acts of individuals or their bodies. The intention to adapt is at the centre of the explanation. A different use of organs may be the consequence, but not the essential part of the explanation as in "Usage of organs". *"In the sea, we realized that we had enemies here, too. Therefore we wanted to grow even bigger, and during the time since then we became what we are today."*

Intentional adaptation over generations: Heredity causes and conserves evolutionary change. Parents intentionally pass on adaptive traits to their offspring, even if they themselves were not adapted to this degree. This gradually leads to evolutionary change. *"Then my mother realized that we spent so much time near the water, so that my little brothers and sisters should rather have a fin instead of two hind legs, because: What do you need legs for, if you don't use them? My own children later got no legs at all."*

Usage of organs: The bodies of individuals change when organs are used more or less frequently in a new environment. Intention (the conscious attempt to "train" an organ) is absent in these explanations, otherwise they would be classified as "Intentional adaptation". Some students also assume that the new traits are then passed on to the next generation. *"During the second step, the whale started living in the sea as well as on land. Therefore the hind legs were rarely used, or not at all. They became weaker and then they vanished entirely."*

Evolution through hybridization: Evolutionary change occurs because individuals interbreed with other species or conspecifics with different traits. Their offspring then partly inherit these new traits. Repeated hybridization leads to the accumulation of new traits. *"These animals cross-bred with animals that lived in the sea. Thus the genes were altered and new structures occurred. For example, these animals cross-bred with dolphins, and the offspring had a fin instead of hind legs."*

Evolution by deviance and natural selection: A single deviant specimen originates from a group of apparently homogeneous conspecifics. Due to its better-adapted traits, it survives and hands down its aquatic traits to all of its offspring. This gradually leads to evolutionary change. *"All animals had four legs. Due to a "birth of chance" [Zufallsgeburt], one of the newly born animals had a fin instead of hind legs. That was an advantage, as he could search for food in the water (...). He passed on his fin to some of his descendants. Over time, more animals with fins were born and reproduced. As food was scarce, the disadvantaged animals died out. Those with an advantage lived on. Due to new "births of chance" they developed further on, until they became the whale of today."*

Evolution by variation and natural selection: Individuals within a population vary in their traits and compete for limited resources. Those with better-adapted traits will produce more offspring. This gradually leads to evolutionary change. Being different from the others is seen as the norm, not the exception. *"When the whale ancestors for some reason (maybe food) started spending more time in the water, some of them had little advantages due to the variability in a species (...). Therefore, these individuals had a bigger chance for a long life and a lot of offspring than the others. So these little advantageous traits would spread until the whales of today emerged."*

5.2 The landscape: which frontiers are there to be crossed?

We identified five key ideas of the Darwinian explanation, which appear as conceptual frontiers on the map (Figure 1). Students' explanation patterns were placed in appropriate areas on the map. The first frontier to be crossed consists of actually *explaining* instead of merely describing the evolutionary changes. An explanation is characterized by a causal mechanism, be it scientific or not. Another frontier we found is to explain evolutionary changes by a causal mechanism instead of a teleological reason. Motives and reasons are much closer to the everyday intentional thinking pattern *Adaptation as an intentional act of individuals,* which several authors have found to be a common pattern (*Denkfigur*) in students' conceptions (Baalmann et al., 2004; Weitzel, 2006). In contrast to many authors of earlier studies, Kampourakis and Zogza (2007a, 2007b) emphasized the important difference between the historical scientific concept of Lamarckism and student conceptions.

Those students explaining evolution at the individual level are to cross the frontier to an explanation that encompasses several generations. The fourth frontier marks the shift from any other causal mechanism to natural selection. However close to the Darwinian explanation, there is still an important frontier to cross: the one between a pattern that explains evolution by *deviance and natural selection* and the "target pattern", which implies a real variation concept. This frontier is meaningful, as deviance still implies a norm, a homogeneous species type from which a single individual differs. Thus, the idea of deviance from a norm is still compatible with typological thinking, whereas variation implies that all individuals differ from each other, which is indispensable for the Darwinian explanation.

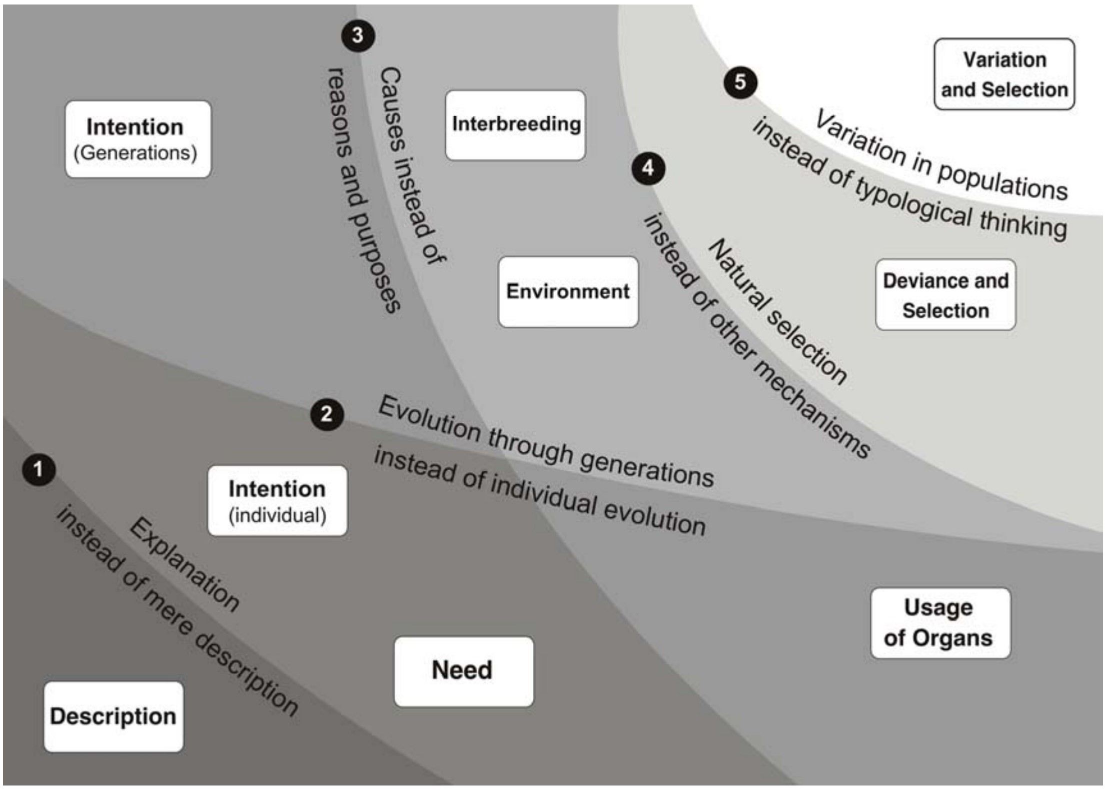

Figure 1
Darwin's conceptual landscape

The squares indicate the explanation patterns found in students' pre- and post-instructional texts on whale evolution. The positions of the squares, as well as the areas and frontiers that structure the landscape, result from a mutual comparison between the explanation patterns and key ideas of Darwin's Theory of Natural Selection. This comparison is based on the model of educational reconstruction (MER). The higher and more to the right side an explanation is located on the landscape, the more scientifically adequate it is judged to be, because it shares more common features with the ”target” explanation for evolution, the Theory of Natural Selection.

5.3 The effect of instruction on learners' conceptual development

Figure 2 shows the effect of the teaching sequence on the conceptual landscape. The learning trajectories indicate the actual learning progress of the entire sample group. We identified a total number of 69 explanations in all 107 pre-instructional texts (Zabel, 2009). After the instruction, the total was 119, a significant increase in the average number of explanations. Whereas in the pre-test only five students used more than one explanation pattern, in the post-test the total number of texts with multiple explanation patterns was 15.

After the instruction, a total of 42 learners used one of the two explanation patterns based on the idea of natural selection: 33 of them combined this with the idea of deviance from a norm, 9 with the true variation concept. However, the number of those learners that explained the evolution of aquatic traits by the usage of organs also increased from 8 to 22.

Overall, the landscape shown in Figure 2 leads to three major conclusions about the effectiveness of the instructional strategy:

1) *More than a third of 107 students successfully learned to explain an evolutionary phenomenon with the help of natural selection.* Although a follow-up test would be necessary

to evaluate the long-term quality of this learning process, it is obviously not at all a hopeless endeavour to teach young students aged 13 the Theory of Natural Selection, despite the complexity of the topic. Nevertheless, the variation concept appears to be difficult to understand and should be given more attention in future instructional settings.

2) *The strategy of cognitive conflict misled learners towards the explanation pattern "Usage of organs"*. The trajectories indicate that 19 students apparently found Lamarck's use and disuse model, by which organisms develop their characteristics, convincing enough to convert to this concept. Five more students remained with this pattern without being attracted to Darwinian ideas. Weismann's findings on inheritance of acquired characteristics obviously did not create a cognitive conflict within these 24 learners.

3) *The learners took various pathways in their learning process*. This conclusion is the overall impression of the longitudinal data expressed by the learning trajectories–the conceptual development of the entire population is rather similar to roaming a landscape.

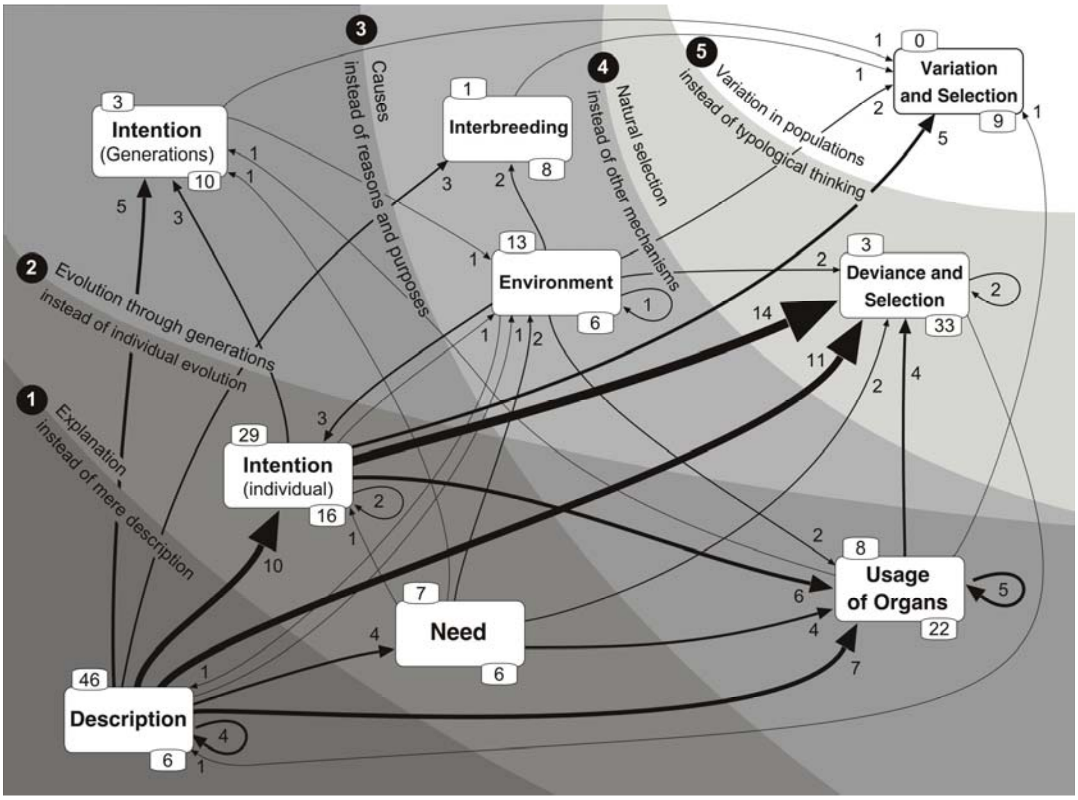

Figure 2
Learning progress of all 107 students

By their thickness and associated number, the arrows indicate how many learners changed from one explanation pattern to another. The pre-instructional abundance of each pattern is marked on the upper left side of the square, the post-instructional one on the lower right side. Marginal deviations from the mathematical sums result from the fact that some of the student texts were characterized by more than one explanation pattern. Furthermore, the 10 student texts coded with the category "single various explanations" are omitted from the diagram.

6. Discussion

Our data indicate that learning evolution theory cannot be accurately described on a one-dimensional scale, but rather as an individual process where some learners use beaten tracks while others tend to leave them and go their own way. Rather than climbing a ladder, the students' conceptual development roams in a landscape where different trajectories lead to the same goal. To an individual learner, his/her own trajectory may still appear as a series of steps. But looking at the entire ensemble of documented learning processes reveals their heterogeneity. Hence, while the one "beaten path" or expected conceptual development appears less important, the frontiers on the map gain relevance. In a landscape with a variety of empirically found student conceptions, frontiers express the learning demand (Leach & Scott, 2002) that separates students' conceptions on this side from those beyond the frontier.

One could conclude from this that we should funnel our efforts into helping the students cross one frontier after another. But the learning process, at least in this content domain, appears to have a slightly different nature: each account that is presented to explain whale evolution has *Gestalt* properties, so the transgression of the frontiers is rather a side effect that occurs with the conceptual change from one account to another, more sophisticated one. This does not mean that scientific concepts such as variation in a population are easy to grasp without intellectual effort. Of course they represent a considerable challenge. But our data suggest that in the learning progression, the different explanations can be interpreted as narratives and thereby function as stepping stones, because they are less abstract and somewhat closer to everyday thinking than are the frontiers (Bruner, 1996; Zabel, 2007, 2009). This reflection directs some attention to the classroom conversations, which were not examined in this study, and thereby to a social constructivist perspective (e.g. Mortimer & Scott, 2003): for if everyday thinking and narratives can function as stepping stones on the way to understanding selection theory, then the communication of these constructs in the classroom should be a fruitful object of future studies.

Our study and its results allowed us to draw a map of the conceptual landscape, where learning processes favouring Darwinian concepts can now be located. The learning trajectories indicate how most of the learners developed and thus give hints for a continued revision of the instruction sequence and teaching methods. For example, the strategy of cognitive conflict applied in this study should be dismissed or altered with good empirical reasons, as it probably encouraged a considerable number of learners to explain adaptation by the *"Usage of organs"*. In contrast to one-dimensional models of learning progress, the spatial representation, based on content-specific conceptual categories, appears to provide a more detailed insight into the process of conceptual reconstruction and the effect of instruction. In other words: mental landscapes provide a "training ground", based on empirical data, where the results of competing teaching experiments can now be evaluated and compared for their effect on the conceptual development of the learner population. The game has begun, may the best instruction strategy win!

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21 CROSS-CURRICULAR TEACHING OF ORIGIN OF LIFE: OPPORTUNITY OR THREAT?

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Abstract

This paper explores the teaching of the origin of life in Science and Religious Education (RE) in secondary schools in England. The experiences and attitudes of teachers and 14- to 16-year-old students were investigated using mixed methods. Cross-curricular collaboration, opinions about covering religious beliefs in the science classroom and student perceptions of the two subject areas were explored. Although most science teachers claimed to mention religious beliefs when covering this topic, and most RE teachers said they included scientific theories, very little collaboration between Science and RE departments was evident. Yet it seems that science teachers could profit from RE teachers' experience in handling controversial subjects, encouraging students to express their opinions and promoting discussion. From science teachers, RE teachers could discover whether or not their reported confidence in teaching the scientific angle is justified. In view of the prevalence of student misconceptions about evolution, and the absence of universal acceptance of the theory, it is important that all teachers who cover it–be they from the Science department, RE, or elsewhere–get it right. This raises the issue of how to encourage cross-curricular endeavours in the face of teacher defensiveness combined with time and workload pressures.

Keywords: evolution; religious beliefs; cross-cultural; cross-curricular; creationism

1. Background

Certain religious groups–literalist Christians and some Muslims, for example–have world views that cannot be reconciled with particular scientific ideas. As the secondary science curriculum in England widens its remit from facts and knowledge to consideration of ethical issues and how the scientific community operates, the potential for conflict is growing. At a time of widespread concern about the low number of students choosing to study science beyond the age of 16, might one of the barriers be a perceived incompatibility with religious beliefs?

The conceptualisation of science and religion is integral to this issue. Much has been written about the natures of science and religion (see Reiss, 2009 for a concise summary). How they are seen to inter-relate is also key, with one of the best-known taxonomies having been proposed by Barbour (2000). He outlines four possible positions: conflict (only one of science or religion is valid); independence (the two are different endeavours); dialogue (the two are related, for instance through similar methodologies), and integration (one informs and supports the other).

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When considering how students relate science and religious beliefs in school there is the additional layer of how comfortable they find the fit of home and school cultures. Aikenhead (2001) postulates that the degree of difference between a student's own culture and the culture of school science, and how well students cope with that difference, determines how easily they can acquire scientific knowledge. Jegede and Aikenhead (1999) outline four types of instructional processes for scientific learning, and the circumstances in which they might be used. When students have world views that are already in harmony with science, "enculturation" can operate, and trouble-free border crossings are possible because the ideas from the two cultures are mutually supportive. However, when there is discord between the two, alternative approaches are necessary. Through "acculturation", the student consciously chooses which parts of science to accept and this can prove empowering. "Anthropological learning" is where the students add scientific ideas alongside their own cultural ones such that concepts are multiplied rather than replaced. For Jegede and Aikenhead (1999), the most dangerous option is "assimilation". Here, the aim is to replace existing cultural concepts with scientific ones, and there is a risk that students will become alienated from science, failing to engage with scientific knowledge and just using it for exams.

Perhaps the most high-profile example of a school science subject that can have a religious dimension is Darwin's theory of how life evolved through natural selection. This challenges aspects of various religious teachings, including the individual creation of each species and the unique position of human beings (McGrath, 1999; Poole, 1990). The truth of the statement "nothing makes sense in biology except in the light of evolution" (Dobzhansky, 1964) is widely acknowledged by science educators, and Darwin's ideas about natural selection have been described as "among the most powerful and significant pieces of knowledge we possess" (Millar & Osborne, 1998). Yet surveys consistently show that a sizeable proportion of the public holds beliefs that are incompatible with evolution. This is particularly prevalent in the US where, according to a recent poll (Gallup, n.d.), 44% of the public favour creationist explanations. Although such views are less widespread in the UK, they are still significant (22% according to BBC/MORI, 2006).

A limited amount of research has been done on the attitudes of teachers and students towards evolutionary theory. For instance, a 19-country survey of teachers and trainees showed that creationist beliefs are correlated with several factors, including strength of religious belief and level of education (Clément & Quessada, 2008). Billingsley, Taber, Riga, and Newdick (2010) reported preliminary research in a study of students' perceptions of the relationship between science and religion.

The inclusion of references to religious beliefs, creationism in particular, in science lessons is a highly contentious issue. Pennock (2002) is of the opinion that creationism should be excluded from the science classroom on the grounds that, as far as scientists are concerned, evolution does not constitute a controversial theory. Indeed, he thinks that creationism has no place anywhere in state schools because it has no evidentiary support. Scott and Branch (2003) also dismiss the call to "teach the controversy" in the science classroom, but concede that it might be covered in other subjects, such as history or comparative religion.

In contrast, Hermann (2008) contends that, as well as providing an exemplification of the nature of science, evolution is ideal for demonstrating a controversial issue. Whilst acknowledging that the controversy is of a cultural nature and most scientists find it uncontentious, he claims that presenting it in a non-threatening way (for instance, using procedural neutrality, whereby students gather their own information rather than relying on the teacher) may encourage participation from some students who would otherwise fail to engage with the theory. Nord (1999) also calls for evolution to be taught to students as a controversial issue which has broader relevance: “Our ongoing cultural conversation about the relationship between science and religion is much more interesting than most educators appreciate, and it strikes me as scandalous that we don’t let students in on this conversation” (p. 33).

Ignoring the religious dimension in science lessons is seen by some as potentially detrimental to students. Reiss (2009) argues that teachers should recognise that a belief in creationism may reflect a student’s world view rather than a lack of knowledge, and that if a creationist view is aired by a student it should not be disregarded. The aim should be to improve students' understanding rather than alter their opinion.

Roth (2007) has raised concerns about the artificial separation of science and religion whereby they are taught at separate times by different teachers, a situation that almost always applies in English schools. He criticises this as contradicting the natural life experience of the students themselves. On the other hand, Mahner and Bunge (1996) claim that science and religion are incompatible, and that religious education should not feature in schools because it might interfere with attempts to instil a scientific way of thinking. Based on an implicit assumption that science is a superior mode of knowing, they recommend that religion be studied from a principally scientific point of view, if at all.

In England, both science and religious education (RE) are normally compulsory up to the age of 16 (although parents have the right to withdraw their children from RE lessons). Unlike in many other European countries, RE is “non-confessional”–that is, no particular faith or denomination is promoted. There is no obligatory RE curriculum but the recommended national framework (QCA/DfES, 2004b) explicitly covers connections between religion and science at key stage 3 (age 11-14), and a unit focusing on creation and origins has been designed for Year 9 (age 13-14) (QCA, 2006). Science is part of the national curriculum, with a blueprint for what must be covered, and it is at key stage 4 (age 14-16) that students study the theories of evolution and the Big Bang in their science programme (QCA/DfES, 2004a). In theory, the context represents an opportunity to make cross-curricular links, something encouraged by the new secondary curriculum in England.

2. Rationale and research questions

Although there is a considerable body of literature which alludes to the teaching of the origin of life, there is little empirical evidence on student and teacher views or behaviour around the issue. Because of the predominance of the US literature, the teaching of RE in schools alongside science has rarely been considered. Another overlooked issue is the situation of Muslim students in Western society, as the emphasis has tended to be on Christian outlooks or on Muslims in predominantly Islamic countries (e.g. Edis, 1999).

The research presented here addresses these areas through three research questions:

- Do science and RE teachers hold different opinions about teaching the origin of life?
- Is the working relationship between Science and RE departments characterised by isolation or collaboration?
- What are students’ perceptions of how the topic is covered in science and RE, and how is this affected by their religious beliefs?

3. Research design and methodology

A short self-completion questionnaire was sent out to 72 science and 71 RE teachers in a stratified random sample of state-maintained secondary schools across England in July 2008. Low response rate proved to be a problem at 34% for RE teachers and only 14% for science teachers. The numbers were supplemented by recruiting an additional, opportunistic sample of science teachers and conducting an online survey of RE teachers.

To supplement the survey with richer data, four case schools were selected to illustrate three contexts: Christian faith school; non-faith school with a catchment of mainly Muslim families, and non-faith school with pupils drawn from no particular religious background. Within these, surveys and focus groups were conducted with students. The research concentrated on the experiences of 14- to 16-year olds, an age at which students are approaching the end of their compulsory schooling but are still legally obliged to follow courses in both science and RE. Small focus groups (of 3 to 4 students) were preferred to single interviews to provide peer support in a topic that might be intimidating (Lewis, 2003). Face-to-face interviews were also carried out with the heads of the Science and RE departments in three of the four schools. Table 1 shows the sample sizes obtained.

Table 1
Sample

Science teachers (survey)	55
RE teachers (survey)	98
Teacher interviews	7
Student survey	209
Student focus groups (total no. of individuals)	64

The main areas of questioning are summarised in Table 2. As shown, some of the topics were not addressed explicitly in the focus group situation to avoid pressurising students on potentially sensitive subjects. However, in many cases this information emerged indirectly.

Table 2
Topic coverage

Main question topics	Teacher survey	Teacher interview	Student survey	Student focus groups
Own views on origin of (human) life	yes	yes	yes	indirect
Influences on viewpoint	no	no	yes	indirect
Views on science/religion inter-relationship	yes	yes	no	yes
Perspectives covered in class	yes	yes	no	yes
Confidence covering religious beliefs (science teachers)/scientific theories (RE teachers)	yes	yes	no	no
Opinion on covering religious beliefs in science lessons	yes	yes	no	yes
Perception of topic as controversial	yes	yes	no	yes
Science/RE departmental collaboration	yes	yes	no	yes

Fieldwork in the case schools took place between June 2008 and February 2009. It was timed so that, according to their teachers, the students had covered explanations of the origin of life in both science and RE.

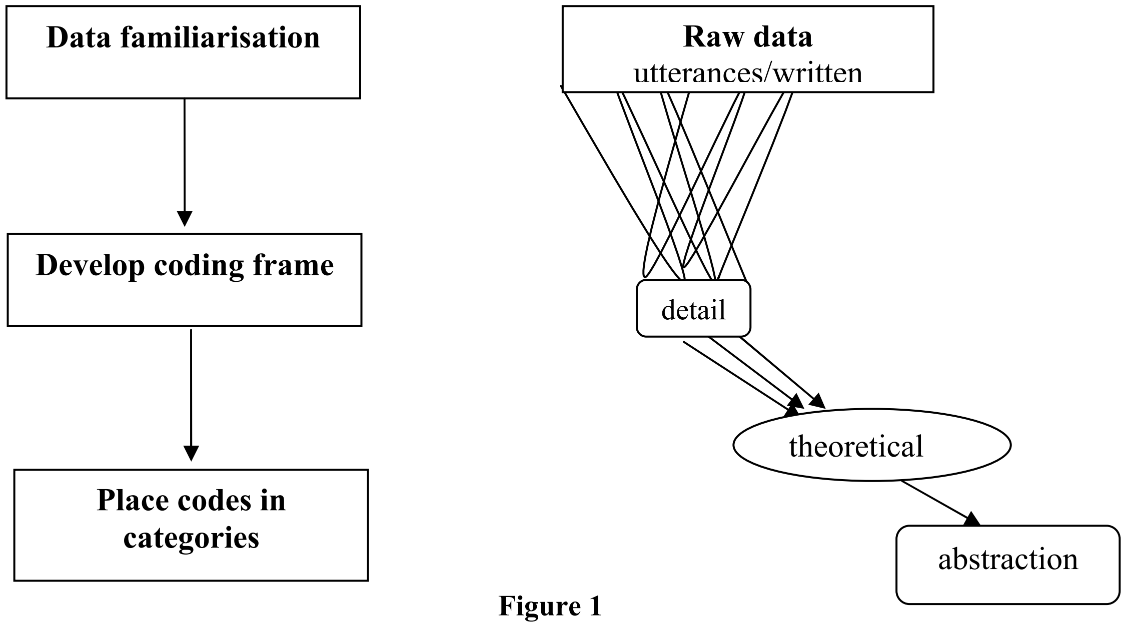

Figure 1
Analysis process

Survey data were analysed using SPSS software and chi-squared tests applied to explore differences between sub-samples on the rating scales. Answers to open questions, and responses in the interviews and focus groups, were initially coded using principles of grounded theory (Strauss & Corbin, 1998) to develop codes that arose directly from the participants' spoken or written contributions (Figure 1). Higher level categorisation was then achieved by studying the data through a theoretical lens particularly informed by Barbour (2000) and Jegede and Aikenhead (1999). An example of how the process was applied in analysis is given in Figure 2.

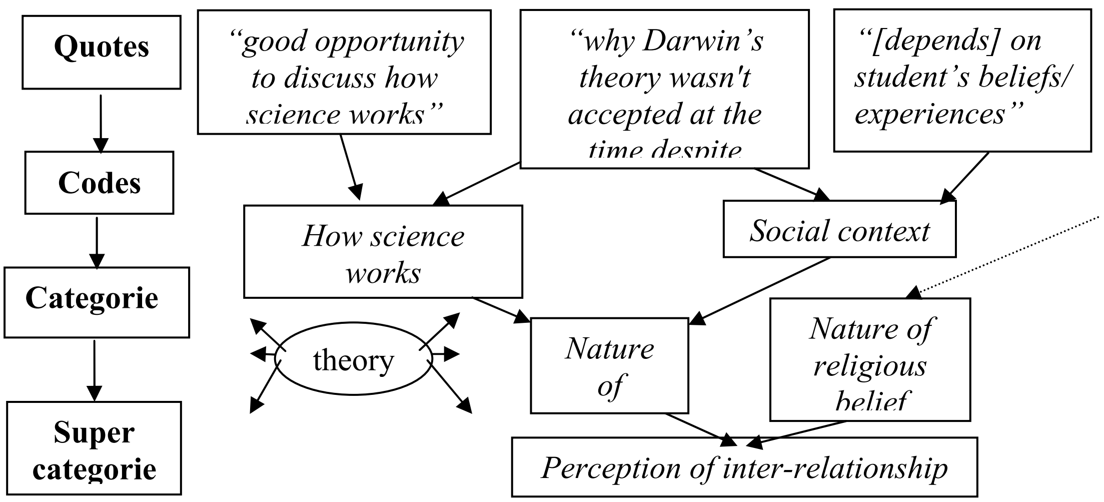

Figure 2
Example of analytical process: importance of covering religious beliefs in science lessons

4. Findings

The survey suggested that teachers' views concerning the importance of covering religious beliefs about the origin of life in the science classroom are very mixed. Around a quarter of science and RE teachers (24% and 28%, respectively) considered it "essential" (Figure 3). Slightly fewer, about a fifth in each case, thought it was "not at all important" (18% science, 21% RE). There was a spread of opinion between the two extremes, with the skew being towards the "important" end of the range in both cases. Although a higher proportion of science teachers opted for the midpoint and RE teachers for either extreme, the difference was not significant ($p>0.05$).

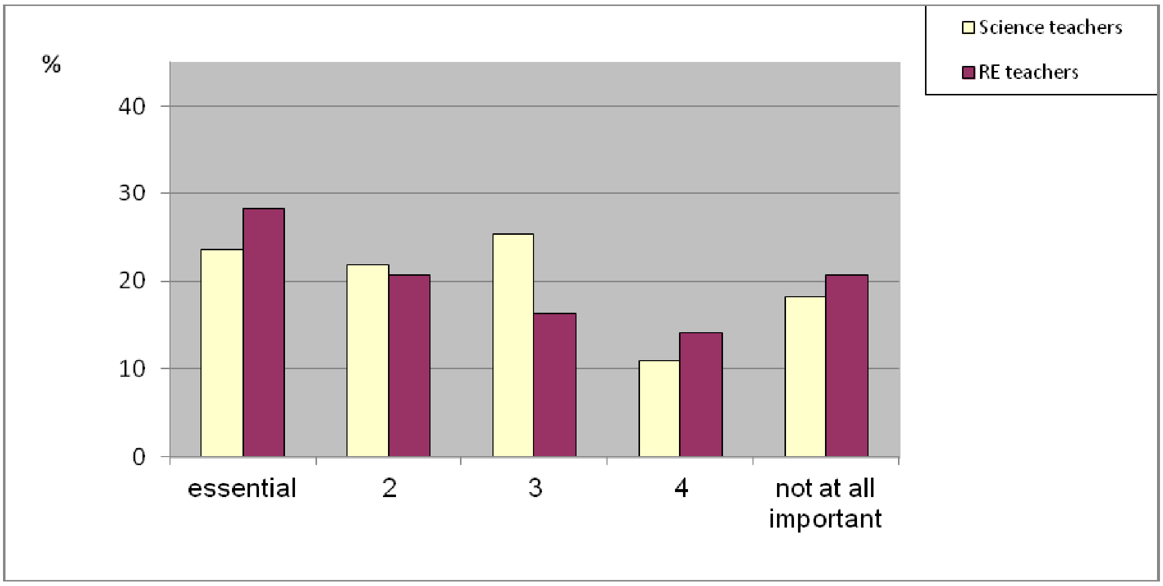

Figure 3
How important is it to cover religious beliefs about the origin of life in the science classroom?

Teachers were asked to explain their ratings. By far the main reason for teachers thinking religious explanations should be included in science lessons was to provide "balance". This was often expressed (by RE teachers and those science teachers who defined themselves as Christian) as explaining that theories are not indisputable facts, and that science has an element of faith.

Some science teachers were motivated to include the religious aspect to help students understand the context within which Darwin's theory was developed and slowly accepted, thus exemplifying a characteristic of "how science works". Several of these teachers included a caveat emphasising that they made clear whether explanations were scientific or not, and kept such diversions short.

For many of the RE teachers in the survey, a potential benefit of science teachers referring to religious beliefs was to demonstrate that science and religion are linked and that the two can comfortably co-exist. These approaches can be assigned to Barbour's dialogue or integration typologies (Barbour, 2000). In contrast, most of the teachers (be they science or RE) who considered it unimportant to cover religious beliefs about the origin of life in the science classroom fell into the conflict or independence categories. For them, the natures of religious and scientific truths were very different, as explained by this RE teacher:

Religious beliefs are...beliefs and not scientific–the science classroom is for those ideas which can be objectively tested and demonstrated–that is the nature of science.

Others thought it not at all important for more pragmatic reasons (e.g. not enough time, not in the exam, covered elsewhere and/or by more appropriately qualified teachers). Yet in practice, there was a degree of commonality between science and RE lessons on the origin of life. Four out of five of the science teachers surveyed (80%) said they usually mentioned religious beliefs in their coverage of the topic, and 91% of RE teachers mentioned Darwin's theory. Furthermore, almost a quarter of RE teachers (24%) stated that they included Big Bang theory in their coverage of the origin of life (this conflation of the origin of the universe with the origin of life was a recurrent theme among RE teachers as well as students).

The individual teacher interviews in the case schools revealed differences in attitude that appeared to be related to the school context. In the school with a large majority of Muslims, faith was seen as integral to the students' lives and, even though they did not share this faith, the interviewed teachers were very aware that most of their students interpreted everything through the lens of their religion. In the faith school, where both teachers interviewed were committed Christians, there was also (what the student focus groups suggested might be excessive) sensitivity around the topic. However, science teachers in the schools representing the non-faith context in terms of school and catchment tended to be unjustifiably blasé about the issue. They assumed that most of their students did not have religious beliefs that would conflict with the scientific orthodoxy. However, the survey showed that almost 30% of these students thought that human life had developed with some divine involvement and 1 in 10 (a greater proportion than at the faith school) agreed that "human beings were created by God pretty much in their present form", i.e. held the creationist stance.

From the students' perspective, as revealed in the focus groups, the two subjects have very different characteristics. For many, science constitutes a collection of facts and evidence about how the world operates, whereas RE addresses questions of "why?" by comparing different beliefs. Contrary to the picture painted by the teachers, very few of the students recalled religious explanations featuring in science classrooms when tackling the origin of life. In RE, they identified an emphasis on airing and exploring opinions through more discursive approaches, which might well include comparing religious and scientific perspectives.

Some religious students perceived their science teachers' approach as blinkered and frustrating because it eliminated or ignored their world view. But there was a minority opinion that religious views should not be considered in the science classroom, because it might be confusing or unsettling. One Muslim student, for instance, made it clear that she did not accept the scientific explanations but she would resent any attempt to raise the conflict explicitly:

I think they should keep it the way it is, the way that we only talk about scientific parts...you know I've been saying that we shouldn't have to question our faith...I think we should just learn about the whole process of the Big Bang, we shouldn't talk about the different religious views in science.

Students, regardless of their own personal religious beliefs, were asked how religiously motivated challenges to scientific explanations of the origin of life should ideally be dealt with in the science classroom. Consistently, their prime concern was that religious beliefs be acknowledged with respect and sensitivity. However, it was considered important that the teacher make clear that the scientific version takes precedence in science lessons because this was what would be needed for the exam.

There was a spread of opinion among the surveyed teachers about whether the origin of life constitutes a controversial topic. Far more RE teachers opted for the non-controversial end of the scale (48%) than the controversial end (15%). The picture was more mixed among the science teachers, with over a third thinking it was not controversial (39%) and slightly fewer saying that it was (31%). However, the difference between the RE and science teachers was not statistically significant ($p>0.05$).

In terms of real life experience, significantly more science teachers found the origin of life controversial in their classroom compared with RE teachers (56% and 34% respectively, $p<0.01$). For science teachers, the problematic student perspectives almost exclusively took the form of resistance to the scientific explanation from students who took their religious teachings literally. RE teachers also encountered such standpoints, but were equally likely to experience issues with students who did not want to engage in the religious arguments at all and sometimes refused to treat religious beliefs seriously.

When the controversy was expressed through student discussion, some teachers welcomed this but others found it a negative experience. Although several teachers explicitly stated that the controversy provides positive opportunities for lively argumentation and debate, a minority found the polarised views difficult to deal with and demanding of careful classroom management, as illustrated by this RE teacher:

Some students are brought up with a belief in the literal interpretation of Genesis, others see Genesis as disproved–I need to ensure that both groups are respectful of others' views.

Most of the students in the focus groups claimed the issue was not controversial for them personally. There were four main reasons for this, three of which suggested easy border crossings into school science (Jegede & Aikenhead, 1999): firstly, some students were unconcerned because they had no religious beliefs or had never bothered considering the matter; secondly, some were religious but had no problems reconciling the explanations; thirdly, some thought how life originated was of minimal importance compared with the meaning of life. There was, however, a category (mainly, but not exclusively, Muslim students) that found the border crossing between religion and science impossible, and they rejected the scientific explanations so emphatically they did not engage with them. There was evidence of a limited group (represented primarily by a very small number of Muslims) who, whilst finding it a controversial and difficult topic that caused cognitive conflict, enjoyed the challenge of navigating their way - possibly through acculturation or even anthropological learning (Jegede & Aikenhead, 1999). This attitude is represented by the following quote from a Muslim girl:

Some religious people may have thought science is just trying to replace God. But 'cause we learn about religion and science together on a daily basis, we really have the choice to decide if there's a conflict or not.

Although several students perceived the issue to be non-controversial–for society at large as well as for themselves personally–others were aware that it could cause difficulties and that these were not always expressed. They recognised that a critical mass was usually needed before anyone was likely to contest what was being taught in class, regardless of the nature of the school, owing to fear of fellow students' reaction or in deference to the teacher.

In a similar vein, teachers in the case schools wanted to create an atmosphere in which students felt comfortable expressing their views, but they were concerned that this was not always achieved. To some extent, this was considered to be a function of the students' age. But a science teacher in the majority Muslim school was worried that her silent students were simply rejecting the scientific explanations out of hand–a concern supported by the focus group data reported above.

RE teachers expressed considerably more confidence covering scientific theories about the origin of life than science teachers felt covering religious beliefs (71% and 44% confident, respectively). This highly significant difference (p=0.001) is illustrated in Figure 4.

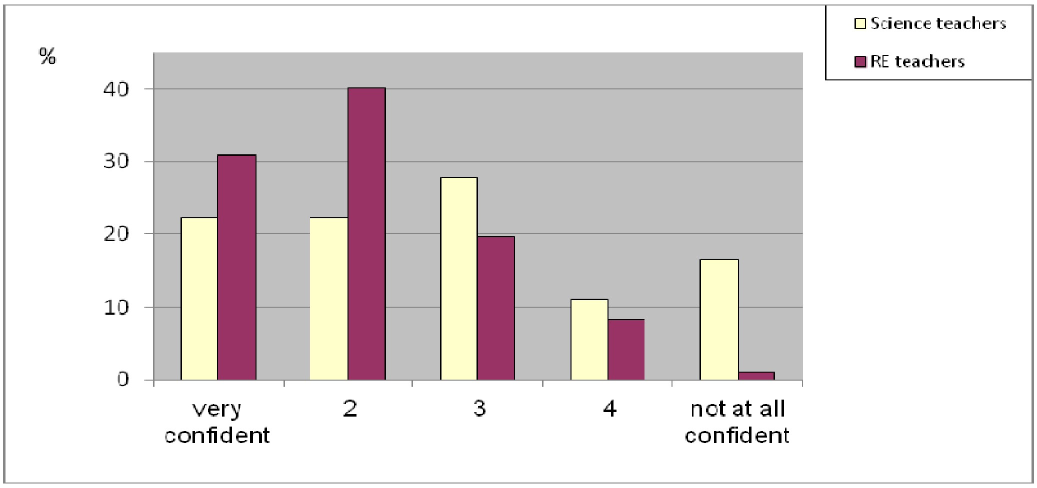

Figure 4
How confident do you feel about covering (religious beliefs*/scientific theories[+])
about the origin of life in the classroom?
(wording for *science teachers, [+]RE teachers)

In the questionnaires and interviews, some RE teachers worried that, whereas they had been trained to handle controversial and sensitive faith issues, science teachers might not have these skills. Meanwhile, there were a few science teachers who saw themselves locked in a battle for students' hearts and minds, as demonstrated by this quote from an interview with the Science department at the school with a non-faith context: *I hope they [RE teachers] don't teach it more strongly than we do–that wouldn't be fair*.

Despite the overlap in subject matter, it was rare for the two departments to work together: about three-quarters said there was very little or no collaboration at all, and just 4% of RE teachers (and no science teachers) reported "a lot" of collaboration. As the vast majority of the RE teachers were operating without input from their science colleagues, the basis for their confidence with scientific theories was unclear. Somewhat chastened, the Head of RE at one of the case schools recalled their struggles to explain the Big Bang theory to students who had not yet broached it in science:

...[we] hadn't anticipated first of all how hard that was–because it's something people talk about casually don't they, oh Big Bang theory, you know how it happens, don't you? Well, no, we don't know how it happens actually and then when you try and explain it to 13-year olds we realised what an enormous thing we'd bitten off.

Two of the case schools (the faith school and the school with a primarily Muslim catchment) were unusual in this regard. Both claimed to have some inter-departmental relationship, driven by consciousness of the religious nature of the student body. However, even in these circumstances most of the collaboration was at an informal level rather than integral to the way the curriculum was operationalised, and often depended on friendships between staff members.

5. Discussion

Even within this small sample it was evident that a range of attitudes and practices exist around teaching the origin of life. Recommendations about how best to cover the topic must recognise this diversity and be sensitive to different contexts. There was a mix of opinions about whether religious beliefs should feature when the topic is being taught in the science classroom, but the reality was that most of the science teachers and nearly all of the RE teachers were already including both scientific and religious explanations to some extent. However, this was happening in the context of little or no collaboration between the two departments in most of the schools surveyed. The findings suggest that building cross-curricular links could be valuable and indeed necessary for three main reasons:

- To ensure that scientific theories are represented accurately in the RE classroom. Although RE teachers expressed confidence in teaching scientific explanations, it is unclear how justified this was. In view of the extent of students' misconceptions about evolutionary theory and debates about how best to tackle these in the classroom (e.g. Jones & Reiss, 2007; Nelson, 2008), it is important that teachers in the RE classroom–where students may first encounter the theory–be adequately supported.
- To provide science teachers with the skills and confidence to sensitively handle any conflicts between the scientific and religious explanations for the origin of life. Science teachers can be uncomfortable dealing with ways of knowing outside the scientific, yet such approaches may be necessary to engage students with different world views.
- To assist those students who do experience a conflict between scientific and religious explanations of the origin of life. Different approaches might be appropriate, depending on the student. Rather than attempting to replace a religious view that clashes with the scientific and risking alienation from the topic, teachers might find it beneficial to adopt the role of "culture broker" to help students constructively engage with and manage the differences they encounter between the two (Jegede & Aikenhead, 1999).

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22 TOWARDS AN INTERLANGUAGE OF TALKING SCIENCE – EXPLORING STUDENTS' ARGUMENTATION IN RELATION TO AUTHENTIC LANGUAGE

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Abstract

In this paper we explore the idea that learning science involves appropriation of school science language and how it manifests in the classroom. This is done through an analysis of peer group discussions in Swedish secondary schools; discussions that served both as an arena for learning and as a research tool. In this arena, the students are offered opportunities to communicate, evaluate and argue knowledge claims. The analysis focuses on the intersection between social languages (colloquial and scientific), and epistemological/conceptual aspects of biological evolution. We explore how words (especially Vygotsky's meaning and sense of words) and semantic patterns manifest in the students' discourse. Specifications are made step by step in negotiations, and the groups of students talk more and more in line with school science language. We understand this to rely on the establishment of an arena where technical terms and scientific models may be introduced, negotiated, and made sense of, particularly in relation to personal and everyday experiences. The students use an interlanguge in which colloquial expressions serve as an asset in sense-making.

Keywords: social language; epistemological and conceptual aspects; biological evolution

1. Introduction

The most frequent applications of the notion *authenticity* (approximate meaning: genuine and trustworthy) in science education refer to 'doing science', either as performed by practicing scientists or as some kind of activity in the students' local environment. In this paper we explore the notion of authenticity in relation to the use of language, since this aspect of doing science is closely connected to learning science in that learning science involves appropriation of the language of science. One suggested way of making school science more authentic is to introduce an argumentative practice in schools, and Jiménez-Aleixandre and Erduran (2008) claim that argumentation can also contribute to scientific literacy, critical thinking, higher-order cognitive processes, and enculturation in scientific culture.

Authentic and genuine language relates to Bakhtin's (1981) notion of social languages being understood as characteristic discourses within subgroups in society, for example professions, interest or age groups. The prevailing use of language in the science community is an example of a social language, and another is the everyday/colloquial language that the students enter school with, a language which originates from everyday experiences

(Vygotsky, 1986). Thus, two kinds of authentic language, the scientific and the colloquial, come into contact in the classroom.

The use of language in school has to take into consideration the idea of code switching (Lemke, 1990) between languages. The ability to use, translate and distinguish between social languages is one of the aims of science education, and the more confidently the students move between languages, the more mature their understanding becomes (Mortimer & Scott, 2003). As the students work toward making sense of scientific language through the use of everyday language, they may develop a new hybrid language–an *interlanguage* (Barnett, 1992; Lemke, 1990). This is a more personal, dynamic, and mixed language in which everyday expressions are a resource, not a hindrance, in sense-making. With the code switching–the use of interlanguage–the possibility of bridging between informal and formal accounts of phenomena increases (Brown & Spang, 2008; Gomez, 2007). The bridging between social languages through interlanguage has been shown to be a productive construct, both when it comes to informing teaching and as an analytical tool in research (cf. Ash, 2008; Brown & Ryoo, 2008; Varelas, Pappas, & Rife, 2006).

The aim of this paper is to explore how the argumentative practice manifests in the classroom, specifically the relations between content-oriented aspects and generic patterns such as social languages. The content concerns biological evolution, an area that continually causes dilemmas when students try to make sense of the scientific view (cf. Bishop & Anderson, 1990; Hokayem & BouJaoude, 2008). The analysis focuses on argumentation in peer group discussions about the origin of biological variation with the following research questions:

- What conceptual notions and epistemological patterns are negotiated in the students' discussions?
- In what ways do colloquial, inter- and school science language manifest themselves in the students' discussion?

2. Research design and methodology

2.1 Sample, context and data collection

The data were generated in a Swedish upper secondary school and included 48 students from two classes participating in the natural science program. The school is a public (municipal) school situated in a middle-class suburb with some rural features; it is the only secondary school in the municipality. It offers all of the national study programmes and attracts most of the students in the vicinity. The students were 17 years old at the time and it was their second year at the school, but their first course in biology.

In this lesson, the students formed three groups, which were divided by the teacher into 12 small groups moving from one activity to another in the order that was most convenient. In all, 29 students in seven of these small groups, most consisting of four members, gave permission to be video-taped. For the discussion, they went to an adjacent room, turned on a video camera, discussed, turned off the camera and continued to the next activity. The remaining 19 students in five groups held their discussions in another room. The students were told that the teacher would not see the tape until the course had ended and grades had been given.

The multiple-choice task discussed by the students was introduced by the teacher as follows: 'Comment on the alternatives one by one and argue for and against. Then, if you are able, come to a mutual agreement. We will follow up the discussion in the next whole class lesson'. The task to be discussed was formulated as:

"Throughout the course of evolution, living organisms have developed a lot of different traits. What is the origin of this enormous variation?

- The traits arose when they were needed
- Random changes in the gene pool of the organisms
- Living organisms strive to develop
- Great variation is needed in order to achieve a balance in nature"

The students' discussions were structured and framed by the formulation of the task. The wording pre-supposed that evolution had taken place and that there is intraspecies variation in traits. The alternatives in the multiple-choice question were designed to illustrate common ideas about the origin of variation.

2.2 Analytic procedure

The analysis principally consisted of three steps:

- Quantitative and qualitative descriptions of what notions were important in the students' discussion.
- Looking at the meaning and sense of the most frequent notions in the students' discussion and dividing the students' discourse into sequences, each of which could be described as colloquial, inter-, or school science language.
- Looking at the interconnections between different social languages in longer parts of the discourse.

After concluding the first step in the analysis, we attempted to understand the ways in which the students made sense of and expressed the meaning of the three central notions: need, randomness, and development. The starting point of this analysis was Vygotsky's (1986) distinction between meaning and sense: *meaning* is the stable, generalised, collective and lexical zone of a word, which in this analysis is close to the scientific language (the way in which the notions are supposed to be understood); *sense* is the situated, personal, local and creative part, dependent on the context of the dialogue, which is how the students interpret and reformulate the notions in their talk. By describing the sense made of the three notions in the students' conversation, and comparing this to the meanings of the notions, we attributed sequences of the conversation to three types of social language: inter-, colloquial and school scientific language. Our hypothesis was thus that these predefined social languages could be empirically discerned and distinguished. These initial definitions of the three social languages were based on a synthesis of the literature on everyday and scientific language (principally Lemke, 1990; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001; Wellington & Osborne, 2001), discourse and interlanguage (principally Ash, 2008; Brown & Spang, 2008; Gomez, 2007), and everyday/colloquial and scientific concepts (principally Roth, 2008; Vygotsky, 1978; Warren et al., 2001). We formulated an explicit definition to use as an analytical guide in this work (see Olander, 2010, for a more thorough discussion):

Colloquial language is open, allowing for the discussion of most topics, as well as different ways of reasoning side by side, and claims can be based on personal experiences. There is room for true recognition of values and emotions, and in fact the talking often points towards values. A consequence of this openness is that great specificity in what is said is not required. Colloquial language is oriented towards oral discussions and is informal in nature.

*Inter*language is characterised by bringing elements of scientific consideration together with personal experiences. It involves translations between languages that open up an arena where talk is more freely constituted, for example, does not adhere specifically to the standards of scientific communication.

School science language is characterised by restrictions on what is discussed and the ways in which it is discussed, for example, talk is more objectified and values become more peripheral. It displays specificity with regard to how notions are used and it is productive in expressing complex causal relationships; claims are based on models or general ideas rather than on personal experiences. The school science language is oriented towards written text production and also displays a degree of formality when used in oral discussions.

In this way, sequences (often one 'sentence' or claim) on need, randomness and development were linked to the three languages. This second step in the analysis proceeds from the level of analysing words to analysing thematic patterns. The foundation and starting point of the analysis is 'notions', but these notions are embedded in utterances that may be somewhat diluted thematic patterns. On the other hand, these utterances are made in all three languages, and as such they contribute to researchers'/teachers' understanding of the students' sense-making of the notions.

To discern how thematic patterns were articulated within the different types of language, which was our third step in the analysis, it was necessary to go back to the whole data set and look specifically for sequences in the discussions where the use of language fluctuated.

3. Findings

This section first presents the overall findings of prominent conceptual notions and epistemological patterns. Then a representative excerpt is given to provide a more detail analysis of these notions and patterns in relation to social languages.

There are three prominent conceptual notions in the students' discussion–key notions taken from the four alternatives presented in the task. These are need and randomness (in particular in relation to each other) and development, both generally and in the context of biology (synonym for "evolution"). The meanings of these notions are dealt with, the context in which they should be understood is negotiated and they are contrasted to their opposites. The use of these conceptual notions in the students' conversation is part of a process of learning. Their use is directed towards making sense, here (at least partially) in relation to the given discussion task. In relation to the three predefined types of languages (colloquial, inter-, and school scientific) several mutual characteristics of students' sense-making emerged.

In colloquial language, students mainly rely on a non-specific interpretation of the notion, often the most generally applicable one, and explanations have strong indications of intentionality. However, reasoning with teleological logic is most frequent, for example 'need in order to survive' or 'developed according to environment'. Value words often reinforce intentionality, for example, development has an implication of improvement. The intended interpretation of the notions and events is often seen as natural and is assigned a taken-for-granted domain of applicability; thus there is no need to explain events.

Interlanguage enables negotiations and delimitations of what the notion is and is not, for example, that randomness is not the only process that explains the development of traits. Furthermore, students explicitly argue that the individual's need and striving for development are not necessary for explaining traits. Technical terms are used, although sometimes in a tentative and mimicking style. When value words such as good/bad/right are used, they are not contextualised with clarifications, for example, what constitutes a good or bad trait in a specific environment.

In school science language, students specify the meaning of notions and mainly link examples to general models or theories. This is done in congruence with a theory or model, for example, need is seen as a result of selection and refers to a 'group' rather than to individuals. Random changes plus environment may lead to selection. Development is seen as a two-step process, starting with an existing variation followed by selection. Value words are appropriately contextualised, for example, 'better trait' is delimited to mean resistance to penicillin in an environment with penicillin.

Thus, the prominent notions were articulated in all three types of languages, and Table 1 exemplifies this with the notion *need*.

Table 1
Examples of students' discourse on the conceptual notion of need

Colloquial language	Interlanguage	School scientific language
- Because it isn't necessary, they don't need it in order to survive	- If everything was great and they had all the traits needed in order to survive in an environment, they hadn't changed for the worse, they change for the better	- Not originated because it was needed, but remained when it was needed in that case

The task of argumentation leads to the students directing their conversation towards building arguments and slashing claims, and in the process, explanations are generated. This allows for more overarching themes to emerge, and forms part of the epistemological pattern. On the one hand, we can identify epistemological resources–the referents of knowledge and assortments lending weight to their plausibility–and on the other hand, epistemological structures–the ways in which notions, explanations, examples, and accounts are linked and constructed. There are three primary dimensions of epistemological patterns visible in the students' argumentation:

- referral to resources– "sources of knowledge" –for example, through naming resources or through linking
- generation of explanations–primarily teleological or causal
- linking between general accounts and specific examples

In each of these dimensions, the argumentation can have different qualities. In particular, it can have more or less scientific quality (scientific vs. colloquial nature). Links between the general and specific can be systematic rather than sporadic, explanations can be causal rather than teleological, and resources can be theories rather than names, which can be linked and integrated rather than named. In this way, an overall quality of the students' discussion can emerge in terms of scientific reasoning. The weakest quality in terms of scientific reasoning is when argumentation solely involves the naming of references (for example, a single name like *Darwin*) while the strongest integrates theoretical resources with causal explanations that also link the general theoretical resource to its manifestation in specific situations.

3.1 Excerpt

As already mentioned, this excerpt exemplifies, in a representative way, the overall findings described above. In this group discussion, the students immediately head into a dialogue about whether the need for traits is an appropriate explanation for their origin. Contextualising their discussion in the development of webbed feet and in surviving DDT, the time scale and rate of change appear as important elements of the validity of the different arguments. In that way, the students consider a teleological explanation and contrast it to a causal one, making use of both need and development.

The discussion starts with Alice identifying the first claim about need as important:

01 Alice: the traits arose because they were needed [alternative one in the task]

02 Anna: I think that the first is right because…wasn't it a duck or something…it would've got some of its webbed feet cause it lived in water…because it is there, it must have developed to become better

Anna starts the argument by attempting to link the general claim in the task to a specific example: the webbed feet of ducks (an example previously used by the teacher). Within that context, Anna starts to construct an explanation: "webbed feet cause it lived in water", making need the origin of development and thus variation–a teleological explanation.

Amber continues to another specific example, quickly passing by the general claim:

03 Amber: yeah, I think it might be a little bit correct in that the traits were needed…for example, with DDT that was used once and that some insects became

04 Anna: resistant

05 Amber: yeah, exactly

Amber attempts to start constructing a parallel teleological explanation for the DDT example, supported by Anna. Amy refutes that explanation, by making a different kind of attempt:

06 Amy: you know, what I think is that there are random mutations and those mutations that favour their further survival they stay…because if it arises, one of those mutations that makes it resistant, then it survives and then their children survive and then that gene stays in the species, and it is thus random variation that arises

Amy gives a general account, linking to the present example through "one of those mutations that makes it resistant", attempting to link them in a causal manner. Anna does not fully agree:

07 Anna: yes, but it still has to develop too

This may be due to different conceptualisations of "develop", where Amy implicitly talks about development, understood as evolution, while Anna uses develop in a more colloquial sense. Amber is not convinced, and attempts to refute Amy's argument by introducing a before and after:

08 Amber: but it wouldn't have been earlier

09 Amy: no cause then it wasn't needed to survive cause then there was no such DDT and it stayed when it was needed, it favours them then…

Amy uses the notion of need differently from its previous use. She gives it a crucial role in determining selection, rather than using it to describe the origin of variation (see 01 Alice above). Amy further emphasizes the selection in the DDT context:

11 Amy: it [DDT] is so strong that it kills everyone without that resistant gene…it was only those [with] that survived

12 Alice: and then they multiplied

13 Anna: okay, with DDT, because it happens fast, but I still think that when it comes to webbed feet that have developed during long time…I think it developed because it was needed

However, Anna only recognises selection in the DDT context, and by going on to the other specific example and introducing a distinction between them (an argument for the contexts being different) in terms of different durations ("happens fast" versus "during long time"), Anna mainly repeats the earlier teleological explanation, apart from stressing the time aspect and the gradual development. Amy is prepared to contrast that explanation to a causal one:

14 Amy: no, a gene appears and if it has some more web then, than the old one…you find that it swims better, gets food easier, it gets…then it survives

Amy now makes the argument much within the context of the example, constructing a causal explanation for webbing. Alice and Anna agree through a very similar argument:

15 Alice: if you imagine that the ducks in the beginning were land birds, and then some started to get web, and then it favoured them in swimming, and those who didn't have any web crawled onto land

16 Anna: they developed their own type of foot

17 Alice: exactly

But now Anna draws the opposite conclusion, and the process of development is discussed:

18 Anna: then they developed because they needed it

19 Alice: no they who were webbed stayed in the water

20 Anna: and got more and more web

21 Alice: yes but not because they needed it

22 Anna: they develop it because

23 Amy: they can't think, I need that gene

24 all: no no

Anna uses development as "change because" and "improvement", while Amy and Alice argue for development as "change" and "selection". Anna agrees, while stressing that it takes time:

25 Anna: but it takes a really long time

26 Amber: I would agree if they changed origin to development [in the task text: "the origin of this enormous variation"], cause I think that it makes a difference

27 Amy: well essentially this is what happens [points to alternative two: "Random changes in the gene pool of the organisms"]

28 Alice: they developed but not

29 Amber: I don't think that number one has to imply that now I need it and then I get it

30 Amy: not originated because it was needed but remained when it was needed in that case

In the final turn, Amy again emphasises that random change is important for the origin of variation while need is important for variation to remain. The students then go on to discuss a new context similarly.

In summary, here are the conceptual notions coupled to the epistemological pattern: need is tied to selection, while development is tied to randomness and variation when causal explanations are constructed; need is tied to the origin of variation and development is used instead of selection when teleological explanations appear. Underlying the entire discussion is the ontological framing of whether things in nature happen for a particular purpose.

4. Discussion and implications

The students chose to focus their discussion on three conceptual notions, and it is perhaps not surprising that need and randomness were prominent given that the multiple-choice question being discussed was seeded with insights from an initial didactical analysis of making sense of intraspecies variation. Despite the rich literature on notions, we would argue that our analysis provides new insights and detailed examples in classroom practice into how students make sense of these notions, especially in light of social languages. The students also negotiated the notion of development, which is a theme that is relatively less touched upon in the research literature. We assume that there are two reasons for students' willingness to negotiate their understanding of the notion of development, one of which is due to the Swedish language. In colloquial Swedish and in school science, the word development replaces evolution more or less interchangeably. However, there are several connotations of the word development, which may have different merits when used scientifically. For example, it could mean that somebody develops an idea or a habit, an engine develops heat or children develop into adults. The other reason is that the word development (as well as evolution) is often conceived of as development towards something, for example, better conditions.

The notions of randomness and need are used as opposites when students explain the origin of intraspecies variation. Both notions are productive, and the more colloquial notion–need–is an intellectual resource when explaining the origin of variation. Without delimitations or negotiations on the notion of need, the school scientific explanation would have been less nuanced and accurate. We argue that colloquial expressions such as 'need in order to' triggers refinements in line with scientific language, such as *not originated because it was needed, but remained when it was needed in that case* (turn 30). The actual process of constructing explanations could be described as learning, although it is hard to separate articulation from learning since they "go hand in hand, in a mutually reinforcing feedback loop" (Sawyer, 2007, p. 12).

The epistemological dimensions mainly touch upon the nature of science in general, such as how to link general and specific accounts in a systematic way, but some aspects are especially pertinent in the domain of evolution. One of these is the epistemological issue of causal or teleological explanations, and we suggest a discussion of preferred explanations in natural science versus legitimate explanations in other sciences and, for that matter, daily life.

The students' discourse also brings to light aspects of argumentation quality, for example, the argumentation from Alice and Amy shows more scientific qualities than that from Amber and Anna. Alice/Amy consistently refer to causal explanations in relation to all proposed examples and turns 15 to 24 show this in a condensed way. Here Alice and Anna together construct an example (15) about birds in water, which now have webbed feet, but they interpret it in two different contexts. The different views deal with the direction of cause and effect. It is stated by Anna as "they developed because they needed it (in the water)" which is contrasted by Alice with "they who were webbed stayed in the water". These rather minor differences in articulation are then negotiated, probably because they indicate a teleological and a causal explanation, respectively. The resources that Alice/Amy refer to are theories and models (see for example turn 6). They persist in this in all examples, while Amber/Anna apply different models to different examples, in this case developing webbed feet and surviving DDT. An interesting sidebar is that both pairs of students co-construct their arguments throughout the conversation, which supports the conclusion in Bennett, Hogarth, Lubben, Campbell and Robinson (2010) that the outcome of a small group discussion is positively dependent on the diversity of views represented in the group. Such diversity increases, according to Wegerif (2008), the chance of opening a 'dialogic space' where different views are present and held in tension in an arena where different social languages are brought into contact and contribute to the students' sense-making process.

The implications for classroom practice include the above detailed descriptions of how conceptual and epistemological issues are dealt with by students in their authentic vocabulary. On a more general level, this implies a greater awareness of how the specific content is communicated in the classroom, and our research suggests that the presence of colloquial language is not problematic in and of itself. On the contrary, what we observed is that over time during the students' discussion, the scientific quality of their explanations improved. The differences between the three notions are discursive delimitations, i.e., it is a matter of specifications of their meanings. For example, specifications are made step by step in negotiations, and the student groups interpret the notions more and more in line with school scientific language. We understand this as relying on the establishment of an arena where technical terms and scientific models may be introduced, negotiated and made sense of, in particular in relation to personal and everyday experiences. In this way, this interlanguage discourse is an arena for learning.

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23 EVOLUTION THEORY TEACHING AND LEARNING: STUDENTS' CONCEPTUAL ECOLOGIES AND TEACHERS' PERCEPTIONS

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Abstract

Using conceptual ecology for biological evolution as a theoretical frame, we explored: factors related to acceptance of evolutionary theory (E.T.) by pre-service teachers of Early Childhood Education (ECE) (student teachers' study), and biology teachers' conceptions, attitudes and teaching of E.T. (in-service biology teachers' study). Specifically, we explored the understanding and acceptance of E.T. among pre-service ECE teachers, and the relationship of that acceptance, taking into account their understanding of E.T. and their parents' educational level. Another important factor was religiosity of these student teachers and their families.

In the student teachers' study, a total of 168 future teachers in ECE were surveyed by filling out a questionnaire. We found moderate acceptance of E.T. to be positively correlated with restricted understanding of E.T. Acceptance was negatively correlated to pre-service ECE teachers' and their parents' religiosity. We did not find any significant correlation between parents' educational level and student teachers' acceptance of evolution. In the biology teachers' study, most interesting was the near non-existence of E.T. teaching in Greek secondary schools, due mainly to lack of time. Teachers asserted lack of knowledge about evolutionary issues; they did not report social pressure against evolution teaching.

Keywords: evolution theory; conceptual ecology; acceptance; knowledge; religiosity

1. Introduction

Evolution theory (E.T.) is broadly accepted as the central and unifying theory of biology. However, despite its significance, regular polls show that the acceptance of E.T. is restricted across adult populations in different countries (Miller, Scott, & Okamato, 2006). Moreover educational research shows that the acceptance of E.T. is restricted and knowledge is limited and controversial among school science students and teachers (Demastes-Southerland et al., 1995; Deniz, Donnelly, & Yilmaz, 2008; Peker, Comert, & Kence, 2010).

For students to become biologically literate, it is essential that they develop a meaningful and scientifically accepted understanding of E.T. However, results from several studies suggest that instruction in evolutionary biology at the high-school level has been absent, cursory, or fraught with misinformation (i.e. Pazza, Penteado, & Kavalco, 2010; Prinou, Halkia, & Skordoulis, 2008). Nehm and Schonfeld (2008) claim that educational research must explore (1) the precise interrelationships among cognitive, affective, epistemological, and religious variables that contribute to anti-evolutionary views in individuals of different ages and educational backgrounds (e.g., Colburn & Henriques, 2006; Dagher & BouJaoude, 1997; Ingram & Nelson, 2006; Sinatra, Southerland, McConaughy, & Demastes, 2003; Southerland & Sinatra, 2003); (2) the design, implementation, and evaluation of interventions that promote accurate cognitive models of evolution (Kampourakis & Zogza, 2008), and (3) methods for reducing levels of anti-evolutionary attitudes in students and teachers. Our project falls within the first line of exploration related to E.T. teaching and learning, as we accept that for both students and teachers, acceptance of E.T. is important for a number of reasons.

It is reasonable to expect that biology teachers' and students' attitudes toward E.T., and mainly acceptance of E.T., will influence evolution instruction (Aguillard, 1999). Therefore, studying the acceptance of E.T. as part of the conceptual ecology (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992) for biological evolution is more promising than studying the acceptance of E.T. in isolation. This is because, in this theoretical frame, the fundamental importance of a number of factors is recognized in controlling learning (Strike & Posner, 1992).

Conceptual ecology in the initial conceptual change model was primarily restricted to the cognitive domain. Later, in response to criticism, Strike and Posner (1992) acknowledged that a wider range of factors needed to be considered to describe a learner's conceptual ecology. These factors serve as the changing conceptual environment in which conceptual change occurs; thus, conceptual ecology controls and modifies this process. This revised conceptual change model was called "revisionist theory of conceptual change" and the importance of the roles of intuition, emotion, motives, and social factors was acknowledged (Strike & Posner, 1992). However, even the revised conceptual change model was subjected to severe criticism, for remaining largely cognitive in emphasis. Another attack came from the world view theory of Cobern (1996), who considered world view as a combination of a number of components, including religion, gender, ethnicity, and science views. Cobern (1996) criticized the conceptual change model because it assumes that learners subscribe to a "scientific" world view by not considering that scientific views are only one component among many competing components in one's world view. World view surfaces especially when a controversial issue such as evolution is taught. For this reason, Cobern (1996) stated that it is not surprising to see some students fail to develop orthodox scientific conceptions even after carefully designed instruction due to interference from other components of their world view. Southerland and Sinatra (2003) believe that continued focus on the intersection of affective and cognitive factors is called for, as we begin to recognize that learning is not solely determined by the characteristics of the content in question or unconscious attributes of the learner (i.e., reasoning ability, background knowledge). All of these models highlight the role of acceptance in learning and specifically, according to the "revisionist" model, acceptance can prohibit the possibility of true conceptual change.

Factors that together are called learner's "conceptual ecology" of evolution theory have been documented in previous research. Demastes, Good, and Peebles (1995) described the conceptual ecology for biological evolution. Acceptance of E.T. is part of this conceptual ecology, which also contains the following five components: (1) prior conceptions related to evolution–understanding of E.T.; (2) scientific orientation (degree to which the learner organizes his/her life around scientific activities); (3) view of the nature of science; (4) view of the biological world in competitive and causal terms as opposed to aesthetic terms, and (5) religious orientation.

Based on the evolution education literature, Deniz et al. (2008) identified four more factors that are potentially related to acceptance of E.T. These include students' (1) reasoning level

(Lawson & Thompson, 1988; Lawson & Weser, 1990; Lawson & Worsnop, 1992; Sinatra et al. 2003; Woods & Scharmann, 2001); (2) perceptions of the impact of E.T. (Brem, Ranney, & Schindel, 2003); (3) epistemological beliefs (Sinatra et al., 2003), and (4) thinking dispositions (Sinatra et al., 2003). Deniz et al. (2008) added parents' educational level as a factor related to E.T. acceptance.

According to Smith's review (2010), science education research has taken an interest in the possible relationships among accepting, believing, and understanding evolution, and in particular, whether the constructs are correlated and if so, the direction of causation. Some studies have shown positive correlations between acceptance and understanding, explaining almost half of the variance in understanding among US in-service teachers (Rutledge & Warden, 2000); in other studies (i.e., among Turkish pre-service teachers), the understanding of evolution alone was able to explain only 3.3% of the variance in acceptance of E.T. (Deniz et al., 2008). Still other studies have found no statistical relationship between these variables (Brem et al., 2003; Lawson, 1983; Meadows, Doster, & Jackson, 2000).

Built on previous research, the present study–part of a wider one on E.T. conceptual ecology and its influence on learning processes–focused on the factors which make up the conceptual ecology of E.T. in Greek students–pre-service teachers of Early Childhood Education (ECE). From the aforementioned factors, we chose to investigate acceptance and understanding, in addition to the educational level and religious orientation of the pre-service ECE teachers and their parents (student teachers' study). The following research questions were explored: (1) To what extent do pre-service ECE teachers accept and understand E.T.? (2) What is the relationship between pre-service ECE teachers' acceptance and understanding of E.T.? (3) What are the effects of some socioeconomic and demographic variables (i.e. parents' education level and religious orientation) on pre-service ECE teachers' acceptance of E.T.?

Teachers' attitudes are known to be strongly influential in the success of the curricula they present, and their characteristics, attitudes, conceptions of self, and intellectual and interpersonal dispositions can influence both the explicit and hidden curriculum in the classroom. It is also recognized that factors contributing to a teacher's willingness to implement the curriculum include his/her knowledge level of the subject, perception of the importance of teaching the subject, and level of comfort with the subject. In our study, we also focused on biology teachers' conceptions and attitudes concerning E.T. and their teaching as a very interesting part of evolution education description.

Greek society and its educational system are interesting from a biological evolution point of view: it has been very successful in exiling evolution education from its "territory" (Prinou et al., 2005; Prinou, Halkia, & Skordoulis, 2008) without any profound persecution or the like. The latter might be correlated to the characterization of Greek society as potentially one of the least "evolution"-educated societies in the modern world. Thus, it seems very probable that this lack of proper education may be related to the fact that this society possesses one of the lower positions on the evolutionary acceptance scale (Miller et al., 2006), being only a few positions above the USA and Turkey in rank.

2. Methods

2.1 Student teachers' study

Participants: A class of future teachers enrolled in an introductory biology course in the Early Childhood Education Department of the University of Athens, Greece participated in the study. Participants in the Early Childhood Education Department have the same educational background in E.T. as the average educated person in Greece. As already mentioned, Greek society might be characterized as one of the least "evolutionary"-educated societies in the modern world and it can be said that the only access that these pre-service ECE teachers have to E.T. is from newspapers, TV documentaries and any scattered information the teachers pass on by their own initiative.

Procedure: We surveyed pre-service ECE teachers during the winter semester of the academic year 2008/09. Our survey took place on the first day of the course by the first author. We received 168 completed questionnaires and responses were used in our subsequent analyses. The measures examined in our survey are presented in the first column of Table 1.

Data collection: Demographics–Pre-service ECE teachers responded to two demographic questions on their parents' educational level, which was measured using six possible options: illiterate-0, elementary-1; junior high school-2; high school-3; university-4; masters and doctorate-5. The highest educational level achieved by either of the parents was used in the analysis.

Understanding–Pre-service ECE teachers' understanding and knowledge of E.T. was estimated by means of a scale with 13 questions consisting of two subscales, one with 8 questions and a Correct-False-Do not know probable answer, and the other with 5 multiple-choice questions. The first subscale had to do with understanding of very basic principles of E.T., the second with understanding of procedures and practices on the evolution of populations. Scoring was as follows: a correct response to a statement received a score of 1 with a probable scale maximum score of 13. A wrong response received a score of 0, so the scale's probable minimum was 0, representing a little understanding.

Acceptance–To assess pre-service ECE teachers' acceptance of E.T., we used the MATE (measure of acceptance of the theory of evolution) scale, developed by Rutledge and Warden (1999). MATE consists of twenty Likert-scaled items containing statements that address the fundamental concepts of E.T. and the nature of science: the processes of evolution, the available evidence of evolutionary change, the ability of E.T. to explain phenomena, the evolution of humans, the age of the earth, and the scientific community's view of E.T. (Rutledge & Sadler, 2007). To score the MATE, we followed Rutledge and Warden's (1999) procedure: (1) the scaling of responses was reversed such that responses indicative of a high acceptance of E.T. receive a score of 5, while answers indicative of a low acceptance receive a score of 1; (2) an individual's score on the MATE was equal to the sum of the scaled responses of all 20 items.

Religious orientation–Pre-service ECE teachers' and their parents' frequency of participating in ecclesiastic activities was recorded by three questions. We chose this parameter as the closest determinant of religious orientation. We calculated a total score of religious orientation (by adding pre-service ECE teachers' and their fathers' and mothers' religious orientation) and in a consequent analysis, we used both scores: individual student teacher's and total religious orientation.

Data analysis: Means, standard deviations, and maximum and minimum of surveys' responses were calculated with the SPSS package and are presented in Table 1. Correlation estimates exposed a weak but significant correlation between understanding E.T. and accepting E.T., students' religiosity and accepting E.T., and total religiosity and accepting E.T.

Table 1
Means, standard deviations, and maximum and minimum scores of survey responses (N=168)

	Mean	SD	Actual	
			Maximum	Minimum
Acceptance of evolution (MATE) *(theoretical max 100-min 20)*	70.95	7.58	90	41
Understanding of evolution - Total scale *(theoretical max 13-min 0)*	5.04	1.59	9	1
Subscale 1 *(basic principles of the evolutionary theory*) *theoretical max 8-min 0*	3.32	1.22	7	1
Subscale 2 *(procedures and practices on the evolution of populations) theoretical max 5-min 0*	1.76	0.93	4	0
Parents' education level *(theoretical max 5-min 0)*	4.35	0.84	5	1
Religious orientation *(theoretical max 12-min 0)*	6.37	2.81	12	0
Students' religiosity *(theoretical max 4-min 0)*	2.07	0.99	4	0

2.2 Biology teachers' study

Ten in-service secondary-school biology teachers, with teaching experience ranging between 4 and 30 years, participated in the study. Nine teach in public schools and one in a private school. We implemented a semi-structured interview with items about E.T. understanding, acceptance and related beliefs, and items about teaching methods and other issues related to their everyday teaching experience. There were also items about the E.T. courses they had attended in their undergraduate studies and their feeling of adequacy in understanding and teaching E.T. Data were processed with NVivo 8.0.

3. Findings

3.1 Pre-service ECE teachers' study

All of the factors related to pre-service ECE teachers' conceptual ecology are presented in Table 1. Specifically:

Knowledge: As expected, knowledge on E.T. was very low (Table 1), with an average total score of 5.04 and 60.9% of the participants scoring from 1 to 5. This score represents both knowledge subscales. In subscale 1–basic principles of E.T.–mean score was 3.32 with 57.1% of the participants scoring from 1 to 3. In subscale 2–procedures and practices on the evolution of populations–mean score was 1.76 with 82.6% of the participants scoring from 0 to 2. Knowledge levels of in-service ECE teachers were a little higher (mean score 6.04) but still lower than that of in-service primary school teachers (mean score 6.39), biology teachers (mean score 8.19) and secondary school science teachers, except biologists (mean score 7.70) (Katakos, Papdopoulou, & Athanasiou, 2011).

Table 2
Comparative scores of E.T. acceptance, measured with MATE scale

Country	Population	Sample size	Mean score of acceptance	SD
USA (Trani, 2004)	Oregon biology teachers	82	85.9	17.48
New Zealand (Campbell & Cook 2003 and personal communication)	Secondary and primary school teachers	36	84.55	-
USA (Rutledge & Warden, 2000)	Indiana biology teachers	552	77.59	19.83
Greece	Pre-service ECE teachers	168	70.95	7.58
USA (Rutledge & Sadler, 2007)	Non-biology majors (test)	61	55.87	17.407
Turkey (Deniz et al., 2008)	Pre-service biology teachers	132	50.95	9.76

Acceptance of evolution: A MATE score of 70.95 shows that a substantial number of our participants did endorse a moderate acceptance of E.T. We classified acceptance score as moderate according to Rutledge and Sadler's (2007) categories (20-52: very low, 53-64: low, 64-76: moderate, 77-88: high and 89-100: very high). Comparative results for acceptance of E.T. (MATE measurements) are presented in Table 2. The mean acceptance score was higher than measures in similar populations in the USA (Rutledge & Sadler, 2007) and to our astonishment, close to or even higher than the mean score of biology teacher samples in the USA and Turkey (Rutledge & Warden, 2000; Deniz et al., 2008).

Parents' educational level: We noted a high parent educational level (Table 1), with mean 4.35, in which 53.3% of the participants placed their father's or mother's education at university level and 35.3% at high-school level. Acceptance levels recorded for in-service ECE teachers were a little higher (mean score 72.73), but still lower than scores for in-service primary school teachers (mean score 75.28), biology teachers (mean score 80.25) and secondary school non-biology science teachers (mean score 76.25) (Katakos et al., 2011).
Religious orientation: We recorded a mean score of 6.37, with partial scores for pre-service ECE teachers of 2.07, their fathers 1.93 and mothers 2.36.

Correlations: We found a significant, albeit weak correlation between participants' knowledge of evolution and their acceptance of E.T. ($r=0.20$, $p<0.05$). We state, with caution, that this finding indicates that participants who have more knowledge about evolution are more likely to have a high acceptance score of E.T. We did not find a significant correlation between parents' education level and participants' acceptance of evolution. We found a significant, albeit weak negative correlation between pre-service ECE teachers' religiosity and acceptance of E.T. score (r=-0.20, $p<0.05$) and total religious orientation and acceptance of E.T. score (r=-0.25, $p<0.01$). Whereas this correlation is negative, we can assert, again with caution, that this finding indicates a reverse relationship between religiosity score and acceptance of E.T.: participants who frequently take part in religious practices are more likely to have low scores of E.T. acceptance. Finally, note the absence of correlation between subscale 1 and 2 of understanding. This corresponds to the very low scores for E.T. understanding, so we assume that this represents a lack of competency to join basic principles of E.T. with an understanding of procedures and practices on the evolution of populations.

Table 3
Correlations among measurements

	1	**2**	**3**	**4**	**5**	**6**	**7**
1. Acceptance of evolution	1						
2. Understanding of evolution	0.20*	1					
3. Subscale 1	0.16	0.81**	1				
4. Subscale 2	0.07	0.64**	0.07	1			
5. Pre-service ECE teachers's religiosity	-0.20*	-0.01	-0.05	-0.00[1]	1		
6. Total religious orientation	-0.25**	-0.07	-0.10	-0.03	0.89**	1	
7. Parent education level	0.01	0.01	0.05	-0.03	0.05	0.10	1

*,**Correlation significant at the 0.05 and 0.01 level (two-tailed), respectively.

3.2 Teachers' study

Our main findings were:

Teaching E.T. in Greek secondary schools: Most teachers reported that they usually do not teach E.T. They asserted that the main reason was lack of time, as E.T. is the last unit in biology textbooks. They accepted that when E.T. is taught, it is only in Greek junior high schools.

"*Yes, in Gymnasium [Greek junior high school], in the third grade, one can teach E.T. You can omit one of the other chapters so that you can teach Evolution, because Evolution is in the last chapter…In Gymnasium, teachers have the freedom to make choices… According to the official guidelines we must teach all of the chapters of the textbook, but if time is insufficient it is unavoidable to omit a chapter…"* (female teacher, 11 years teaching experience).

Teachers did not report either encouragement or discouragement toward teaching E.T., with very few exceptions.

"…No people in charge, or school advisor in science, have ever told us anything against teaching evolution. But, also, nobody talks in favor of teaching evolution. Only in one case, during in-service teachers training–you know…the preliminary courses, Mrs. T., a teacher in charge at a center supporting School Science Laboratories, told us: 'If I were you, I would omit another chapter and I'd choose to teach evolution. If students will not hear something about Evolution in the 3rd grade, in Gymnasium, they will never hear anything about this topic.' And these words were…not encouragement…but a statement about what we can

do…we are concerned about other topics...why not teach such an interesting topic like Evolution for example…" (male teacher, 4 years teaching experience).

In high schools, E.T. is not necessary for students to complete schooling, as it is not included in the topics tested in the examinations needed for acceptance to Greek universities.

"...In high school we teach biology in the 2^nd^ and 3^rd^ years. In the 2^nd^ year, there is no evolution teaching included, you know, we teach about cells, molecules and metabolism. In the 3^rd^ year, evolution is in the 3^rd^ chapter of the textbook and it is never included in general Greek examinations [for universities]…except for one year…" (male teacher, 4 years teaching experience).

It is impressive that one of the teachers reported that he *"…cannot see a reason for teaching evolution in junior high school as it is not a prerequisite for students' further studies in high school…"* (male teacher, 25 years teaching experience).

Knowledge shortage: The teachers reported lacks in both subject matter and pedagogical knowledge concerning E.T. The first held true for teachers with a scientific background in biology as well. They reported a lack of preparation for teaching.

"...in university we had a course [about E.T.], it was for one term only. ...The content was about gene frequencies and so on but I think that this content was very specific…a high academic level. …Generally speaking, at university we were not taught a content appropriate for secondary school teaching…We are talking about proteins, but in such a complicated way, that it is not useful in education…It is not the aim of the university to prepare teachers, but to educate scientists and researchers…" (male teacher, 4 years teaching experience).

In-service teachers' training courses did not suffice to overcome this lack of competence.

"…various educational theories…theories that all result in active learning…but nothing related with teaching biology, nothing about evolution…You know training is for all science teachers together…" (female teacher, 11 years teaching experience).

Social pressure and religiosity: The teachers did not describe social pressure against teaching E.T. in either schools or other social settings. Most of the teachers believed that this is also true for their students. Teachers, especially the less experienced ones, did not believe that religiosity is an obstacle for teachers to teach or for students to learn evolution.

"No, I don't think so…that religiosity prevents any teacher from teaching evolution… Especially for students, I don't believe that they will have any problem to go against religion, not nowadays…" (male teacher, 4 years teaching experience).

Finally, it is worth noting that some of the teachers *experience a controversy between their religious beliefs and their scientific understanding,* but they try not to communicate this to their students.

4. Discussion

Our study was conducted in a country that is characterized by an almost total absence of teaching about evolution and has one of the lowest degrees of acceptance of E.T., combined with a high religiosity of the population (Eurobarometer, 2005). This context is quite different from that depicted for students' and teachers' groups in some previous similar studies (i.e. Greek-Orthodox vs. Catholic, Protestant and Muslim populations) (Dagher & BouJaoud, 1997; Deniz et al., 2008; Trani, 2004). This study, in the conceptual ecology framework, therefore combines the contribution of parameters of the cognitive domain, such as knowledge, and sociocultural factors, such as students' degree of religiosity and students' parents' education level.

In such a religious cultural frame and given the low level of E.T. knowledge recorded in this study, the score of moderate acceptance of E.T. was unexpected. This is even more interesting if we take into account the type of students we addressed in our study, relative to studies in the USA or Turkey. In these latter countries, similar studies were conducted with people that had long engagement with E.T. by being in service or prospective biology teachers (Deniz et al., 2008; Rutledge & Warden, 1999, 2000). In contrast, we addressed students of education who had little or no previous engagement with E.T.

In contrast to the unexpectedness of the E.T. acceptance score, the significant negative relationship of religiosity scores with E.T. acceptance were expected, but this relationship was found to be weak. An interesting point for further research would be the type of religious background or the type of fundamentalism seen in a certain society and its contribution to the conceptual ecology of evolution education. We maintain, albeit with caution due to methodological differences, that our findings are in agreement with those of previous research (Clément, Quessada, Laurent, & Carvalho, 2008; Quessada & Clément, 2008) showing that anti-evolutionist beliefs are linked to several parameters, including country, religion, degree of belief in God, and level of religious practice. Our findings are also supported by previous results of elevated proportions of anti-evolutionary/creationist convictions among the Greek-Orthodox (most of them living in Romania and Cyprus). It seems reasonable to accept that the kind of religiosity and the substance of religious fundamentalism seen in a specific society must also be taken into account when making up the conceptual ecology of acceptance of E.T.

Our data showed a weak but significant relationship between understanding evolution and its acceptance. This finding corresponds to some studies in the field (Brem et al., 2003; Deniz et al., 2008; Lawson & Worsnop, 1992; Rutledge & Warden, 2000 Routledge & Mitchell 2002), but contrasts with others (Bishop & Anderson, 1990; Sinatra et al., 2003). Indeed, it appears that there are cases in which students may have an understanding of E.T. without accepting its validity, while in others it is the content of one's knowledge that serves as a barrier to, or facilitator of acceptance.

The observed low levels of understanding and relationship between acceptance and understanding highlight the importance of teaching E.T. not simply as part of the biology curriculum but rather as a frame and as a unifying theme. It is necessary to use, as much as possible, teaching methods and activities suited to promoting both accurate cognitive models of evolution and pro-evolutionary attitude. This means that we need various open-ended activities in biology classrooms to enhance critical thinking and help students make informed decisions.

We also examined the effects of family background on pre-service ECE teachers' acceptance of E.T. by examining parents' education level and their degree of religiosity relative to pre-service ECE teachers' degree of acceptance of evolution. Deniz et al. (2008) hypothesized that students whose parents have more education will support scientific views more often than their peers whose parents have less education. While their results supported their hypothesis, we did not find a similar correlation. It seems realistic to suggest that, in our case, we dealt with a population of student teachers whose parents had a higher degree of education overall, something that did not leave grounds for smooth distribution and correlations. On the other hand, the fact that we found a significant negative correlation between pre-service ECE teachers' and their families' frequency of church attendance and acceptance of E.T. score supports of Deniz et al.'s (2008) hypothesis that family background is part of the conceptual ecology of the learner.

We expected the teachers' study to provide a deeper understanding of the situation with respect to teaching and learning E.T. in Greece. In previous research, a remarkable proportion of biology teachers were found positive toward E.T. teaching, but many lacked adequate knowledge (Prinou et al., 2005). Here, teachers supported the initial statement that E.T. teaching is in fact absent from the Greek educational system; we came to realize, that, sadly, this situation is accepted and is not a source of dispute or debate. We still maintain the expectation that broadening the number of participants in the teachers’ study will reveal greater variation in attitude toward E.T. teaching.

5. Conclusions

Our study was an effort to explore the factors related to the acceptance of E.T. among prospective ECE educators using conceptual ecology for biological evolution as a theoretical lens. As it was an integral part of our research design, we repeated the measurements, and added one for thinking dispositions at the end of a course for pre-service ECE teachers (Athanasiou & Papadopoulou, 2010). The course was embedded in their formal studies and had evolution as its central unifying theme and framework. The results showed better levels of acceptance and understanding of E.T., an indication of the significance of teaching evolution. For the participants of the present study, understanding and accepting E.T. is of great importance, as it is expected to influence the kind of narrative about life and its processes on Earth with which children will be familiar in the early stages of their education. Our findings also indicate the necessity to establish, develop and support the teaching and learning of E.T. in Greek secondary education. Our findings further indicate the necessity to investigate other factors of conceptual ecology in various cultural frames. Concerning teachers, our findings reveal the necessity to enhance the teaching of evolution theory in universities, even in biology departments, and improve teachers' training in pedagogical content knowledge about E.T.

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Appendix

I. Sample questions used to measure pre-service teachers' understanding of evolution:

Subscale 1. Underline "Yes" or "No" or "Do not know" for each sentence: *(answers accepted as accurate are underlined)*
Q3: The first animals to settle on land were probably partially dependent on water for survival.
<u>A. Correct</u>, B. False, C. Do not know
Q6: In Modern Darwinian Theory it is accepted that changes happening during an organism's lifespan will be inherited by its offspring.
A. Correct, <u>B. False</u>, C. Do not know

Subscale 2. Select only one answer by circling the first capital letter of the sentence: *(answers accepted as accurate are underlined)*
Q10: A bat wing and a dog's forefoot are homologous structures. This implies that:
A. These structures fulfill the same function
B. Bats are evolved from a dog's ancestor
<u>C. These are similar structures because of common ancestry</u>
D. The ancestry is not common but the structures fulfill the same function
Q 13: An alteration in the arrangement of nucleotides in a chromosome, possibly resulting in either a structural or physiological change in the organism is called:
A. Genetic drift
<u>B. A mutation</u>
C. Natural selection
D. A recessive gene

II. Sample items ranked by the MATE Likert scale:

Indicate your agreement or disagreement with the following statements. Tick only one box for each of the following statements.
1=Completely disagree, 2=Disagree, 3=No opinion, 4=Agree, 5=Completely agree

	1	**2**	**3**	**4**	**5**
4. Modern humans are the product of evolutionary processes which have occurred over millions of years.					
8. The theory of evolution cannot be correct since it disagrees with the Biblical account of creation. (reverse coding)					

24 STUDENTS' UNDERSTANDING OF EVIDENCE FOR EVOLUTION

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Abstract

This paper examines secondary students' use of evidence and argumentation about evolution. The objectives are to analyse: 1) what sort of data do students consider evidence of evolution, 2) the capacity of students to construct arguments by connecting data to claim through justifications. Five groups (N=124) of 10th and 11th graders were asked about how they would convince someone that evolution has taken place by choosing different pieces of data as appropriate evidence to support the claim. Collected data included individual written responses and video and audio recordings of students' discussions in small groups. Written results showed that students have some difficulty justifying why the evidence supports the claims about evolution. Only in one item were most students able to connect the evidence with the theory through a justification. The fact that 17% considered that an increase in human height is evidence of evolution related to an adaptation to the environment reveals their problems with interpreting the theory and the persistence of teleological ideas. This, in turn, indicates the relevance of working with argumentation in the science classroom as a way of promoting knowledge construction by students.

Keywords: argumentation; evolution; use of evidence; justification; scientific explanations.

1. Use of evidence about evolution: rationale and objectives of the study

This paper examines the students' use of evidence and construction of arguments about evolution. The objective is to examine students' capacity to recognize appropriate evidence for evolution and to articulate this understanding in their scientific arguments about the theory. The research questions are:

1) What sort of data do students consider evidence of evolution?

2) How well do students construct arguments by connecting data to claim through justifications? We examine the construction of justifications, as this constitutes a criterion for quality arguments.

The study is framed in the literature about argumentation and evolution learning.

- **Why is it important to work with evidence in evolution?**

Scientific explanations are developed through argumentation (Berland & Reiser, 2009). There is a body of research showing the relevance of argumentation for learning science (Jiménez-Aleixandre & Erduran, 2008; Sandoval & Reiser, 2004). This research suggests that argumentation should be a component of instruction and learning. Attention to argumentation

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is reflected in policy papers, recognizing the use of evidence as one of the three dimensions in scientific competency (OECD, 2006). Nevertheless, at least in Spain, argumentation is not frequently implemented in the classroom as evidenced, for instance, by students' difficulties with the use of evidence (Jiménez-Aleixandre & Bravo, 2009).

Learning to evaluate and use evidence, to coordinate evidence with claims, and to construct explanations supported by evidence is crucial in science learning. In particular, in evolution, evidence plays an important role in three aspects:

– Understanding evolution requires students' comprehension of the *range of evidence supporting it*, and of how these pieces of evidence have been instrumental in the acceptance of the theory of evolution by the science community. As Tavares, Jiménez-Aleixandre, and Mortimer (2010) point out, this understanding is necessary to construct arguments, that is, support claims with appropriate data. Duschl (2008) suggests a shift in the focus on what we know towards a focus on how we know what we know and why we believe it, that is, to use criteria to evaluate claims. Darwin's theory that living beings are the product of evolution and that the evolutionary process is driven largely by natural selection could be accepted without appealing to evidence. But that would not be our goal when teaching evolution.

The process of accepting evolution constitutes an example of the role of evidence in the evaluation of a theory. Kampourakis and Zogza (2009) show that evolution instruction can be more successful when students are not only taught scientific explanations, but also given the chance to discuss them in the classroom. To us, this suggests that learning evolution (and other science topics) is supported by dialogic discourse processes in which students are engaged in the practices of choosing and evaluating evidence.

– Evidence plays an important role in *supporting evolution theory against creationists' attacks*, which attempt to generate doubts about its validity. Working in the classroom with the use of evidence about evolution is a way of preparing students to be able to respond critically to these creationist claims. For instance, it is necessary to know how to use evidence in order to criticize the claim that evolution is "only a theory". In the introduction of a book discussing current evidence for evolution, Coyne (2009) indicates that such a book is not necessary for the evidence for atoms. In Dawkins' words, evolution is a hypothesis that was once vulnerable to falsification, but has so far survived. Therefore, engaging students in the use of evidence about evolution is a way of giving them tools to evaluate these claims, which can be found in the media, or sometimes even in books.

– Working in the classroom with evidence about evolution may be a way to make students consider *evolution as a process occurring today* which is connected with their everyday life, rather than as a theory explaining phenomena that took place only in the past.

The question addressed in this study is:

– What do students consider evidence of evolution?

As analyzed in another study (Puig & Jiménez-Aleixandre, 2009), understanding the information from data does not necessarily imply connecting these data with a conclusion through a justification. However, we consider justification a criterion to distinguish quality arguments, so the question is broken down into 1) an examination of data considered to be evidence by students, and 2) the capacity to coordinate these data with the claim. We propose that the difference between data and evidence is in their role in the argument, and agree with Koslowski, Marasia, Chelenza, and Dublin (2008) in considering evidence to be data or information that are integrated into a causal explanation.

2. Research design, methods and participants

The participants consisted of five groups (N=124) of 10th and 11th graders from two schools, in the context of classroom activities related to Darwin's bicentennial in 2009. The task assumed a scenario in which the students needed to convince someone of the soundness of the theory of evolution, and they were asked:

1) to select from four pieces of information one or more of which they considered the most obvious evidence for evolution, and

2) to justify why they thought that these pieces were evidence of evolution theory.

Students were presented with the four pieces of information (see Appendix), three of which corresponded to evidence for evolution, while the fourth (item 3) did not.

Below we summarize each item and delineate what the students need to understand from it in order to solve the task.

– Item 1 *Archaeopteryx,* presents two pictures of this fossil, pointing out that it combines traits from birds, such as feathers, with others from reptiles, such as claws. It constitutes evidence for evolution because it proves the existence of transitional forms (sometimes termed 'missing links') or intermediate stages, as predicted by a theory of common descent. These fossils document changes experienced by the organisms, also illustrating that evolutionary processes are very slow.

– Item 2 *Whales,* focuses on the existence of vestigial legs inside the body of whales. The existence of vestigial organs such as the whales' hind limbs is evidence of their four-legged terrestrial ancestors. As Coyne (2009) points out, vestigial traits constitute evidence against theories of 'design': designing useless limbs does not make sense. It is reasonable to interpret them as evidence of modification of pre-existing forms.

– Item 3 *Height,* is adapted from a statement in a book of popular science (Diehl & Donnelly, 2008) claiming that the increase in human height since the time of our great grandparents is an example of evolution. It is not evidence of evolution, but rather of the influence of environment on gene expression, or phenotype. It was included because it is a confounding piece of information circulating in popular science books and it could be used to check whether students are able to distinguish appropriate evidence. The results of a preliminary study (Puig & Jiménez-Aleixandre, 2009) revealed that 6 out of 24 students considered this height increase as evidence of evolution.

– Item 4 *Insecticides,* mentions the increase in resistance to insecticides among disease-carrying insects. It is an example of a mechanism, rather than of the common origin of species. Research shows that most students interpret this as a change in individuals actively 'adapting', rather than as differential survival (Jiménez-Aleixandre, 1992). However, we decided to include it because it shows that evolution is a dynamic process that is still operating today.

Choosing among the items required that students first understand the two claims making up part of the theory of evolution: the *origin of species*, claiming that all living beings descend from one or a few common ancestors, and *natural selection*, or the mechanism of differential survival accounting for the evolution process. Items 1 and 2 relate to the origin of species, while item 4 is related to natural selection. Item 3, the increase in height over a few generations, constitutes evidence for the influence of environment on gene expression.

Collected data included individual written responses and video and audio recordings of students' discussions in small groups and in the general debate. Data were interpreted in terms of the use of evidence. The methodology involved examining students' responses with a focus on justifications, which are considered a criterion for quality. The categories emerged from an interaction of the data with previous approaches to the coordination of evidence with claims and with the quality of students' use of evidence (Kuhn, 1991; Sandoval & Millwood, 2005; Sandoval & Reiser, 2004).

After the categories were defined by the authors, a third researcher from the team also codified half of the responses, yielding 84% inter-rater reliability. The differences were discussed and agreement was reached. We discuss the findings of the two research questions consecutively.

3. Findings: students' understanding of evidence for evolution

3.1 What do students consider evidence of evolution?

The results on the first research question, *What sort of data do students consider evidence of evolution?* are summarized in Table 1. Note that students could choose more than one item.

Table1
Items chosen as evidence of evolution
The percentages correspond to students choosing each item, so the sum is more than 100%, as they could choose several

Group/ Item	Item 1 Archaeopteryx	Item 2 Whales	Item 3 Height	Item 4 Insecticides
11th graders (N=102)				
A (N=26)	11	12	5	9
B (N=27)	14	17	2	5
C (N=25)	5	8	1	14
D (N=24)	15	9	10	7
E, 10th graders (N=22)	18	13	6	2
Total (N=124) %	63 51%	59 48%	24 19%	37 30%

The items chosen with higher frequency were 1 (Archaeopteryx) and 2 (whales). This also held true for each group individually, except group C in which item 4 (insecticides) was preferred. The choice of Archaeopteryx may be related to the fact that it is discussed in their textbooks (and in most Spanish textbooks) as an example of paleontological evidence for evolution.

There were 24 students, 19%, who selected item 3, height, as evidence of evolution. It should be noted that although differences in height as compared to our remote ancestors might be considered an example of evolution, an increase in average height over a few years or generations, for instance in Galicia 12 cm in the last 70 years or 5 cm in the last 25 years, is related to better nutrition and generally better health conditions. Instances of responses justifying the choice of this item are:

In my opinion, 3 is clear evidence for evolution, stating that current generations are taller than our grandparents or great grandparents, an obvious reason being that now...we are better nourished and diseases are easier to cure. (A4)

Although this student interprets height increase as a consequence of environmental changes, he or she considers it evidence of evolution.

I think that it may be used because you see that something has changed, that there was some sort of genetic mutation, on account of life conditions and needs being different. (D18)

This response shows confusion about the origin of mutations, interpreted as the cause for the height increase.

I believe that it is obvious evidence because human beings evolved little by little with time. In antiquity, human beings were quite short, and little by little they evolved, perfecting their body. (E1)

This response is an instance of teleological positions about evolution, a trend towards 'perfection'.

In summary, most students chose items constituting appropriate evidence for evolution. A different question, whether they were able to explain why, is explored in the next section.

3.2. How do students connect data to claim through justifications?

The second research question examines *how students construct arguments by connecting data to claim through justifications*. It analyses students' responses to the second part of the task, asking them *to justify why they thought that these pieces of information were evidence of the theory of evolution*.

It explores their capacity to coordinate evidence to claims by means of justifications, equivalent to Toulmin's (1958) 'warrant'. According to Toulmin, the warrant indicates the bearing on the conclusion of the data, answering the question: 'How do you get there?' We think that it is easier for students to select evidence than to build adequate justifications (Puig & Jiménez, 2009). An instance of a potential justification, in a reference argument constructed by the authors for item 1, illustrating the step from data to the claim of origin of species by common descent, is presented in Figure 1.

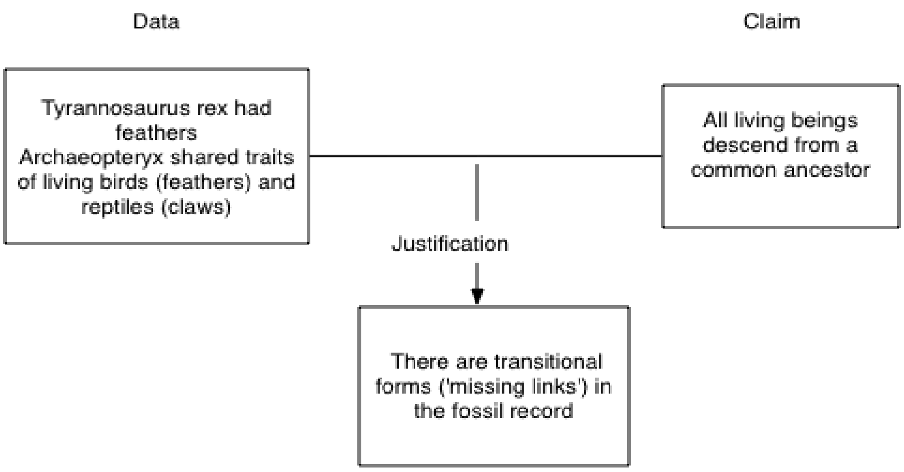

Figure 1
Reference argument for item 1 Archaeoptery

Students' responses were distributed into four categories (plus absence of explanation of the choice), resulting from an initial analysis of a sample and iterative processes of refining the categories of interaction with the data. The categories reflect different levels in the quality of the arguments, as we think that articulating a justification shows an understanding of the role of the evidence. In metaknowledge about evidence, we understand statements about the role of evidence or the criteria for evaluating it, a distinction drawn from Schwarz et al.'s (2009) proposal about modeling. Although responses in this second category, metaknowledge, do not build justifications, they reflect a certain awareness of the role of evidence. The categories of pseudoevidence and non-evidence are drawn from Kuhn (1991). The results are summarized in Table 2. Note that the students were to justify only the pieces of evidence that they chose, so the numbers of responses for each item are only those reflected in Table 1 (63 for item 1, 59 for item 2, etc.) and the percentages refer to those numbers. Each category is characterized below, illustrated with students' responses.

Table 2
Students' justifications about why each piece of information was evidence of evolution

Categories/Items chosen	**Item 1 N=63**	**Item 2 N=59**	**Item 3 N=24**	**Item 4 N=37**	**Total**
Justification connecting data to claim	24 38%	19 32%	4 17%	9 24%	**56**
Reference to metaknowledge about evidence	5 8%	5 9%	–	1 3%	**11**
Pseudoevidence: discussion about the information	21 33%	27 46%	15 62%	24 67%	**87**
Non-evidence	7 11%	3 5%	–	1 3%	**11**
Lack of explanation (just marked the choice)	6 10%	5 8%	5 21%	2 6%	**18**

– *Justification connecting data to claim*: In this category were placed the responses that connect the data (information from each item) with the claim, through a justification. This requires: 1) identification of the data as evidence for evolution; 2) coordination of the evidence with the claim about the theory of evolution. Some instances are:

Item 1: *I think that it is evidence for evolution because it means a connection between reptiles and birds, and later each of them evolved in a different way, until they came to be as they are today...It is also a piece of evidence because although this species does not exist, living beings today keep traits similar to it.* (B2)

Our interpretation is that this student identifies Archaeopteryx as a link connecting birds and reptiles, although the formulation is not the same as in the reference argument, and relates it implicitly to the claim.

Item 2: *A piece of evidence for evolution is that inside whales there are bone remnants of hind legs, which means that they descend from a common ancestor possessing legs*... (C9)

This response connects the vestigial limbs to the claim of a common ancestor.

There are some responses addressing two items, for instance:

Items 1 and 2: *To me, the most obvious pieces of evidence, and those that better demonstrate the theory of evolution are the first and second because they show that there is a relationship* *among living animals and ancestors such as dinosaurs, which means that one way or another they evolved, probably through mutations, producing animals that live today*. (B16)

– *Reference to metaknowledge about evidence*: Although these responses do not offer justifications, we interpret them as reflecting a certain degree of awareness about the role of evidence or the criteria for evaluating it. Criteria about evidence explicitly mentioned by students include, for instance, coherence or potential testing.

Items 1 and 2: *I chose 1 and 2 because they seem to me the most scientific. I picked them because they are coherent, make sense and, most important, they have been tested...* (E21)

...because they [Items 1 and 2] *are facts that have been proven and may be tested.* (E10)

We placed the 11 responses making references to criteria about evidence in this category, even when in some cases it could be debated whether these particular issues 'may be tested'. We did not expect these students to draw distinctions such as between empirical testing and retrodiction (retrospective prediction). Most responses in this category corresponded to items 1 and 2 and to students from group E. The transcripts of the oral debates, not addressed here due to space constraints, also indicated the use of criteria for evaluating evidence in class E. We discuss possible reasons in the next section.

– *Pseudoevidence*: Kuhn (1991) characterizes pseudoevidence as a scenario depicting how the phenomenon might occur. It is illustration rather than genuine evidence, and can be differentiated from the latter because pseudoevidence cannot be distinguished from a description of the causal sequence. The responses placed in this category explain or reveal (or sometimes just repeat) the information from the item but without connecting it to the claim.

Item 4: *Insects increase their resistance to insecticides, in the beginning a little amount of insecticide would have an effect on them and eliminate them, but these insects were evolving and creating their own defences, so each time more amount of insecticide is needed in order to have an effect on them.* (C25)

This student makes an attempt to explain the resistance to insecticides, but without justifying why it is considered evidence for evolution. It could be categorized a Lamarckian notion of active and progressive adaptation, which does not consider the possibility of pre-existence of some resistant individuals in the population.

– *Non-evidence:* Kuhn (1991) characterizes as non-evidence a range of responses, which 1) imply that evidence is unnecessary or irrelevant; 2) make assertions not connected to a causal theory, or 3) cite the phenomenon itself as evidence regarding its cause. In our study, this category is represented by the third case in most instances responses that seem to accept the information as evidence for evolution without explaining why it is evidence. Some of them appeal to authority, making reference to its source: scientists, documentaries, etc.

Item 1: *Because it is an opinion of the intellectuals of science who say that birds have evolved from dinosaurs*. (E3)

Item 2: *...I saw once, on a National Geographic program, that whales have a sort of legs inside their body that are not developed.* (E13)

Some questioned the information presented in the items as unreliable, such as A5, but focused on the information itself, without framing it in the theory of evolution.

Item 2: *I do not think that carnivorous dinosaurs would have feathers, but as I never saw a dinosaur, I do not know. On the basis of the images about how dinosaurs were, transmitted by documentaries and other media, this option does not present* [sic] *to me as true.* (A5)

This student explains why he or she did not choose item 1, in particular the lack of feathers on *Tyrannosarus rex*, on the grounds of images seen in documentaries. This is an instance of the influence of the media and informal science learning and of the relative status of ideas transmitted in school and out of school contexts.

As summarized in Table 2, the highest frequency corresponds to the category of pseudoevidence, illustrating how the phenomenon occurred rather than connecting it to the claim. The only item with a higher proportion of responses (38%) building justifications is *Archaeopteryx*, which is also the most frequently chosen. As discussed above, this may be related to the presence of this particular example in their book. In the 11th grade, the teacher had introduced it as an instance of an intermediate form relating birds and reptiles.

4. Conclusions and educational implications

The examination of what pieces of information do students consider evidence of evolution and of how they relate this evidence to the claim, points to differences related to the contexts of the items. In particular, it was not easy for students to connect data with the claim through a justification. Most responses belonged to the category of pseudoevidence, which is coherent with results from other studies reporting students' difficulties in explaining how given evidence provides support for claims (Sandoval & Millwood, 2005) or in connecting the evidence to the claim (Puig & Jiménez-Aleixandre, 2009). It was easier for students to justify why the evidence provided in item 1, Archaeopteryx, is evidence of evolution, than in other contexts.

To appreciate how students understand the role of evidence, it is interesting to analyse how biology textbooks address this issue and, in particular, which evidence they present in the evolution lessons. It is not possible to discuss this in detail, due to lack of space, but we can point out that most of the evidence cited in 10th- and 11th-grade textbooks makes reference to evolution rather than to natural selection. The types of evidence are mainly paleontological, anatomical and embryological. Archaeopteryx is an example presented in the textbook that these students were using. This suggests the need for a variety of examples from different organisms and in different contexts, to support students' transfer of knowledge.

There is a group of responses, particularly from group E, that were categorized as references to metaknowledge. This could be related to the teaching approach in this classroom, where students are required to carry out projects and report on the evidence for their conclusions (Jiménez-Aleixandre & Fernández-López, 2010).

Our interpretation is that there is a connection between the use of evidence and the content of the tasks. In the responses to items 3 and 4, there are explanations assuming adaptation as an 'active' process, as reported in the literature on evolution learning (Jiménez-Aleixandre, 1992; Kampourakis & Zogza, 2009). In particular, when applying the complex model of natural selection, as in the insecticide example in item 4, studies report students' difficulties in changing their explanations. In item 3, about height increase, there are responses framing evolution in terms of 'improvement' and 'progression', perhaps influenced by statements from the media; 19% of students chose this item as evidence for evolution, although some of them correctly attributed the increase to changes in environmental factors. This may be related to the use of the term 'evolution' in everyday language in Spanish as synonymous with 'change'. In this way, working with evidence may also be a way to explore how students apply models, such as evolution or natural selection, to real contexts. Developing competency in argumentation and the use of evidence is not independent of the context, but a part of science learning.

ACKNOWLEDGEMENTS

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Appendix

–1 Today scientists think that carnivorous dinosaurs such as *Tyrannosaurus rex* had feathers. The pictures show an older fossil, thought to be an ancestor of both dinosaurs and birds: *Archaeopteryx.* This animal possessed traits that living birds have, such as feathers, and others characteristic of reptiles, such as claws on its wings.

–2 Some marine mammals, like whales, have undeveloped bone remnants of hind legs hidden inside their bodies.

–3 This claim is written in a popular science book "Everybody knows that people are now taller than their grandparents or great grandparents. This is evidence of evolution.

–4 Many insects that transmit diseases such as malaria show an increase in resistance to insecticides such as DDT, related to the massive use of those insecticides.

25 THE ORIGINS OF HUMANKIND: A SURVEY OF SCHOOL TEXTBOOKS AND TEACHERS' CONCEPTIONS IN 14 COUNTRIES

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Abstract

To investigate the difficulty teaching human origins, and particularly the possible link between values and taught scientific knowledge, research was carried out in 14 countries, in the context of the project BIOHEAD-Citizen. In eight countries (Cyprus, Estonia, Finland, France, Hungary, Italy, Romania, Senegal), this topic is included in the biology syllabus; in the six other countries (Algeria, Burkina Faso, Lebanon, Morocco, Portugal and Tunisia), it is not.

Analysis of the images of timelines or trees depicting evolution revealed that *Homo sapiens* is never represented by a woman alone, only twice by a couple, and never with ethnic diversity. *Homo sapiens* is generally at the top or end of the evolutionary schemas, indicating a goal-ended conception of evolution. Thus scientific knowledge related to human origins can be mixed with implicit values.

In the 14 countries, 5,706 teachers (primary and secondary school teachers of biology or national language) completed a questionnaire. Conceptions differed greatly among countries. Creationist conceptions were correlated with level of belief in God, as well as with shorter training at university. In the countries where evolution is included in the students' curriculum, the biology teachers' conceptions were less radically creationist than when it was not included in the curriculum.

Keywords: human evolution; implicit values; science syllabuses; science textbooks; teachers' conceptions

1. Introduction

On 21 June 2006, the InterAcademy Panel (IAP), representing 68 national science academies, published a joint statement on the teaching of evolution: *"We, the undersigned Academies of Sciences, have learned that in various parts of the world, within science courses taught in certain public systems of education, scientific evidence, data, and testable theories about the origins and evolution of life on Earth are being concealed, denied, or confused with theories not testable by science"* (IAP, 2006). This collective declaration reflects the difficulties involved in teaching evolution, due to the interactions between scientific knowledge and values concerning the teaching of this topic. In recent years, our knowledge of the evolution of mankind has been significantly modified, with each new discovery immediately popularised in the media. While many people are fascinated by our origin, paradoxically, this precise topic is not taught in some countries. For instance, in Lebanon, evolution was included in the new syllabus following the civil war (Harfouch & Clément, 2001), but today it is no longer compulsory and is taught in only some schools. In other cases, such as Greece (Lakka & Vassilopoulou, 2004), human evolution is in the syllabus but is not always taught. Prinou, Halkia and Skordoulis (2007) specified that, in Greece, from 1983 until 2000 *"the evolution of humankind was only taught to a small percentage of pupils–those who were prospective candidates of medicine."* Since 2000, human evolution has been included in a chapter on the theory of evolution which is *"omitted from the subject matter of courses in the Upper Secondary School, a practice that reveals at least the underestimation of its importance"* (Prinou et al., 2007, p. 1).

School syllabuses, textbooks and teachers' conceptions can be analysed as one step in didactic transposition. Proposed by Verret (1975) and then by Chevallard (1985), the concept of didactic transposition is used to analyse the way in which some scientific knowledge is chosen and then transformed in order to be taught. Typically, it considers three levels of transposition: the reference knowledge, the knowledge to be taught and the taught knowledge. In fact, there are more than three steps, one of them being related to school textbooks. None of the steps are limited to scientific knowledge and they can be analysed as interactions between scientific knowledge (K), values (V) and social practices (P): the KVP model (Clément, 2006; Clément & Hovart, 2000). Several scientists and philosophers have analysed the interactions between scientific content and socio-cultural context, particularly for the evolution of mankind (Cohen, 1999; Gould, 1981).

Quessada and Clément (2007) introduced the concept of didactic transposition delay (DTD). This is the delay between the date on which a scientific publication appears and the date on which its content is introduced into a syllabus or school textbook. Analysing the history of French science textbooks, Quessada and Clément (2006a, 2006b) measured different DTDs. The DTD for syllabuses could be either shorter or longer than for textbooks. The lengths of these DTDs were correlated to different parameters of the socio-cultural context, such as the importance of the subject matter and the popularisation of the specific topic, as well as concurrent dominant values (ideologies, beliefs, etc.). Social pressure was particularly important with respect to teaching the origins of mankind.

These results, related to current and past French socio-cultural context, led to the development of a larger comparative approach: the European project "BIOHEAD-Citizen" (Biology, Health and Environmental Education for better Citizenship). Participants from 19 countries worked on six topics, one being the origin of humankind (coordinated by M. P. Quessada and P. Clément). The 19 countries were chosen for their socio-cultural, geographical and historical differences in order to test specific hypotheses regarding comparisons among European and non-European countries, among religions (countries which are mostly Catholic, Protestant, Orthodox or Muslim, and having various levels of atheism or agnosticism) and, within Europe, among the North and South, East and West, etc. The conceptions related to this topic were analysed with the KVP model (Clément, 2006), mainly as possible interactions between taught scientific knowledge (K) and values (V). The results presented here are restricted to the 14 countries for which the questionnaire administered to the teachers included a question about human origins: Algeria, Burkina Faso, Cyprus, Estonia, Finland, France, Hungary, Italy, Lebanon, Morocco, Portugal, Romania, Senegal and Tunisia. This research presents three complementary sets of data: the biology syllabuses of the different countries, the images of *Homo sapiens* in evolutionary trees of biology textbooks, and the teachers' answers on the questionnaire.

What implicit values can be identified in the images of humans in school textbooks? Can we find the same images, the same implicit values, in textbooks from countries that contrast in their historical, geographical, economic, political, cultural or religious contexts? Which implicit values can be identified in the teachers' conceptions? What are the interactions between social practices, concurrent values, and scientific knowledge taught about human evolution in each country?

2. Methodology

The methodology used in the context of the BIOHEAD-Citizen project is presented in detail in Clément and Carvalho (2007) for the six topics of this project; for the topic "human origins", see Quessada (2008), Quessada, Clément, Oerke and Valente (2008), Quessada and Clément (2009), Clément and Quessada (2008, 2009). The information therein is summarized here.

2.1 Analysis of syllabuses in the 14 countries

One research team per country (except for France, with two teams) was involved in this work. We collectively defined the indicators to analyse the national syllabuses for all school levels (primary and secondary schools). The topic "human evolution" was generally taught in the biology course, but in some cases it was taught in the context of history (Cyprus), psychology (Portugal) or philosophy (Algeria, but just suppressed during the time of our research). Here, we only use the indicator "presence or absence" of the topics "evolution" and "human evolution" in the biology syllabuses.

Analysed syllabuses were used in the 2004/5 school year. Since 2005, the syllabuses of some countries have changed. For example, biological evolution was introduced in Morocco in 2008.

2.2 Analysis of the textbooks containing information on human origins

In the BIOHEAD-Citizen Project, the textbooks were analysed using the same grid in each country. The data used in the current work come from only a small part of that grid. We analysed 50 schemas containing representations of *Homo sapiens*. These images were collected from 18 science textbooks, from nine different countries: Cyprus (1), Estonia (2), France (4), Italy (6), Lebanon (1), Portugal (1), Romania (1), Senegal (1), Tunisia (1). Burkina was not included in the project when this part of the work was being performed. In Finland and Hungary (countries which teach human evolution from its own chapter), there was no timeline or tree of evolution with a representation of *Homo sapiens*. In Portugal and Tunisia, we found such a timeline or tree of evolution with a representation of *Homo sapiens* in the chapter on evolution, although no specific part of the textbook dealt with human evolution.

The images of *Homo sapiens* were grouped into several specific categories: nude man without beard, nude man with beard, dressed man with suit, dressed man (other than suit), couple, small group of people, shadow of unidentifiable gender, brain, and skull. The position of *Homo sapiens* in the schema was analysed in relation to a finalistic or non-finalistic conception.

2.3 Analysis of teachers' conceptions

In the 14 countries, teachers filled out a long questionnaire, including 15 questions related to evolution and 17 questions related to their own characteristics (gender, age, level of training, socio-political or religious opinions). In each country, the sample was a balanced set of primary school teachers (P), secondary school teachers who taught biology (B) and secondary school teachers who taught the national language (L). In these three categories, half of the sample consisted of in-service teachers (In-P, In-B and in-L) and the other half of pre-service teachers (Pre-P, Pre-B and Pre-L). For each of these six sub-samples, about 50 teachers were interviewed: about 300 in each country (sometimes more when we tested complementary hypotheses, as in France, Lebanon and Tunisia; sometimes less when the country was small). In total (for the 14 countries), 5,706 teachers filled out the questionnaire. Some of the information gathered to characterize the interviewed teachers is presented in Table 1.

Table 1
Samples from 14 countries (total = 5,706 teachers)

	Country	Total	including biologists	*% Atheist. Agnostic*	*% Catholic*	*% Protestant*	*% Orthodox*	*% Muslim*	*% Othe*
BF	**Burkina Faso**	**296**	**110**	*2.4*	***45.6***	*18.6*	*0.0*	*24.7*	*8.8*
CY	**Cyprus**	**322**	**66**	*4.0*	*9.0*	*1.2*	***77.3***	*0.0*	*8.4*
DZ	**Algeria**	**223**	**88**	*1.3*	*0.0*	*0.0*	*0.0*	***91.9***	*6.7*
EE	**Estonia**	**182**	**108**	***43.4***	*7.7*	*14.8*	*2.2*	*0.5*	***31.3***
FI	**Finland**	**306**	**121**	*15.0*	*1.0*	***66.3***	*2.9*	*0.0*	*14.7*
FR	**France**	**732**	**319**	***50.5***	***38.1***	*1.9*	*0.3*	*1.5*	*7.7*
HU	**Hungary**	**334**	**112**	*15.3*	***46.4***	*16.2*	*0.0*	*0.0*	*22.2*
IT	**Italy**	**559**	**150**	*12.3*	***78.7***	*0.5*	*0.0*	*0.0*	*8.4*
LB	**Lebanon**	**722**	**261**	*0.4*	*21.1*	*0.4*	*8.3*	***65.0***	*4.8*
MA	**Morocco**	**330**	**186**	*0.6*	*0.0*	*0.0*	*0.0*	***97.3***	*2.1*
PT	**Portugal**	**350**	**111**	*9.4*	***76.3***	*7.4*	*0.0*	*0.0*	*6.9*
RO	**Romania**	**273**	**127**	*7.3*	*8.1*	*7.0*	***71.1***	*0.0*	*6.6*
SN	**Senegal**	**324**	**120**	*0.9*	*8.3*	*0.0*	*0.0*	***89.2***	*1.5*
TN	**Tunisia**	**753**	**326**	*1.9*	*0.0*	*0.0*	*0.0*	***96.0***	*2.1*

The questionnaire consisted of questions which had been validated by previous research, and submitted to the steps described in Clément and Carvalho (2007) and in Quessada (2008): translation from the reference languages of the project (English and French) to the national language (using parallel independent translations, then a comparison with a back-translation); pilot interviews in most of the countries; the use of a longer pilot test in each country, then analysing the answers, their reliability after one month for the same pre-service teachers, multivariate analyses and finally a selection of the most discriminating questions.

Here we only present the answers from two questions (see below). They are significantly correlated to the data from the other questions related to evolution (Quessada, 2008). Question B48 (God) was one of a list of factors to rate (natural selection, chance, environment, intelligent design, viruses, transposons).

B28. Which of the following four statements do you agree with most? Select ONLY one sentence:

$\boxed{1}$ It is certain that the origin of humankind results from evolutionary processes.

$\boxed{2}$ Human origin can be explained by evolutionary processes without considering the hypothesis that God created humankind.

$\boxed{3}$ Human origin can be explained by evolutionary processes that are governed by God.

$\boxed{4}$ It is certain that God created humankind.

Indicate your evaluation of the importance of the following factors in species evolution
(tick only ONE box for each line):

		Great importance	Some importance	Little importance	No importance at all
B48.	God				

3. Results

3.1 Is the topic "origins of humankind" taught in these 14 countries?

In four countries (Algeria, Burkina, Lebanon and Morocco), there was nothing related to biological evolution. This topic has been more recently included in the syllabuses in Morocco (2008) and Lebanon (2009). In Burkina, it is taught only in some schools using the French programme. In three countries (Romania, Senegal, Tunisia), evolution was taught in only one level, the last year of secondary school. In the seven other countries (Cyprus, Estonia, Finland, France, Hungary, Italy, Portugal), evolution was taught in three to six levels and was generally introduced in the primary schools (< 12-year-olds, Figure 1).

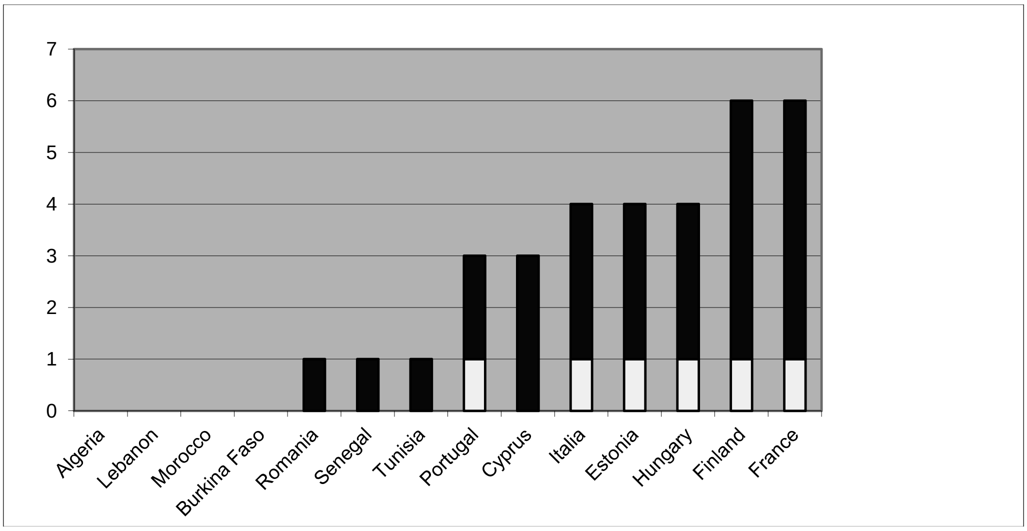


Figure 1
Number of grade levels in which evolution is included in the biology programmes of 14 countries (black = > 12 years old, white = < 12 years old)

In six countries (Algeria, Burkina, Lebanon, Morocco, Portugal and Tunisia), there was nothing on the topic of human evolution. However, in Portugal, human evolution was included in the psychology syllabus. In Tunisia, evolution was taught, but not human origins. In the eight other countries (Cyprus, Estonia, Finland, France, Hungary, Italy, Romania, Senegal), the origins of humankind were taught with evolution (Figure 2).

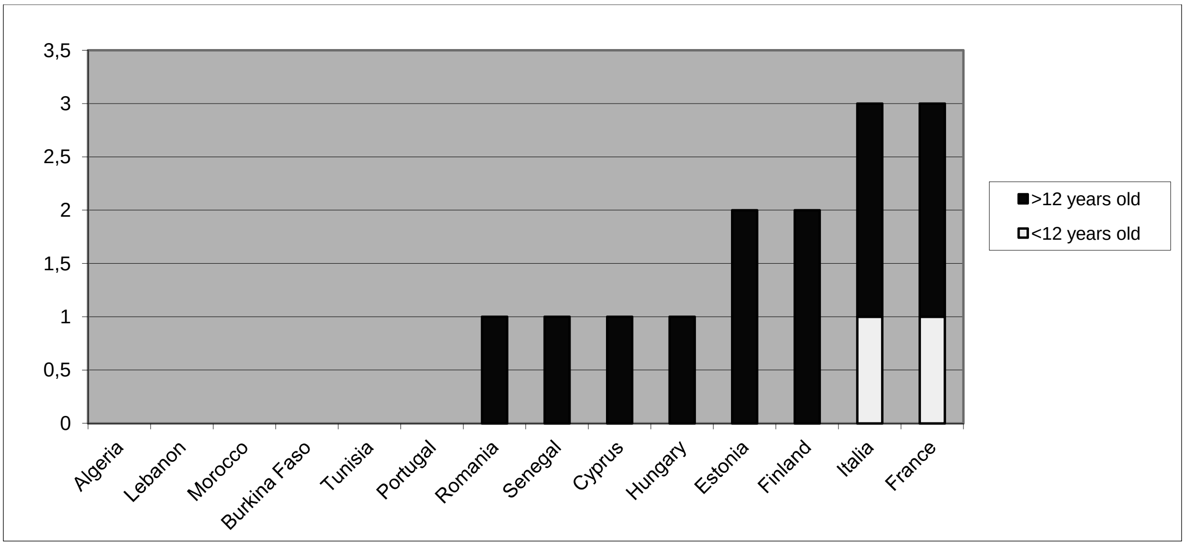


Figure 2
Number of grade levels in which human evolution is included in the biology programmes of 14 countries

3.2 The images of human beings illustrating human evolution in school textbooks

In the 18 textbooks analysed, we found 50 images showing human evolutionary trees or timelines (sequences) containing at least one illustration of *Homo sapiens*. These images were classified into nine categories: nude man with beard (14), nude man without beard (9), man dressed in suit (9), skull (9), man dressed in other than suit (5), couple (2), shadow (1), brain (1). *Homo sapiens* was never represented in these textbooks solely by a woman. Only twice (in a French textbook and in an Italian one), was *Homo sapiens* represented by a couple. In the evolution schemas, all representations of humans had white skin; not one image illustrated ethnic diversity.

Most of the textbooks illustrated human biological evolution as linear and finalistic, projecting an image of a white-skinned, male *Homo sapiens*. Figure 3 illustrates the most frequent type of drawing of this linear human evolution. Here, *Homo sapiens* appears as a naked, white-skinned man, resembling the prototypical image of Adam.

Another frequent representation of *Homo sapiens* was as a male human, with characteristics of occidental society (white-skinned, occidental clothing and/or tools and accessories). The images below (Figure 4) show a man wearing modern blue dress in an Italian book, and even in the Senegalese textbook, a white man with a suit.

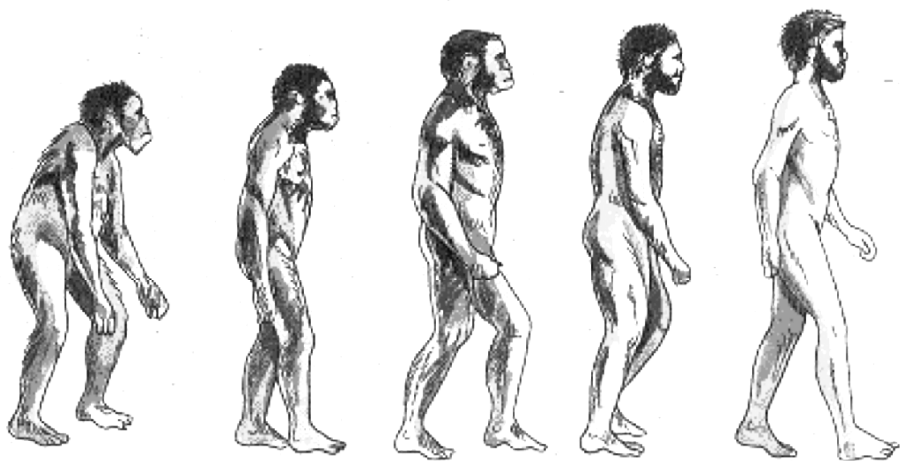
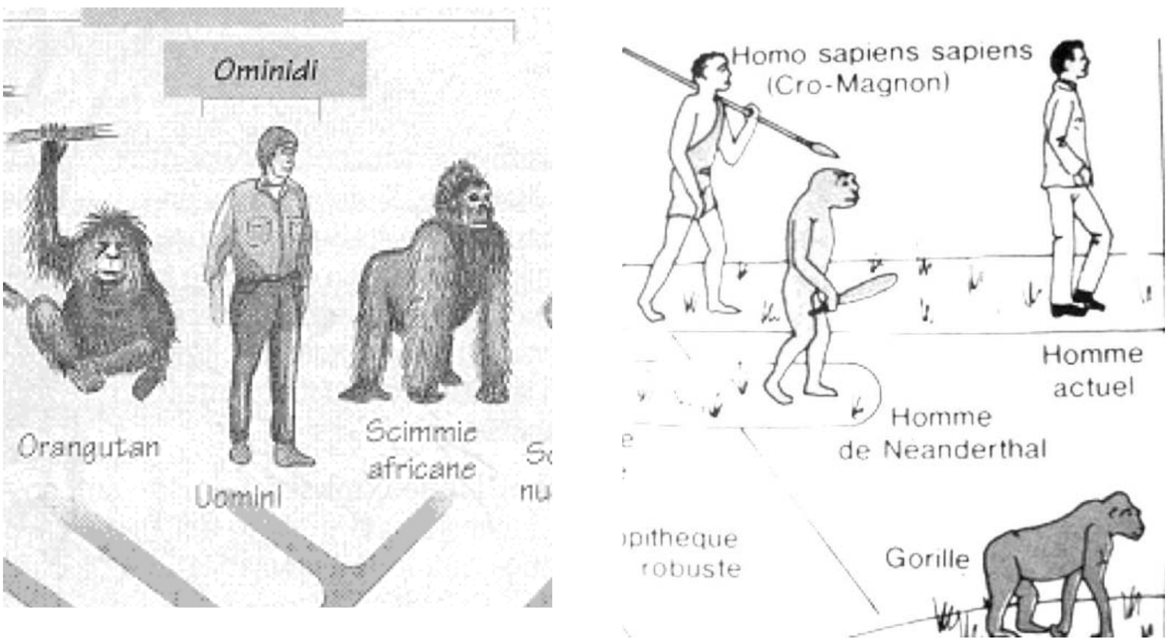


Figure 3
Linear conception of human evolution, ending with a white-skinned and bearded man. Modified from: Colombi, Negrino, & Rondano, 2001, p. 277 (the original is in colour)



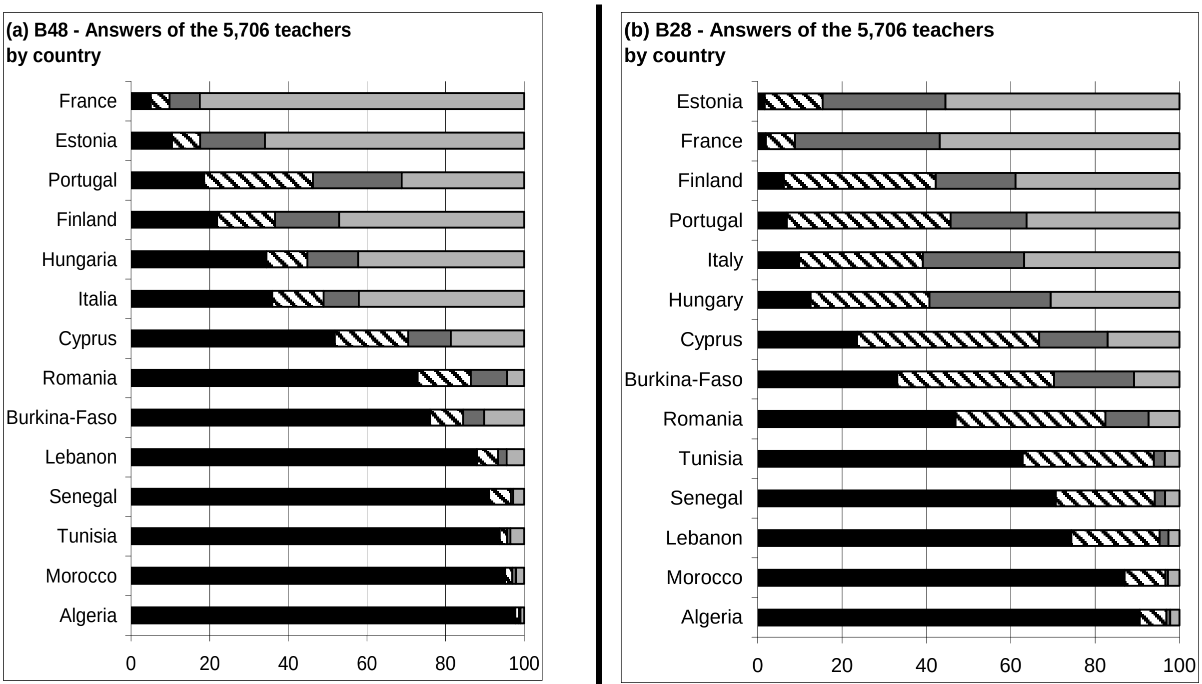
Miller & Levine, 1998, p.209 Désiré, 1983, p.314.

Figure 4
Two representations of an occidental male *Homo sapiens*
(modified: the originals are in colour)

Consequently, in the great majority of the textbooks analysed, biological evolution ends with an occidental white male *Homo sapiens*.

3.3 What are the teachers' conceptions related to human origins?

In answer to question B48 (Figure 5a), related to *"the importance of God in species evolution"*, 8% of the teachers ticked *"great importance"* or *"some importance"* in France, while this percentage increased to 95 or more in Lebanon, Senegal, Tunisia, Morocco and Algeria. Nevertheless, some of these teachers were also evolutionists. In answer to question B28 (Figure 5b), 2% of the French teachers ticked the radical creationist item ("*It is certain that God created humankind*"), whereas 62 to 92% of the teachers ticked it in Tunisia, Lebanon, Senegal, Morocco and Algeria. Other teachers had conceptions that were both creationist and evolutionist, ticking the third item ("*Human origin can be explained by evolutionary processes that are governed by God")*: 6% of teachers in France and Algeria, to 32% or more in Tunisia, Burkina, Portugal, Finland, Romania and even 43% in Cyprus (Figure 5b).



(a) B48. *Indicate your evaluation of the importance of God in species evolution (tick only one of the 4 boxes)*

	Great importance	*Some importance*	*Little importance*	*No importance*
1. God				

(b) B28. *Which of the following four statements do you agree with most? Select* *ONLY* *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.

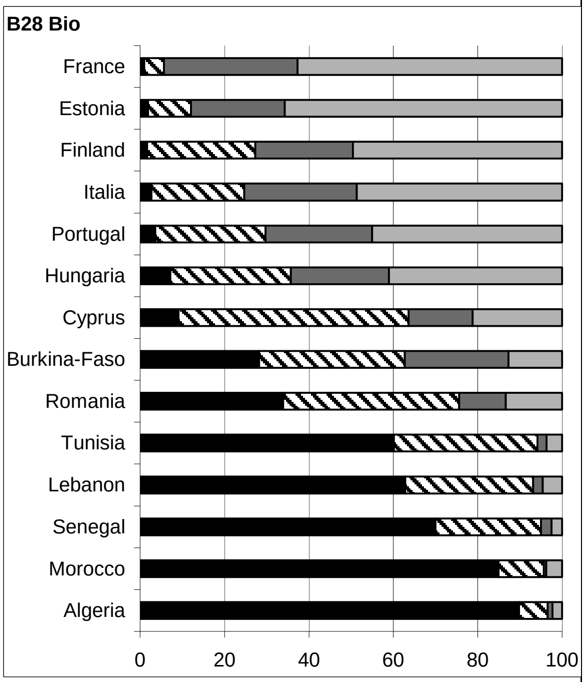
Human origin can be explained by evolutionary processes that are governed by God.

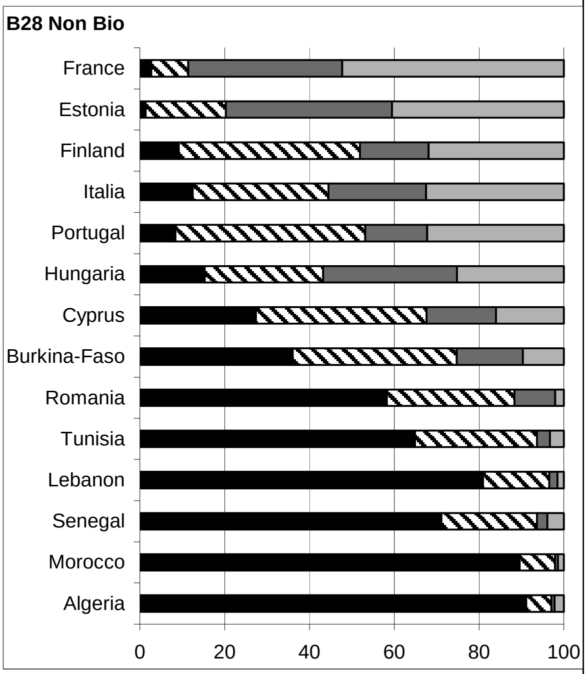
It is certain that God created humankind.

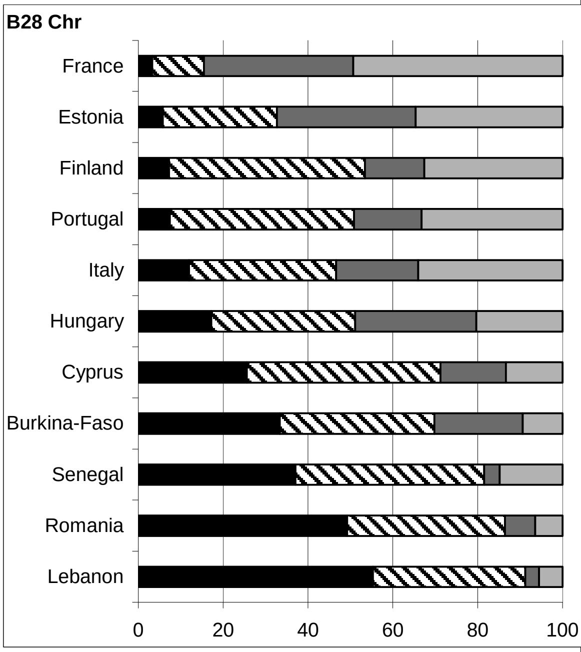
Figure 5

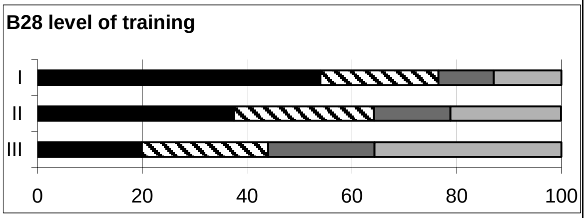
Teachers' answers to questions B48 and B28 (5,706 teachers in 14 countries)

Further analysis of the answers to question B28 (Figure 6) revealed major differences among the 14 countries. Even when comparing only the Christian teachers' answers (Figure 6, B28 Chr), there were very significant differences among countries, showing a strong influence of national socio-cultural context.









B28 Bio - Answers of the 2,205 biologist teachers, country by country

B28 Non Bio - Answers of the 3,501 non-biologist teachers, country by country

B28 Chr - Answers of the 2,449 Christian teachers, country by country

B28 Level of training - Answers of the 5,706 teachers, for the following levels of training: I = ≤ 2 years at university. II = 3 or 4 years. III = ≥ 5 years.

B28 - *B28. Which of the following four statements do you agree with most? Select ONLY 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 huma

Human origin can be explained by evolutionary processes that are governed by God.

It is certain that God created humankind.

Figure 6

Teachers' answers to question B28 (5,706 teachers in 14 countries)

The answers of the "biologist" teachers (biology teachers in secondary schools + primary school teachers with a diploma in biology; their number is indicated for each country in Table 1) were not so different, within each country, from the answers of their non-biologist colleagues. The difference between biologist teachers and other teachers was nevertheless significant in nine countries (Chi2 with the Bonferroni correction): Cyprus, Estonia, Finland, France, Hungary, Italy, Lebanon, Portugal and Romania. In these countries, biologist teachers were more evolutionist than their colleagues, often with a more important amount of creationist + evolutionist conceptions (item 3 in question B28). In four of the five countries where there was no significant difference, Algeria, Burkina, Morocco and Tunisia, human evolution was not included in the syllabus (Figure 2).
Another important result is shown in Figure 6, graph “B28 Level of training”. There was a direct positive correlation between the time a teacher had trained at university and his/her acceptance of evolution: 19% radical creationist conceptions related to the origin of mankind when the level of teachers' training was ≥5 years at university; 36% with 3 or 4 years of university; 53% with 2 years or less at university.

4. Discussion and conclusions

Studies on Evolution teaching have been performed in various countries and often show the great importance of social context with respect to curriculum and textbook contents: Barberá, Beatriz and Pérez-Pla (1999) on Spanish biology curricula; Jiménez Aleixandre (1994, 1996) on Spanish textbooks; Swarts, Anderson and Swetz. (1994) on Chinese, American and Soviet secondary-school biology textbooks; Skoog (1984) and Rosenthal (1985) on US textbooks. We focused our study on human evolution, for which the obstacles and difficulties are exacerbated (Quessada 2008; Quessada & Clément 2006a, 2006b, 2007). Skoog (2005) also studied the coverage of human evolution in 20th century in US high-school biology textbooks and in current science standards. He ascertained that before 1960, human evolution was given little attention in biology textbooks. In the following two decades, the situation with regard to human evolution worsened in that information was minimal. In 1990, human evolution was unrestricted. By 2004, three states included the teaching of human evolution in the state science standards.

Our comparative study shows great differences between countries (with respect to syllabuses and teachers’ conceptions): the social context strongly influences the way evolution is (or is not) taught, particularly human evolution. In other articles, we analysed the social factors which are correlated with the teachers’ conceptions (Clément & Quessada, 2008, 2009; Quessada, 2008; Quessada, Munoz, & Clément, 2007): the degree of belief in God and in religious practice, the economic status of the country and the teachers' level of training. In the present paper, limited to the evolution of humankind, we also show that the longer the teachers trained at university, the greater is their acceptance of evolutionist ideas. Moreover, in most of the countries where human evolution is taught, the conceptions of teachers who had training in biology are less radically creationist, more creationist-evolutionist than those of their colleagues.

This raises the problem of teachers’ training: how can human evolution be introduced in syllabuses when teachers’ conceptions are not evolutionist? What training can help effect this change? Our results encourage longer training periods for future teachers in every country, incorporating more biology. They also suggest incorporating an epistemological approach of science in their training, to help teachers differentiate belief from scientific knowledge, to consider religion and science as two non-overlapping domains, i.e. the non-overlapping magisterial (NOMA) proposed by Gould (2000). This could be a first step to introducing the topic "evolution of mankind" in schools of any country.

The present work, along with previous articles (Quessada et al, 2008; Quessada & Clément, 2009), also shows that social representations of human evolution coming from images in textbooks are more or less the same in all countries teaching evolution: *Homo sapiens* is nearly always an archetypal male with white skin, either naked or dressed in occidental clothing. The DTD is important, being more than 15 years: scientific representations with bush-like, non-linear evolution schemas were very rare in 2004 textbooks. These results show that scientific messages related to the origins of humankind are generally mixed with implicit values such as finalism (end-goaled evolution), sexism and occidentalism. Teachers have to identify these epistemological obstacles and try to explain the possible interaction between taught science and values to develop critical attitudes in pupils.

ACKNOWLEDGEMENTS

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26 BRAZILIAN TEACHERS' CONCEPTIONS ABOUT CREATIONISM AND EVOLUTION

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Abstract

The identification of teachers' conceptions about evolution is important because it enables understanding, for example, how they cope with issues related to the creationism versus evolution conflict inside the classroom. This work was developed within the framework of the European project BIOHEAD-CITIZEN, which considers that scientific knowledge and teachers' attitudes and values can influence teaching practices. A questionnaire was designed for 19 countries in Europe, Africa and the Middle East. This current paper extends the BIOHEAD-CITIZEN project to a South American country, Brazil, aiming to assess the evolutionist and creationist conceptions of six groups of in-service and future teachers. The questions on evolution were worked out as dependent variables and multivariate analysis was carried out. The results agree with previous results obtained from 12 other countries, in that in-service and future biology teachers give more importance to natural selection and the evolutionary process than other groups of teachers. Compared with those countries, however, the total Brazilian sample shows a higher percentage of creationist conceptions, particularly for Brazilian biology teachers and future teachers. As discussed herein, this may not be an obstacle to teaching evolution as these teachers accept both creationism and evolutionism concomitantly.

Keywords: teaching biology; biological evolution; creationism, Brazilian teachers

1. Introduction

The assessment of teachers' conceptions about evolution is important in understanding how they cope with issues related to the creationism versus evolution conflict in the classroom. Meadows, Doster and Jackson (2000) claimed that these issues can disturb American biology teachers who think it crucial that students learn biology evolution without questioning their personal and community values or world vision, which might be in opposition to evolutionary theory. Similarly, teachers need to cope with their own unease triggered by conflicts between evolution and their religious beliefs or personal values.

This study was developed within the framework of the European project BIOHEAD-CITIZEN (Biology, Health and Environmental Education for Better Citizenship) (Carvalho, 2004; Carvalho & Clément, 2007), aimed at improving our understanding of how different aspects of citizenship are, or may be promoted through biology, health and environmental education. This project takes into account not only that scientific knowledge on these topics

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is rapidly developing but also that teachers' attitudes and values can influence school practices. A questionnaire was designed, translated and validated for use in 19 countries with geographical, historical, cultural, social, religious and political contrasts in Europe, Africa and the Middle East. Some of the results on teachers' evolutionist and creationist conceptions can be found in Clément and Quessada (2008, 2009), Lopes (2008), Quessada and Clément (2010), and Quessada, Munoz and Clément (2007).

This current paper extends the BIOHEAD-CITIZEN project to a South American country, Brazil, to assess the conceptions of six groups of teachers (in-service primary school teachers, biology teachers and Portuguese language teachers, and corresponding future teachers) from São Paulo State about the topic of evolution, in particular about their evolutionist and creationist conceptions. The research questions can be formulated as follows: Do the different groups of Brazilian teachers have different conceptions about evolutionism and creationism? Are there differences between the conceptions of Brazilian teachers and those of the BIOHEAD-CITIZEN project?

1.1 The context of this work

Having been developed under the project BIOHEAD-CITIZEN, this study is based mainly on the teaching of science, but also covers the area of social psychology in the context of social representations (Moscovici, 1984). In the field of didactics of science, the term "conception" is better accepted (Astolfi, Darot, Ginsburger-Vogel, & Toussaint, 1997) than the term "representations" (Clément, 1994). Duit (2007) has produced an updated list of scientific papers developed upon the conceptions of teachers and students.

The project BIOHEAD-CITIZEN assumes that the views of different players in the educational system emerge from the interaction of scientific knowledge (**K**), systems of values (**V**) and social practices (**P**) (Clément, 2006). Although the concepts can be examined under other conceptual frameworks, the KVP model (Figure 1) has been very useful in the analysis of important characteristics of taught knowledge, enabling an understanding of the worth of a scientific presentation as related to science and values or social practices, within an epistemological scope. Knowledge (K) refers to information from the scientific community. The values (V) in this model are considered in the large sense of the term, including opinions, beliefs and ideologies. For example, sexism, racism or xenophobia are all considered, as well as the search for truth by means of science and "scientific ideologies", as defined by the epistemologist Canguilhem (1977) to characterize trends in the biological sciences, such as reductionism, anatomization or absolute genetic determinism. Social practices (P) range from teaching practices inside the classroom to the current social conception which features not only the students' future career, but also influences citizens-to-be.

The aim of the research project BIOHEAD-CITIZEN is to explore multiculturalism related to the teaching of controversial and important topics such as health education, sex education, environmental education, and evolution (especially the sensitive issue of human origin), epigenesis associated with the socio-cultural determinism of human behaviour, and reductionism in the teaching of human genetics (Carvalho & Clément, 2007).

A priori we might assume that knowledge is universal, having as its reference the same publications, and thus all curricula and textbook contents should be the same in all countries. Similarly, all teachers' conceptions should be the same, regardless of the subject they are addressing. The development of BIOHEAD-CITIZEN shows that this idea is not correct, especially for these "live issues" that are often the topic of social and scientific debates (Albe & Simonneaux, 2002).

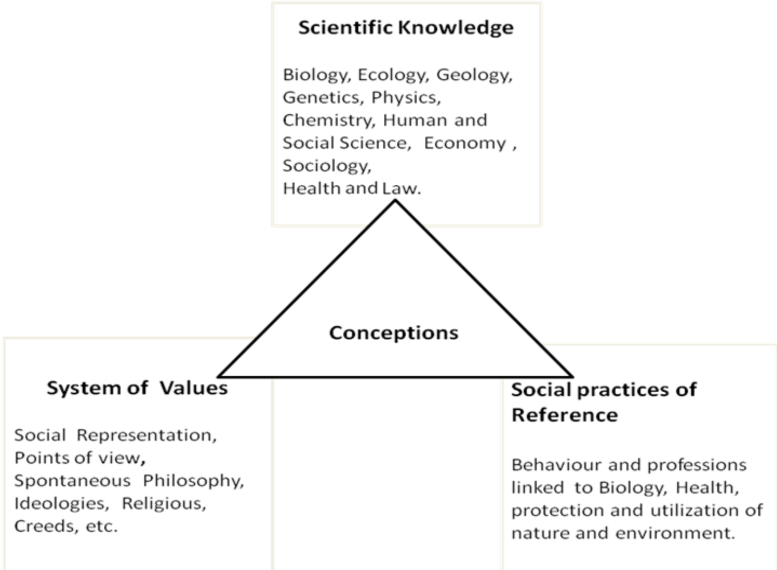

Figure 1
The KVP model. Conceptions in light of scientific knowledge, system of values and social practices of reference (Clément, 2006)

2. Evolutionism and creationism

The history of the Earth and humanity can be explained in light of creationism or evolution. The first is based on the concept that a Creator (God) gave rise to the world with all living beings, as it is today. Based on what is written in the Bible, the Anglican Archbishop James Usher (1581-1656) proposed that the world would have been created on 23 October 4004 BC at noon, i.e. around 6000 years ago (Gould,1996). The idea that all species have remained unchanged since their establishment is termed fixism.

In contrast, the theory of evolution assumes that all forms of life have undergone many changes throughout the Earth's history, including the presumed extinctions which have occurred throughout. The theory is based on evidence obtained through fossil records, analysis of anatomy and embryology, comparative biochemistry and geological and cosmological molecular studies (Mayr, 2009).

From the use of radiometric dating methods, for example, it is estimated that the Earth originated nearly 4.5 billion years ago and that life emerged on the planet approximately 3.5 billion years ago (Orgel, 1998). Contrary to creationist theory, which places the individual on a different level from other living beings, the theory of evolution, based on the proposal of the English naturalist Charles Robert Darwin (1809-1882), proposes that all living organisms descend from a common ancestor. Based on fossil evidence and molecular studies "it is likely that the lineage of the human species arose between five and eight million years ago" (Mayr, 2009, p. 28).

Given the different views on the origin of Earth and humanity, radical creationists and evolutionists have diametrically opposing views. The anti-evolutionists, i.e. the radical supporters of creationism, refuse to accept the theory of evolution. They claim that this is just a "non-proven theory" and that there is no consensus among scientists themselves about various aspects related to it. They quote as an example the age of the universe and the Earth, as well as issues which have not yet been clarified in the evolution of species. In this regard, the geneticist Theodosius Dobzhansky, in his 1973 article entitled "Nothing in Biology makes sense except in the light of evolution", argued that there are many divergences among scientists, but those are issues that contribute to the development of science and added: "Seen in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light it becomes a pile of sundry facts, some of them interesting or curious but making no meaningful picture as a whole" (p. 129).

The clash between creationists and evolutionists becomes more evident in discussions about the teaching of evolutionary theory in biology classes. A striking example is the debate that is occurring most vigorously in the United States, where society demands that the theory of evolution be taught on equal footing with that of creationism. Meadows et al. (2000, p. 102) commented on the fact that these issues put biology teachers in an uncomfortable position: "Biology teachers face the demanding challenge of crafting a learning environment that mediates colliding agendas. They want students to deepen their understanding of biological evolution in order to become scientifically literate citizens. At the same time, they also want to support, rather than undermine, the values of students, parents and communities whose worldviews can oppose the teaching of evolution. On a private and often unspoken level, many biology teachers themselves must face their own unresolved conflicts between biological evolution and their personal worldviews."

In this regard, it is pertinent to ask: What are Brazilian teachers' conceptions about the origin of life and humankind? Are they either creationist or evolutionist? Or can they believe in both ideas concomitantly? Considering that the views of different players (in this case teachers and future teachers) emerge from the interaction of scientific knowledge (K), systems of values (V) and social practices (P) (Clément, 2006), we discuss the results of our study within the framework of the KVP model.

3. Materials and methods

The entire BIOHEAD-CITIZEN questionnaire, containing 144 questions, was distributed, from September until December 2008, to six groups of São Paulo countryside teachers and university students (future teachers): 50 in-service primary school teachers (In-P), 50 in-service biology teachers (In-B), 50 in-service Portuguese language teachers (In-L), 50 future primary school teachers (Pre-P), 50 future biology teachers (Pre-B), 50 future Portuguese language teachers (Pre-L). It should be emphasized that this is a convenience sample and therefore cannot be generalized to the total population of in-service and future teachers in Brazil.

Following the guidelines of the BIOHEAD-CITIZEN project, the future teachers filled in the questionnaire at the university where they were studying, while the in-service teachers filled it in at the schools in which they were teaching. They filled in the questionnaires anonymously in the presence of the researcher, as explained in detail elsewhere (Munoz, Bogner, Clément, & Carvalho, 2009).

The fifteen "Evolution" questions used in this work are shown in the Appendix, and the answers were assessed by multivariate analysis. This method has become a standard in investigating complex data featuring the behaviour of many individuals, dependent on many variables (Lebart, Morineau, & Warwick, 1995). To analyse the answers, we used principal component analysis (PCA, Lebart, Morineau, & Warwick, 1995). We further performed a between-group analysis (Dolédec & Chessel, 1987) to complement the initial PCA (which differentiated all of the individuals) to show the differences among groups' conceptions (groups of teachers, level of training, religions, and faith). We used the Monte Carlo test to analyse the levels of significance of differences between groups. The statistical analysis was performed using the software package SPSS statistics for Windows, version 17.

4. Data analysis and discussion

4.1 PCA of all "Evolution" variables

The PCA summarizes a large number of questions, to identify a limited set of important conceptual guidelines, characterized by a coherent set of answers to certain questions. The most remarkable eingenvalues featured principal component 1 (first bar in Figure 2), represented by the horizontal axis (C1) in Figure 3. The second component, corresponding to the vertical axis (C2) in Figure 3, was somewhat weaker (Figure 2), such that the first component expressed the highest variance among respondents (27%).

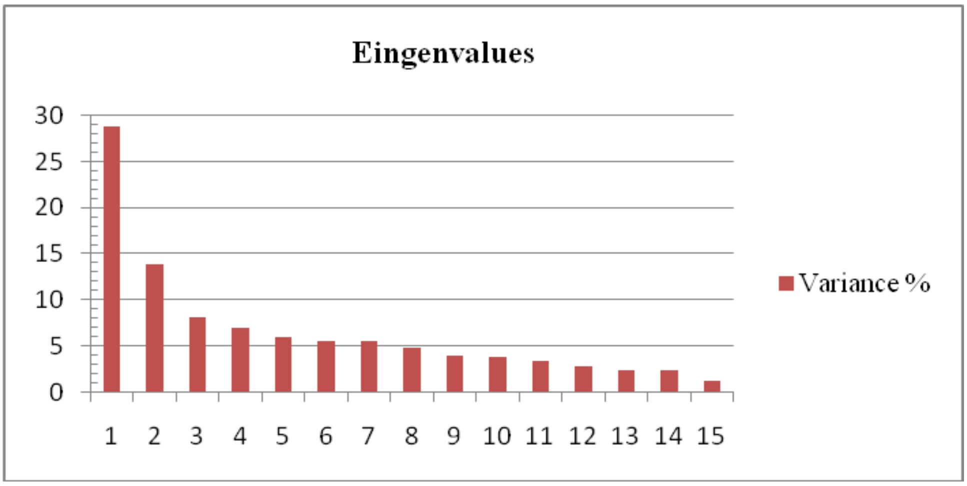

Figure 2
Histogram of eingenvalues, featuring the proportion of variance reflected by each component of the PCA
The first two bars are the most important ones and represent the axes on the graph shown in Figure 3

The "Evolution" questions, or variables, that structured principal components 1 and 2 are presented in Table 1 and projected in Figure 3.

The variables structuring axis 1 (horizontal) oppose the creationist (Figure 3, left) and evolutionist (Figure 3, right) views. These are conceptions associated to beliefs and values (V). The variables that define axis 2 (vertical) are related to familiarity with biological sciences (the role of Intelligent Design (B44), Viruses (B47) and the Surrounding Environment (B45) on evolutionary processes). These are conceptions associated to scientific knowledge (K) about evolution.

Table 1
Questions that contributed most to principal component 1, their formulations in the questionnaire and their coordinates on axes C1 and C2

	Variable/Question	C1	C2
B43	Indicate your evaluation of the importance of the following factors in species evolution (great importance; some importance; little importance; no importance at all).	0.755	0.177
B28	Which of the following four statements do you agree with most? ∗ 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.	0.755	0.342
A64	Which of the following four statements do you agree with the most? ∗ It is certain that the origin of life resulted from natural phenomena. ∗ The origin of life may be explained by natural phenomena without considering the hypothesis that God created life. ∗ The origin of life may be explained by natural phenomena that are governed by God. ∗ It is certain that God created life.	0.746	0.405
B48	Indicate your evaluation of the importance of the following factors in species evolution: Importance of God in species evolution (great importance; some importance; little importance; no importance at all)	0.613	0.489
B45	Indicate your evaluation of the importance of the following factors in species evolution: Importance of surrounding environment in species evolution (great importance; some importance; little importance; no importance at all)	0.601	0.515
B46	Indicate your evaluation of the importance of the following factors in species evolution: Importance of transposons (jumping genes) in species evolution (great importance; some importance; little importance; no importance at all)	0.598	0.495

Table 2
Questions that contributed most to principal component 2, their formulations in the questionnaire and their coordinates on axes C1 and C2

	Variable/Question	C1	C2
	Indicate your evaluation of the importance of the following factors in species evolution (great importance; some importance; little importance; no importance at all):		
B44	A program inside the organism (intelligent design)	0.360	0.653
B47	Viruses	0.370	0.571
B45	Surrounding environment	0.601	0.515
B46	Transposons (jumping genes)	0.598	0.495
B48	God	-0.613	0.489

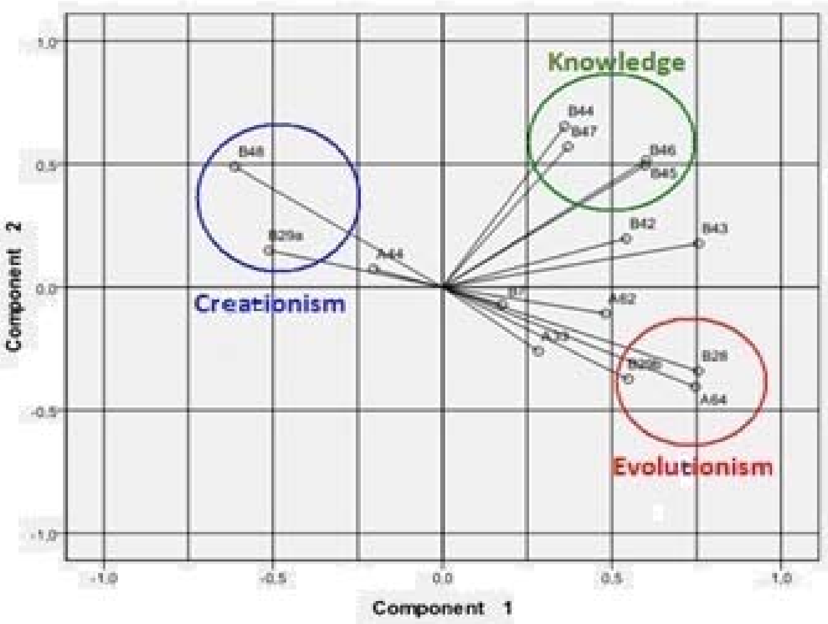

Figure 3
Graphical representation of the PCA analysis on "Evolution" questions, allowing analysis of the significance of the space defined by principal components 1 and 2 which are, respectively, the horizontal and vertical axes. Each question represents a vector; the length of its projection on each of the two axes indicates its contribution to the definition of that axis.
The circles that group the more structural issues of the axes were added manually to the graph.

Questions B45, B46 and B48 (Importance of the Surrounding Environment, Transposons and God in the evolution of species) are involved in both axes, indicating an interaction (KV) between "Values" (axis 1) and "Scientific Knowledge" (axis 2). Questions B45 and B46 come close to overlapping, and both point to the top right of the graph, indicating that the evolutionary conceptions (far right) are more correlated with the importance given to Surrounding Environment and Transposons (and therefore more positive about axis 2) and vice versa. In contrast, the B48 variable points to the left, indicating that creationists emphasize the importance of God in the evolutionary process.

The importance of natural selection, indicated by vector B43 in the top right quadrant of Figure 3, is highly weighted on axis 1 but less weighted on axis 2. This shows that natural selection is of the upmost importance for evolutionists and that creationists do not see it as relevant, perhaps rejecting it as being associated to more materialistic philosophies, such as capitalism or racism. In addition, its low weighting on axis 2 might be related to those people (creationists or evolutionists) who interpret natural selection as a scientific theory rather than an ideology, in a manner not conflicting with their moral values.

Results of the cross-tabulation between B29a and B29b (Table 3) show that out of the total sample (N=282), 6% (18) do not accept the theories of evolution or creationism, while 46% (N=132) cope well with both conceptions, suggesting that these views are not relevant to their system of values. About 20% (N=57) of the respondents accept the theory of evolution, but refuse the theory of creationism. Finally, 27% (N=75) accept creationism, but do not accept evolutionism, showing that creationism is stronger in this sample.

Table 3
Cross-tabulation between questions B29a and B29b

		Question B29b		Total
		Yes	No	
Question B29a	Yes	18	75	93
	No	57	132	189
	Total	75	207	282

4.2 Analyses between classes (groups of teachers)

Figure 4 shows the distribution of teacher and future teacher groups as a function of the two principal components (C1 and C2). In-B and Pre-B teachers are clearly separated from both In-L and In-P teachers. Between them lie the Pre-P and Pre-L groups. These results indicate that biology education may be an important factor in developing scientific knowledge about evolution.

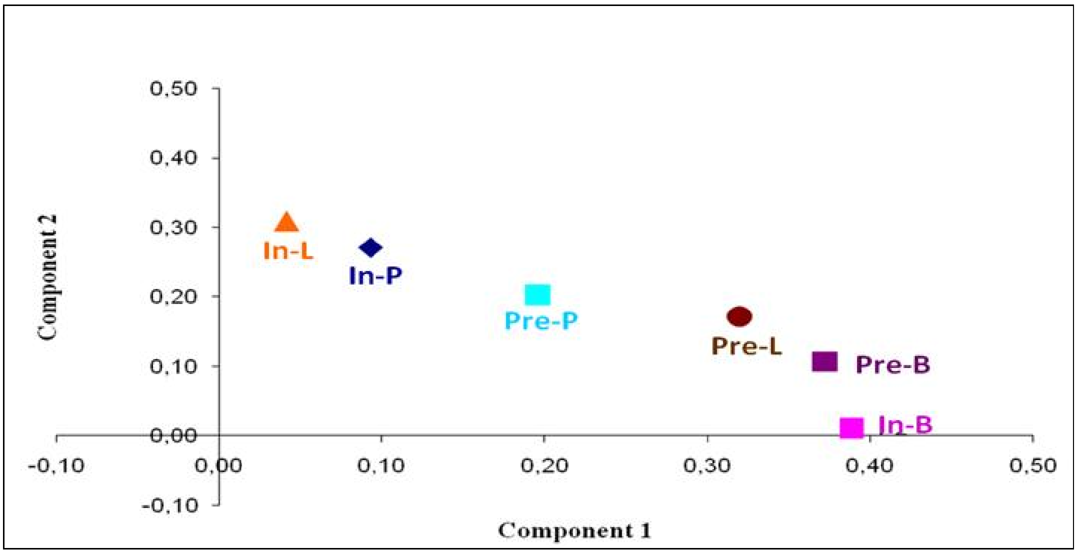

Figure 4
Distribution of teachers' and future teachers' groups as a function of the two principal components (C1 and C2)

When looking at the answers of the different groups of teachers and future teachers it becomes clear that most In-P, Pre-P, In-L and Pre-L teachers have creationist conceptions. In contrast, less than half of the In-B and Pre-B teachers have creationist conceptions (Figure 5A, B and E). In agreement with our results, a recent survey in Brazil (Schwartsman,2010) published in April 2010 in the newspaper *Folha de São Paulo,* revealed that "the majority of Brazilians (59%) matches the acceptance of Darwinian process with faith in the conduct and supervision of God, located in a plane superior to nature."

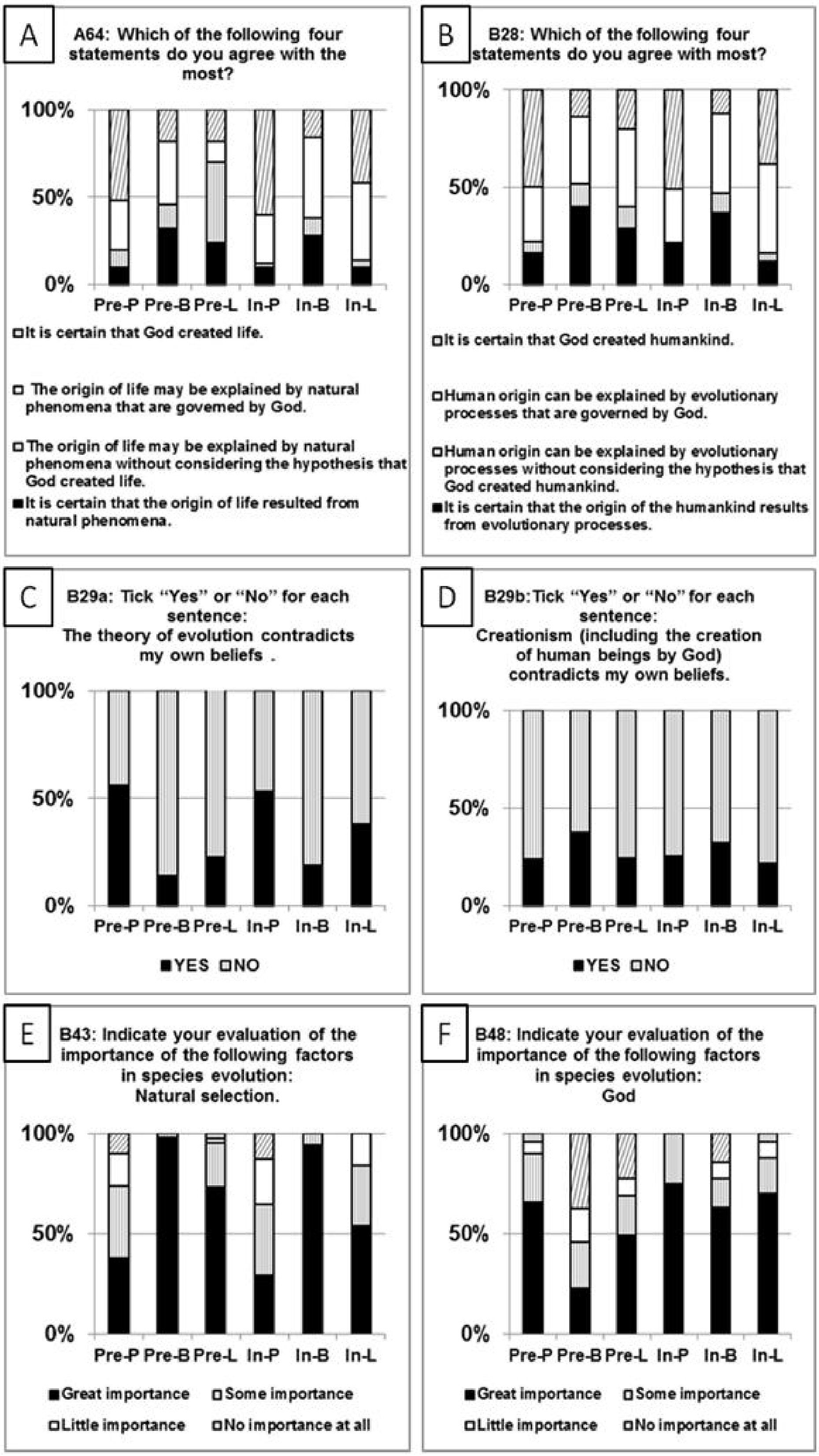

Figure 5
Answers of groups of teachers and future teachers to questions A64, B28, B29a, B29b, B43 and B48 (A-F, respectively)

Most teachers and future teachers of all groups answered that the theory of evolution (Figure 5C) does not contradict their own beliefs; similarly, creationism does not contradict their beliefs either (Figure 5D).

Almost all In-B and Pre-B teachers (over 90%) placed great importance on the process of natural selection with respect to the evolution of species, while only 30 to 40% of In-P and Pre-P teachers, respectively, placed great importance on this process (Figure 5E). The In-L and Pre-L teachers were between these groups, ranging from 50% to 70%, respectively.

These results are in agreement with previous results from 12 other countries (Quessada et al., 2007), in that the biology teachers and future biology teachers gave more importance to natural selection and the evolutionary process. However, the total Brazilian sample showed a higher percentage of creationist conceptions.

5. Final remarks and conclusions

With the KVP model in mind (Clément, 2006), our results show a strong influence of religious values (V) on conceptions about the origin of life and humankind, and they show that this influence is less strong for biology teachers and future teachers than for the other groups, indicating that Knowledge (K) is an important factor in acceptance of the theory of evolution and rejection of God's influence on the creation of life. The variable “social practices” (P) was not focused on in this study. Although in general our results are in agreement with previous studies carried out within the BIOHEAD-CITIZEN project (Quesada & Clément, 2010; Quessada et al., 2007), the Brazilian in-service and future biology teachers still showed a stronger effect of religion relative to the other countries studied.

All of the Brazilian respondents forming the groups of in-service teachers and future teachers understand the importance of natural selection for evolution. On the other hand, almost half of them do not invalidate the hypothesis of a Creator who rules that process. This reinforces the studies by Quessada and Clément (2010) claiming that evolutionism and creationism are not necessarily conflicting views. Furthermore, in this sense, we also agree with Gould (1999) who argues that religion and science are “non-overlapping magisteria”, having separate domains of teaching authority.

Why do the respondents accept both creationist and evolutionist ideas, with no apparent conflict between them? Does this constitute an obstacle for evolution teaching?

One possible answer to the first question can be taken from the model of changes in conceptual profile (Mortimer, 1995), which explains that people do not need to abandon or replace their previous/alternative conceptions to understand a scientific concept, i.e. it is possible for two or more meanings of the same word or concept to coexist in a single person, to be evoked in the suitable context. In this sense, it is plausible that the in-service and future biology teachers in this study understand the ideas of evolution without dismissing their own world views. As stated by El-Hani and Bizzo (2002, p.19): “…the teaching of science should, above all, show students how a set of problems is solved by the scientific perspective, broadening the spectrum of possibilities available to them. Now, the question of whether or not students believe in the scientific conceptions, rather than only understand them, can be properly understood as a problem of an intimate nature of the student being examined by him in the context of his worldview, in the light of ideas that have strength and power.”

We understand that the teacher’s acceptance or refusal of evolutionist ideas is a personal matter, as it is for students. Inside the classroom however, the teacher’s role is to arouse students' motivation to understand the scientific concepts and to explain that within their own individual contexts, scientific conceptions and alternatives have their validity and range (El-Hani & Bizzo, 2002). This obviously does not mean that values and creeds should be taught on an equal footing with science in the classroom. However, teachers should promote the explication and discussion of values and creeds so that the students acquire a critical attitude about life and, in this way, they can corroborate toward better citizenship.

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Appendix

"Evolution" questions:

A33. The emergence of the human species (*Homo sapiens*) was just as improbable as the emergence of any other species.

I agree I don't agree

A44. The emergence of the human species (*Homo sapiens*) was the aim of the evolution of living species.

I agree I don't agree

A62. In the list below, tick the THREE expressions that you think are the most strongly associated with the origins of humankind.

☐ Adam and Eve ☐ Australopithecus ☐ Creation ☐God ☐ Natural Selection

A64. Which of the following four statements do you agree with the most? (tick only ONE answer)

☐ It is certain that the origin of life resulted from natural phenomena.
☐ The origin of life may be explained by natural phenomena without considering the hypothesis that God created life.
☐ The origin of life may be explained by natural phenomena that are governed by God.
☐ It is certain that God created life.

B7.	The chimpanzee should be included in the genus *Homo*, notably because 98.5% of its DNA is identical to that of *Homo sapiens*.	I agree	I don't agree

B28. Which of the following four statements do you agree with most? (select ONLY one sentence)

☐ It is certain that the origin of 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.

B29. Tick "Yes" or "No" for each sentence:

B29a - The theory of evolution contradicts my own beliefs.
☐ Yes ☐ No
B29b - Creationism (including the creation of human beings by God) contradicts my own beliefs.
☐Yes ☐ No

Indicate your evaluation of the importance of the following factors in species evolution. (tick only ONE box for each line)

		Great importance	**Some importance**	**Little importance**	**No importance at all**
B42	Chance				
B43	Natural selection				
B44	A program inside the organism (intelligent design)				
B45	Surrounding environment				
B46	Transposons (jumping genes)				
B47	Viruses				
B48	God				

Section 6 Environmental education: Field-work

27

CONCEPTIONS AND ATTITUDES OF STUDENTS AND STAFF DURING THE IMPLEMENTATION OF SCHOOL AGENDA 21

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Abstract

This study focuses on identifying values, specifically conceptions and attitudes towards sustainable development (SD) and implementation of Agenda 21 in a school. Data were collected from a questionnaire. Responses of 80 students and 22 staff members at an agricultural school were analysed. Students' responses highlighted the centrality of the environmental dimension of SD. The difference between staff's and students' conceptions of SD related to the categories of "responsibility" and "awareness". Related activities within school, students and staff mentioned a very limited number of actions, essentially "eco-friendly gestures". These actions are necessary but not sufficient to achieve sustainable development, and may constitute a basis for more complex actions. The factors referred to as hindering commitment to SD were both institutional and psycho-social in nature. SD redefines the boundaries between the academic subject approach/a-disciplinarity (or the cross-curriculum approach), teacher/person who educates, class/school/local surrounding territory, knowledge/values, acting/thinking. These boundaries change the modes of action and the organisation of the teaching-learning activity by introducing new players, values and relationships.

Keywords: sustainable development; conceptions; school Agenda 21; environment; education

1. Theoretical framework

The Brundtland Commission's definition of sustainable development (SD) as "*development which meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987), is one of the first and still most widely used. To complete this definition, the International Council for Local Environmental Initiatives (ICLEI, 1996), in its Local Agenda 21 Planning Guide, describes and schematizes three spheres making up SD: *environment, economy and community* (society). True SD is then development that meets the "triple bottom line" where all three spheres interact on an equal basis. This conception of the three dimensions/pillars of SD has been widely incorporated into teaching (Summers & Childs, 2007).

However, as a legacy of former civics instruction and an initial trend in environmental education, the French school system has adopted an eco-friendly position rather than a reflexive and critical perspective. The focus is on dictating the way in which we should behave by presenting us with a series of "eco-friendly gestures" (turning lights off, sorting the rubbish, etc.). From a critical perspective on Education for Sustainable Development (ESD), it is important to define more ambitious educational goals than these simple "eco-friendly gestures". It is about training social stakeholders to think for themselves, and to show responsibility (Jonas, 1992). According to Mappin and Johnson (2005), who analysed this transition from environmental education to ESD, the objective in the 1970s was to encourage behavioural change. In the '80s, it was to encourage personal change, i.e. an understanding of one's own personal attitudes and motivations which guide decision-making. Later, in the '90s, a change in social values and in the system as a whole became fundamental to sustainability.

However, SD has been subjected to so many different interpretations, and even economic and political appropriations, that the notion of sustainability has lost some of its real meaning. Agenda 21 is an action-plan for the 21st century adopted by the Earth Summit in Rio (1992). It proposes recommendations in various areas, such as poverty, health, housing, pollution, agriculture, etc., with 27 principles that must be followed for its implementation. At the level of the local authorities, Agenda 21 integrates the principles of SD, based on proposals from the public. In France, Committee 21 has supported this mission since 1994. The objective set out in Agenda 21 claims to be consensual but is too vague, and even inoperative, according to numerous local Agenda 21 developed in schools. SD is then analysed as *"a clever and seductive strategy aimed at the stakeholders in the politico-economic sphere. It is important to convince them to integrate social and environmental preoccupations into their economic growth agenda"* (Sauvé, 2007). The civic question of governance, currently a much debated piece of rhetoric in France, is an additional factor in the transition from environmental to sustainable. Therefore, setting up Agenda 21 programmes in schools is considered to be a project for which the collective dimension is essential (Fortin-Debart & Girault, 2005), where the importance of responsibility is a major aspect which helps us to understand implication of students and staff.

SD is a socio-scientific issue in which social values get mixed in with scientific goals, which are themselves under debate or controversial (Simonneaux & Simonneaux, 2009). Socio-scientific questions lead to the development of specific forms of reasoning (Sadler, Chambers, & Zeidler, 2004). From the perspective of critical rationality in decision-making, knowledge of science is necessary but insufficient. Furthermore, the sciences do not form a homogeneous group proposing a single analysis or single solution. The sciences are not independent of the conditions from which they emerge and they carry values within their very structure (Habermas, 2002). Setting up a SD programme in schools may be considered an authentic situation, a legacy of environmental education enlightened by socio-scientific questions.

1.2 Research questions

The aim of this research was to identify conceptions and attitudes towards SD and draw attention to the implementation of Agenda 21 in schools. An analysis of the attitudes and conceptions then allows us to discuss values of ESD.

1.3 Context

The study was carried out in an agricultural secondary school, located in a rural area near the Pyrenees, in France. The secondary school's Agenda 21 project was set up gradually by the headmaster and his team, along with a part-time project leader. Partners from outside the school, academic authorities and others, also offered their support. These external and internal factors are necessary to ensure the success of the project. Official circulars, explaining how to implement SD in a school context, were sent out to help the school and its partners (Laidin, 2007). Guidance on integrating SD issues was also given in school programmes.

1.4 Methods, participants and data sources

The sample was made up of different members of the agricultural secondary school who have been involved in the implementation of a school Agenda 21 project for several years. These included 22 members of the teaching and technical staff, and 80 students, 25 of which have "eco-delegate" status (Table 1). In each class, the eco-delegates are students elected within the framework of the Agenda 21 project. The students counted in the survey were aged 16–21 years and were either studying toward a technological Baccalaureate specialising in "science and techniques of agronomy and life sciences" or following a vocational agricultural course. Most of the students in the courses offered at the school are male and the gender imbalance was even greater in the eco-delegate group (Table 2).

Table 1
Gender and status of the sample

	Status of the sample		**Total**
Gender	**Staff**	**Students**	
Male	11	52	63
Female	11	28	39
Total	22	80	102

Table 2
Gender distribution in the sample of students

	Gender of the students		**Total**
Group	**Male**	**Female**	
Non eco-delegate	32	23	55
Eco-delegate	20	5	25
Total	52	28	80

Data were collected using a questionnaire which consisted of six closed and eight open questions. The students filled in the questionnaires during school time and the staff during their working hours. The themes in the questionnaire related to 1) the different conceptions of SD; 2) the different SD actions already set up in the school; 3) new developments in the behaviour of the person filling in the questionnaire and his/her close circle of family and friends; 4) the reasons why people do not seem concerned about SD; 5) the notion of responsibility and more precisely "being responsible" in terms of SD.

The answers to the open questions were post-coded (Altman, 1974), which generated mutually exclusive categories of our taxonomy (Table 3). Elaborate valid taxonomies impose an inter-subjectivity that is obtained by working together as a team, in four-way discussions during face-to-face team meetings. It must be faithful to the body of the data and reliable among researchers by items.

All results were analysed with SPSS-PASW18 software. We used the most appropriate statistics to evaluate the validity and inter-rater reliability of the outcomes (Crombach's alpha). After reaching the objectives of validation and verification of different alpha reliabilities ranging around ($0.852 < \alpha < 0.893$) in the test/retest and split-half correlation, we created taxonomies which could be used by teachers and researchers working on SD. These tools save a considerable amount of time when analysing open questions, but also when creating closed questions.

Table 3

Taxonomy of coding for responses to the following question: What terms are linked to SD? (categories based on 1047 initial terms)

Categories	Examples of terms used
Stakeholders	farmers; human beings
Basic needs	nourishment; food; organic food; hygiene; sanitary facilities; health
Awareness	thinking of future generations; behaviour; gaining awareness; society; man-nature relationship
Economy	consumption; entreprise; production; wealth
Environment	biodiversity; climate; ecology; ecosystem balance; nature
Damage management	reducing the greenhouse effect; fighting against pollution; new technology; non-polluting cars
Resource management	car-pooling; conserving water; recycling; sorting waste; protecting the planet
Territory management	land management; country; development schemes; territory; towns
Impact of human activities	waste; noise disturbance; household waste; motor vehicle pollution; global warming
Politics	democracy; social equilibrium; equity; fighting poverty; power
Responsibility	citizenship; collective consciousness; participation; respect; solidarity between generations
Resources	agriculture; biofuels; biomass; water; energy
Integrated production	organic production
Social	social development

2. Results

2.1 A dominant conception of the environmental dimension of SD

On the basis of 1047 initial terms, even though the social and economic dimensions of SD were also taken into account, the results highlight a dominant conception of the environmental dimension of SD (Figure 1). The students' responses confirmed a highest frequency of this dimension (Léna & Simonneaux, 2008).

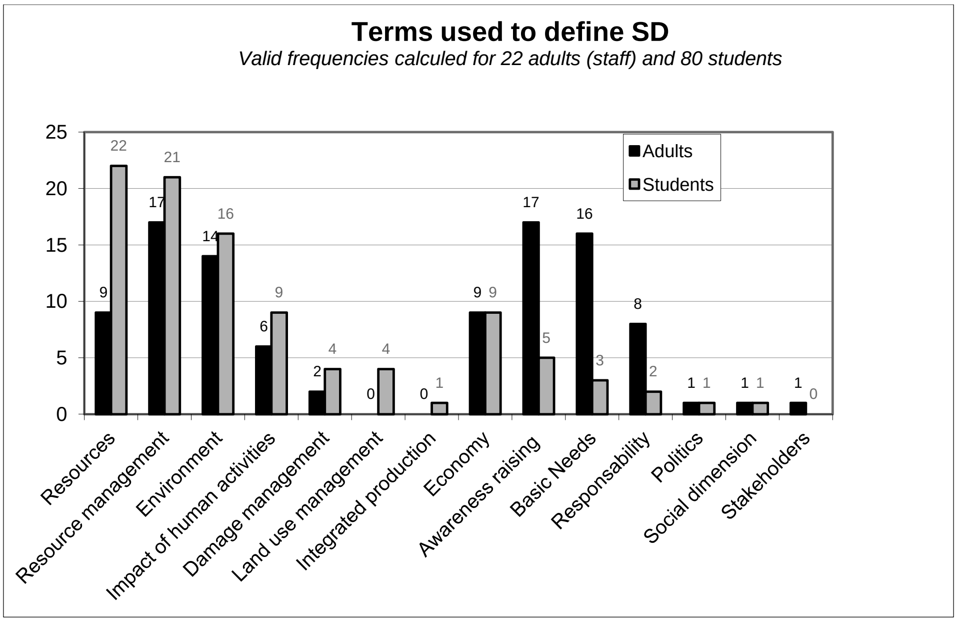

Figure 1
The most used terms by the students and staff to define SD

Table 4
ANOVA of categories between staff and students

ANOVA: categories of SD by staff versus students	F	Significance
Stakeholders	104.851	0.000
Politics	66.459	0.000
Responsibility	53.651	0.000
Awareness	35.732	0.000
Basic needs	8.357	0.005
Economy	8.232	0.005
Damage management	3.576	0.014
Impact of human activities	2.055	0.156
Social	1.554	0.216
Environment	0.665	0.418
Resource management	0.535	0.467
Integrated production	0.058	0.811
Territory management	0.019	0.892
Resources (In their definitions, the terms "Resources" and "Resource management" are two different categories)	0.002	0.962

Furthermore, Table 4 reveals the significant differences that can exist between the various conceptions of SD. Important differences were found for “stakeholders”, “politics”, “responsibility” and “awareness”, which are all dimensions relating essentially to staff reasoning. In contrast, categories related to the environmental dimension revealed proximity between staff and students (Table 5).

Table 5

Comparison of students and staff for categories occurring the most and least frequently

Definition of SD	Categories mentioned first (five most frequently represented categories)	Categories rarely represented
Staff	Resource management Awareness Responsibility Environment Economy/Resources	Stakeholders Integrated production Social
Students	Resources Resource management Environment Impact of human activities Economy	Territory management Basic needs Integrated production

2.2 Differences between staff’s and students’ conceptions

We were thus able to highlight the significant differences in the staff’s and students’ conceptions of SD. In the closed question: Rank the eight statements from closest to furthest from your own conception of SD, the students associated SD, first and foremost, with the environmental dimension (Nature conservation actions; Increasing respect for and appreciation of nature; Gaining a better understanding of the workings of nature, etc.), whereas the staff gave priority to more complex goals, which we categorized as “Awareness” (Only way to protect future generations; Acting to ensure the world’s equilibrium; Commitment from each citizen, etc.).

The staff incorporated the three pillars of SD into their reasoning while the students focused on the environmental dimension. Moreover, for both staff and students, the first references concerned the management domain linking SD to “eco-friendly gestures” (Table 5). These gestures focus essentially on individual behaviour and not on collective actions identified in the “Territory management” or “Politics” categories. Staff was much more concerned than the students about aspects relating to responsibility.

2.3 Commitment of students with eco-delegate status

In the above results, we grouped together students and eco-delegates. However, more detailed analyses tended to show that eco-delegate status confers significant differences ranging from ($0.23 < F < 0.51$; sign. < 0.005) in the categories of: “Stakeholder”, “Basic needs”, “Economy”, “Environment”, “Territory management” and “Politics”, but no significant differences in any of the other terms given by the 80 students. Thus, the eco-delegates had conceptions which were qualitatively and significantly more varied than those of their peers.

Commitment to action was a priority for eco-delegates, whereas the students who were not so actively involved had a more global vision of sustainability. Do these differences in attitude explain the differences in the amount of knowledge they have of the actions already set up in the school? The results confirmed that values play a prominent role in the design and organisation of educational activities concerning SD, at least for the staff. This linkage between knowledge, values and action should be explored during the transition from rationality to reasonableness. It results in a shift from optimisation of benefits to incorporation of moral and ethical values in decision-making.

2.4 Influence of gender

The high number of males among the eco-delegates was the first sign of a difference in the conceptions of SD (Table 2). However, although the body of data was quite large, we found very few significant differences linked to gender. All else being equal, the biggest difference related to gender concerned the "Damage management" category ($F = 35.732$, $F < 0.008$). Putting the differences in frequency into perspective, non-parametric tests showed that females are significantly more concerned about handling damage caused by humans than their male counterparts.

2.5 A limited vision of the actions already set up in the secondary school

The students and staff mentioned a very limited number of actions when answering the following question: What are the actions bound to sustainable development which have taken place in your school? On average, 2.12 actions were mentioned, whereas dozens of actions have been listed in this school over the past few years (Figure 2).

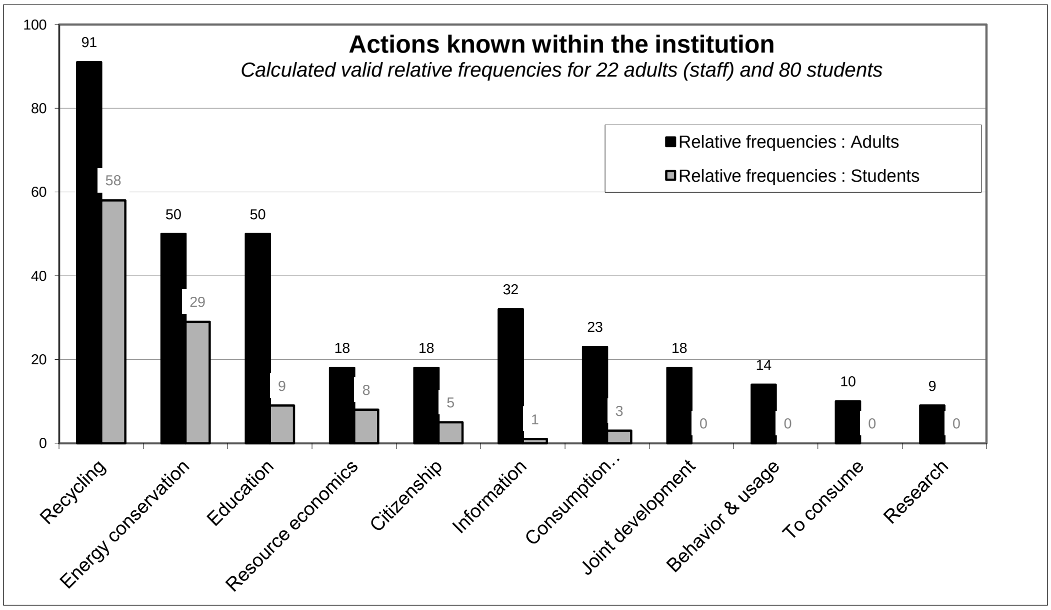

Figure 2
Actions reported by staff and students (relative frequency): frequencies are reported per 100 adults (staff) and 100 students

In terms of their knowledge of the actions operating within the school, the eco-delegate students were less different from the staff than they were from their peers who did not have eco-delegate status (Table 6). Similarly, it appears that the information provided by the eco-delegates was not significantly different from that provided by the school staff. Therefore, although the eco-delegates were as well informed as the staff, their peers were not. Two hypotheses emerge: the first is that the eco-delegates do not pass the information on to the other students in their class, and the second is that the eco-delegates have the same amount of information as their peers but are more committed to SD and thus better able to mobilise this information when filling in the questionnaire.

Table 6
Post-hoc comparison test between staff, students and eco-delegates

(I) Role	(J) Role	(I-J)	Standard error	Significance	Confidence interval 95%	
					Inferior limit	Superior limit
Staff	Eco-delegate	0.163	1.879	0.996	-4.51	4.83
	Other students	-8.104*	2.933	**0.027**	-15.39	-0.82
Eco-delegate	Staff	-0.163	1.879	0.996	-4.83	4.51
	Other students	-8.267*	3.069	**0.032**	-15.89	-0.64
Other students	Staff	8.104*	2.933	**0.027**	0.82	15.39
	Eco-delegate	8.267*	3.069	**0.032**	0.64	15.89

Multiple comparisons
Action_SD_School Taxonomy level 1: Tukey test.

In addition, and very surprisingly, it appeared that the students were mentioning actions led within school Agenda 21, while the staff was not. However, after consulting with the project leader, we realised that the students considered some of their daily activities to be actions initiated by the school whereas this was not, in fact, the case. It was “simply” a question, here, of the know-how and social skills they had acquired in school rather than actions taken within the framework of a particular project.

2.6 Changes in daily life

To be considered a success, an individual's training must involve the acquisition of new knowledge and skills. In this context, we asked what had changed in the respondents' daily lives following the different training projects and actions. The changes concerned mainly the “Damage management” category (Figure 3), such as using fewer chemical products in the workplace, avoiding unnecessary pollution, disposing of waste in the proper place, or more generally fighting against environmental pollution. Priority was, once again, given to the environmental dimension of SD.

2.7 Obstacles

We asked why people do not get involved in SD actions. The aim of this question was to highlight obstacles to SD. There were no significant differences in the suggestions given by the staff, students and their eco-delegate peers (Figure 4).

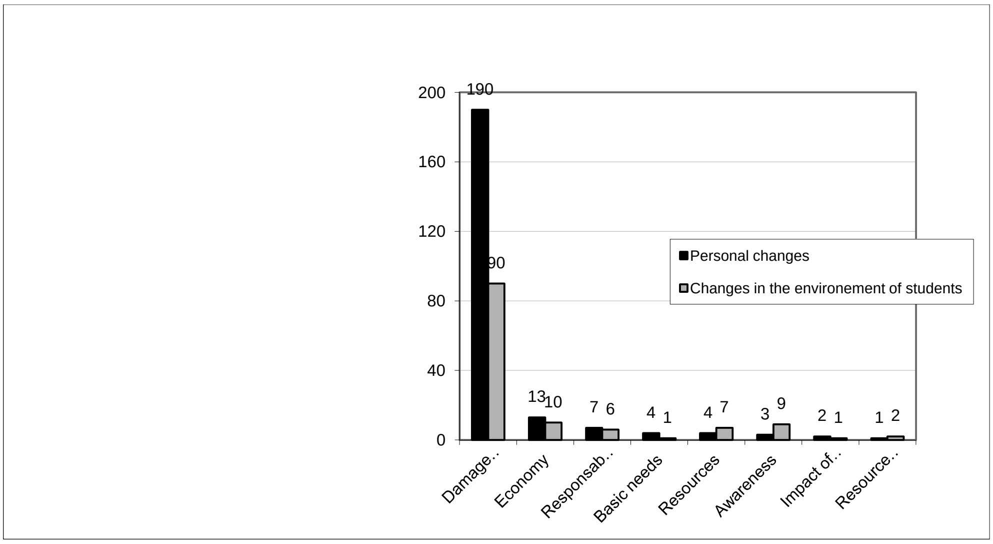

Figure 3
Changes related to sustainable development

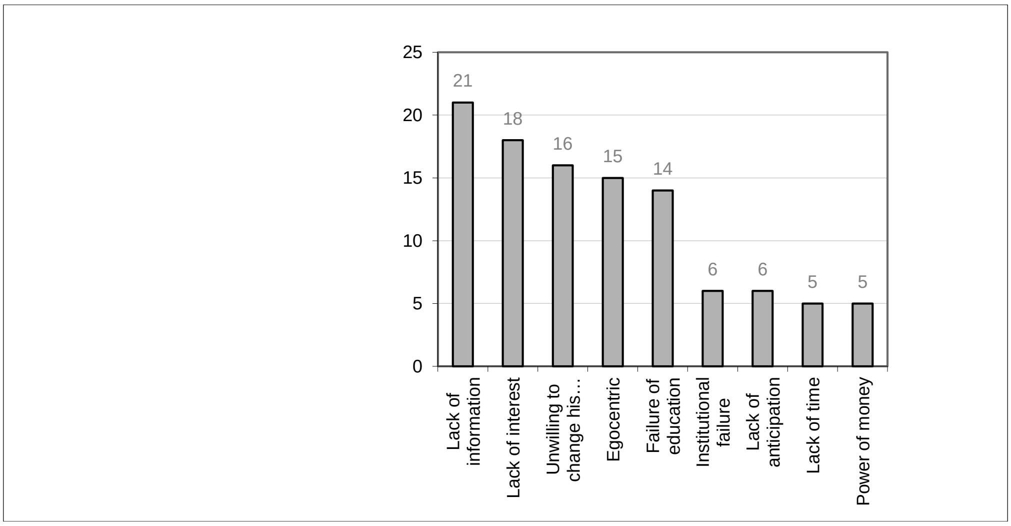

Figure 4
Obstacles to becoming involved in SD actions (valid relative frequencies)

The first obstacle to getting involved in SD is clearly a deficit of information (Figure 4). Information seems to be lacking, even within the school, as we saw earlier when we asked students and staff to list actions that were already in place. However, even the educators admit that it is a bit simplistic to think that someone who is well-informed will modify his/her behaviour. This idea is regularly challenged when setting up educational actions. The obstacles which followed were related to lack of interest; in short, we show no concern for others or for the future. This could perhaps be partly linked to a lack of education, which comes in fifth on the list. These initial reasons alone represented 80% of the obstacles to SD and consisted of both institutional and psycho-social barriers. Over 12% of the reasons for not being involved in SD actions were linked to the power of money, to imaginary additional costs or to false reasons given by industrialists to avoid spending a fortune on protecting the environment (manipulation).

3. Discussion

We found some previously proven results on conceptions of students and staff, which were related to the environmental dimension of SD (Summers & Childs, 2007; Walshe, 2008). This remains close to the analysis of Beaugrand (1990): "Students adjust and change their conceptions when they are confined in schools". Our results highlight a dichotomy between school and their daily lives outside school.

3.1 From "damage management" to "resources management"?

When the students talked about life outside of school, in terms of changes in both their own personal behaviour and that of their close circle of family and friends, the main theme was "damage management", whereas in school they referred to "resource management". The same distinction appeared in the staff's results.

These differences in perception of what happens in and out of school can be interpreted in two ways, which are potentially complementary and cumulative. We can consider them to be the effect of action, namely of the implementation of Agenda 21. The students and the educational community can act positively upon their environment. School becomes an area where things are "possible", environment is a resource and is no longer viewed in terms of constraints and degradation. Outside of school, especially when faced with sometimes over-dramatized media coverage, one may experience a feeling of helplessness and of only suffering the "damages" because individuals have no control over this larger reality. Events are presented in terms of their negative effects whereas at school, the events are presented in terms of resources and the anticipation of future needs. Is taking action conducive to learning? In vocational didactics, Pastré (1999) draws attention to the danger of confusing the outcomes of an action with the outcomes of the learning process. This confusion appears to have been kept alive in the current school context: challenges of working in a team over the long term, the division of educational sequences, culture and the syllabus, all rooted in the disciplines. Under these conditions, it seems to be difficult to go beyond the action/learning dichotomy.

3.2 Commitment of those involved in an educational approach to SD

How do the different players in the school feel about this active, quasi-militant dimension of Agenda 21? We must stress that all members of the educational community endorsed the principles and goals of SD, but not all were committed to the same extent. The answers to the questions concerning the changes induced by SD issues showed that these changes are limited (fewer than one in three modified at least one of their habits and only 20% changed more than one way of doing things), that they concern the environmental aspects (first sorting waste, then conserving electricity and water), and finally, that they noticed mainly similar individual actions in their close circle of family and friends (sorting waste, saving on water). These are "eco-friendly gestures", actions which are necessary but not sufficient, but they may constitute a basis for more complex actions. The risk of such pedagogical participation is "*the exclusion of important themes such as material growth and global social*" (Laessøe, 2010).

3.3 Areas of action

SD redefines the boundaries between the approach by academic subject/a-disciplinarity or cross-curriculum approach, teacher/person who educates, class/school/local surrounding territory, knowledge/values, acting/thinking. The educational act is put into context and therefore differs according to the given environment. The teachers commit themselves preferentially to those who are linked to their own discipline. The conception of the three pillars of SD allows the teachers to split the actions into three groups: those relating to the environment, those relating to the social sphere and those relating to economics. They then link the different SD actions to the corresponding academic discipline. The conceptions of the secondary school teacher's job and of the learning process likely also explain the form of commitment adopted by the staff: the teacher is above all an expert in his/her field; school is a place for learning through understanding rather than through "acting". This doing/learning dialectic is probably present in the culture of this secondary school because of its orientation towards technical and vocational courses.

The redefining induced by these boundaries changes the modes of action and organisation of the teaching-learning activity by introducing new players, new references and new relationships. What emerges is a change in the teacher's role or "job" and the student's role or "job". It seems to us that since the mentioned actions are not related to all of the traditional class activities, it is more a question, for the moment, of superimposing a new teaching practice over an existing one. Indeed, since communicating these initial results to the teaching staff, an effort has been made to present all of the actions of Agenda 21 along with the main themes which structure them, integrating, more explicitly, the educational goals and the classroom activities.

The difference between staff's and students' conceptions of SD concerned the categories of "Responsibility" and "Awareness". Regarding the question on the notion of what "being responsible" is, the differential between staff and students persisted on this individualist conception, with a larger proportion (nearly 30%) of the staff linking responsibility to the societal dimension (future, consequences, future generations, etc.). This is a more reflexive stance which reveals the different way in which students and staff relate to time. The staff probably function on a very different time scale, projecting themselves beyond their own generation, whereas the students, most of them under the age of 20, are still going through the period of identity construction–a period in which any projection into the future remains much more virtual and more difficult to detach from their subjectivity. Another difference concerns the social and civic aspects, which were of secondary importance to the students. The relationship to the Other or to the World (Charlot, 1999) is still being established for the students and is more stable for the staff. Concerning projections into the future, we can see that the students have difficulty, not only in terms of anticipating future needs, but also in terms of future societal choices. A potential teaching method to develop might be work on long-term scenarios (Lloyd & Wallace, 2004).

We note that a certain number of elements which remained implicit throughout the project must nevertheless be considered as fundamental. "Act in order to understand, understand in order to act". This slogan, often used in teaching or training, including situations linked to SD, is worth challenging and specifying.

4. Conclusion

This study of the several hundred responses of 80 students and 22 staff members of an agricultural school enabled us to highlight different conceptions of what SD could be, of the way they define it, of the initiatives set up in the school but also in the students' proximal environment. We also gain better knowledge of the impact of training for SD on day to day behaviour and habits. Furthermore, this study allowed us to emphasize the potential obstacles to personal commitment.

An analysis of the players' conceptions demonstrated the difficulty the great majority have in imagining what is at stake globally in this type of action. The evaluation of such educational activities should, rather, be oriented towards understanding the dynamics involved and cannot be reduced to measuring a hypothetical level of performance or effectiveness, be it in the cognitive or praxeological domain. The evaluation indicators can only be local and determined by context.

The evolution of the secondary school's Agenda 21 project seems to have gone beyond the "eco-friendly gestures" to progressively integrating educational challenges. A second group is in the process of filling out the questionnaire used in this study, with the aim of gaining better longitudinal knowledge and observing the effects of educational actions on the conceptions of SD, over time. Finally, concerning the optimum conditions and the obstacles to setting up an Agenda 21 project, the support of an extended team composed of management staff, a project leader and external partners, whether these are from the academic authorities or others (for example, ADEME), is fundamental to broadening the modalities and the scope of the actions. This type of cooperation is one of the main conditions essential to the success of the project. All things considered, this type of cooperation must in itself be endorsed by official circulars regarding the implementation of SD in schools.

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28 "IT IS NOT THE CO_2 ITSELF, IT'S THE IMBALANCE!" CONCEPTUAL RECONSTRUCTION OF THE CARBON CYCLE IN GLOBAL WARMING

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Abstract

Aim of this study was an evidence-based and theory-guided development of learning environments on a key issue of global warming: the global carbon cycle and humans' impact on it. Using the model of educational reconstruction, we developed and evaluated different learning environments based on students' and scientists' conceptions sampled in a reanalysis of empirical studies, own interviews (n=11) and teaching experiments (n=24). The analysis of conceptions showed that all students–and scientists–refer to the same schemata. Our teaching sequences on global warming, aimed at a conceptual reconstruction, were based on students' schemata. In the context of global warming, our approach proved to be appropriate for the reconstruction of everyday conceptions toward more scientific concepts. Our analysis of students' conceptual development concerning the carbon cycle showed that learning about the carbon cycle is not based on a change of concepts but on their reconstruction. Thus the term conceptual reconstruction seems more appropriate to describing learning about the carbon cycle than the term conceptual change.

Keywords: conceptual change; educational reconstruction; everyday conception; climate change; carbon cycle

1. Problem

Global warming is a serious threat to our biosphere, with economic, ecological and social consequences (IPCC, 2007). Transferring public concern for global warming into effective everyday action requires knowledge of the causes and risks of climate change (UNCED, 1992). An analysis of students' conceptions of global warming shows that even after instruction, they often differ from scientists' conceptions.

Aim of our study was an evidence-based and theory-guided development of learning environments on a key issue of global warming: the global carbon cycle and humans' impact on it. On the basis of students' conceptions, we developed different learning environments using the model of educational reconstruction (Duit, Gropengießer, & Kattmann, 2005).

2. Theoretical framework and key objectives

The theoretical framework of our investigation relies on three different, albeit interdependent theories: the moderate constructivist epistemology (Duit & Treagust, 1998) defines learning as a construction of individual conceptions; the theory of conceptual change, which we prefer to call conceptual reconstruction to indicate its different meaning (Duit & Treagust, 2008; Kattmann, 2008), describes factors which enable successful learning processes. Consequently learning environments on global warming have to be connected to students' pre-conceptions and their experiences in this domain to enable fruitful learning; experientialism (Lakoff & Johnson, 1999) describes understanding as embodied. This means that our basic conceptions grow out of bodily experience with our physical and social environment. These experiences are conceptualised in schemata. If phenomena cannot be experienced directly through our senses we use imagination to understand those imperceptible the applied framework distinguishes between embodied and imaginative conceptions. The latter are not directly grounded in physical experience, but use embodied schemata to understand these phenomena (Lakoff, 1990). Based on this framework, the study deals with three research questions: (1) Which conceptions do students and scientists employ in explaining the causes of global warming? (2) What is the experience-based source for conceptions of climate change? (3) Which learning pathways do students take in working with educationally reconstructed learning environments?

3. Research design and method

The research design was based on the model of educational reconstruction (Duit et al., 2005). Within this design, scientists' and students' conceptions are compared to develop effective teaching and learning activities. Scientists' conceptions of global warming were extracted from various scientific textbooks and the IPCC (2007) Report. Students' conceptions were sampled in a reanalysis of 24 empirical studies on everyday concepts of global warming (i.e. Boyes & Stanisstreet, 2001; Ekborg & Areskoug, 2006; Hansen, 2010), our own interview study (n=11, 18 years old, 5 female, 6 male) and our teaching experiments (n=24, 18 years old, 11 female, 13 male). All students attended German grammar schools and had no prior instruction in climate change. Based on the educational reconstruction of global warming, we set up and evaluated learning environments in 10 teaching experiments, each lasting about 65 to 90 minutes, in which we examined learning processes on the global carbon cycle in small groups of 2 to 3 students.

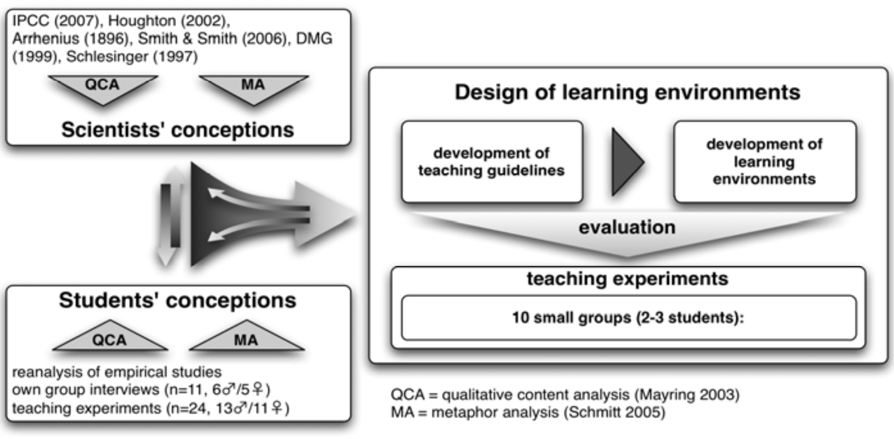


Figure 1
Research design-the model of educational reconstruction

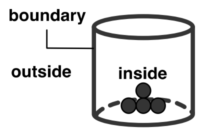
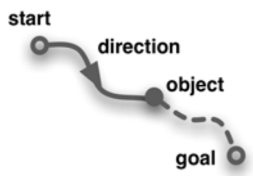
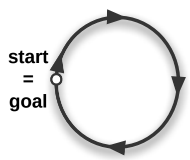
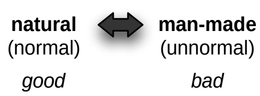
The teaching experiments and interviews were conducted by the paper's first author. Wilbers and Duit (2001) describe the simultaneous role of researcher as interviewer and teacher as beneficial for studies in science education, since the research situation resembles the authentic classroom. All data were audiotaped (interview study) or videotaped (teaching experiments), transcribed and investigated by qualitative content analysis (Mayring, 2003) and metaphor analysis (Schmitt, 2005). To ensure the quality of the data analysis, all data were externally and consensually validated (Steinke, 2004) by discussion in the first author's working group, and cross-checked with other studies in the field.

4. Results

4.1. Conceptions of the carbon cycle

The analysis of conceptions of climate change by experientialism shows that students and scientists have different conceptions of the global carbon cycle, but both refer to the same schemata. Schemata are conceptual systems that evolve directly from experience. Thus they are often the source of abstract conceptions, such as those on climate change.

Table 1
Schemata used to understand the carbon cycle

The container schema (Lakoff, 1990)… …is based on the experience of our body as a container with a sharply delineated boundary between inside and outside, and with inputs and outputs. Regarding the carbon cycle, this schema is used to think of different carbon stocks as containers containing carbon.	
The source-path-goal schema (Lakoff & Nunez, 1998)… …is based on our locomotional experience of moving from A to B. In this schema an object moves from a starting point to a goal. The direction of movement is defined by start and goal. Regarding the carbon cycle, this schema is used to describe carbon flows from one container to another.	
The circle schema (Johnson, 1987)… …differs from the source-path-goal schema insofar as start and goal are identical. The circle starts at one point, proceeds through a series of events or places and ends where it began. In the context of carbon flows, the carbon cycle is thought of as a closed system through which carbon moves but is never lost.	
The natural vs. man-made schema (Wachbroit, 1994)… …describes what is natural and man-made. *Normal* or expected things are perceived as *natural* and *a-normal* things as *man-made*. Students use this schema to distinguish between normal processes and processes initiated by man.	
The balance schema (Lakoff, 1990)… …shapes our conceptual system with our first attempts at walking instead of crawling. This schema follows a logical sequence in which each change is followed by a counter-change. This schema is used to differentiate balanced carbon fluxes from unbalanced ones.	

The container, source-path-goal and circle schemata are combined into a more complex container-flow schema when thinking about the carbon cycle:

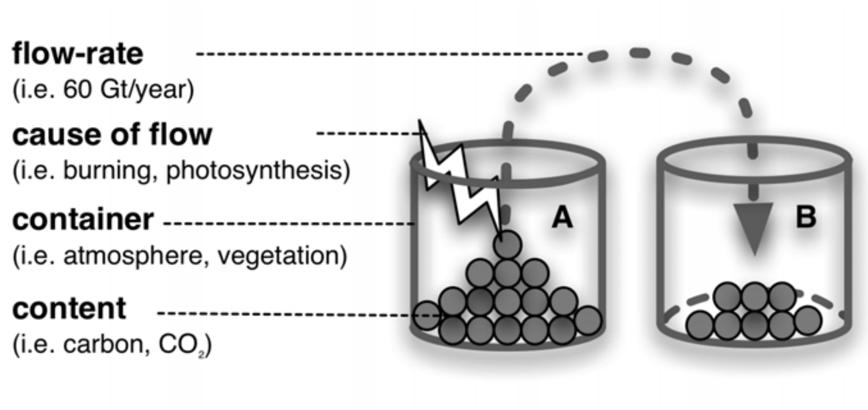
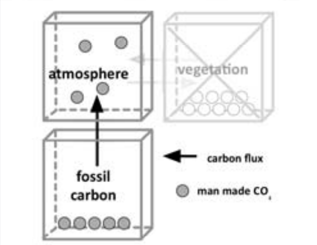
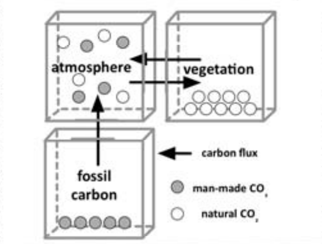
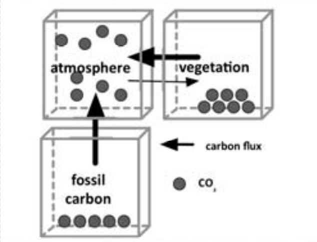


Figure 2
The container-flow schema

With these schemata in mind, we categorised the conceptions of the carbon cycle. We identified three thinking patterns in students' and scientists' conceptions based on a detailed analysis of their conceptions of global warming as well as a reanalysis of studies on students' conceptions of climate change (Niebert & Gropengießer, 2009, 2011).

Table 2
Thinking patterns of students and scientists on causes of global warming
*Some students expressed parallel thinking patterns

thinking pattern	man-made CO_2	man-made vs. natural CO_2	imbalance in carbon cycle
anchor citation	*Burning fossil fuel emits detrimental CO_2, burning wood does not emit CO_2.*	*Burning fossil fuel emits man-made CO_2, while respiration emits natural CO_2.*	*Burning fossil carbon and cutting trees emits more CO_2 than trees can capture.*
global carbon cycle in the container-flow schema			
source	*9 out of 24 students**	*6 out of 24 students**	*13 out of 24 students* & scientists*
cause of climate change	emission of CO_2	emission of CO_2 by burning of fossil carbon	imbalance by deforestation and burning fossil carbon
used schemata		circle schema	circle schema
	source-path-goal schema	source-path-goal schema	source-path-goal schema
	natural vs. man-made schema	natural vs. man-made schema	balance schema

The thinking pattern *man-made CO_2* shows that some students do not take CO_2 to be a natural component of the atmosphere, whereas the thinking pattern *natural vs. man-made CO_2* implies that different containers contain different sorts of CO_2. The adoption of the schema *natural vs. man-made* is very common: even some scientists term CO_2 produced from burning fossil carbon as *man-made*. But while students are referring to the existence or structure of CO_2 when terming it natural or man-made, scientists are referring to the cause of the emission.

4.2. Teaching guidelines emerging from educational reconstruction

On the basis of students' conceptions, we defined their learning demand on the carbon cycle and explicated it in three learning guidelines:

(1) see CO_2 as a natural compound of the atmosphere

(2) reflect on the natural vs. man-made schema

(3) explain climate change by imbalanced carbon flows

4.3. Educationally reconstructed learning environments

Based on the identified learning demand, we developed different learning environments which referred to the above-mentioned teaching guidelines. In the teaching experiments, two central learning environments (Niebert, 2009) were evaluated with regard to their effects on students' conceptual development. The first environment was aimed at modelling the carbon cycle in a container-flow model (Box 1). The basis for the modelling was a text about the carbon cycle and its man-made changes:

(1) amount of carbon in different carbon stocks

Vegetation: 2500 Gt; atmosphere: 750 Gt; oceans 38,000 Gt; fossil carbon: 10,000 Gt [1 gigaton (Gt) = 10^{15} g]

(2) the natural carbon cycle

About 90 Gt of carbon is emitted from the oceans into the atmosphere every year. The same amount of carbon flows back from the atmosphere into the oceans. Photosynthesis captures 120 Gt of carbon each year and stores it in land organisms; 60 Gt of this carbon is released by plant and animal respiration. The other 60 Gt are stored in the organisms, and emitted by decomposers when the organisms die.

(3) the anthropogenic carbon cycle

By the burning of coal, oil and gas, 6.5 Gt carbon is emitted from the stock of fossil carbon. An additional 1.6 Gt carbon is emitted from the vegetation into the atmosphere by deforestation.

Box 1
Modelling the carbon cycle in a container-flow model

Students were asked to explain the causes of climate change by using the model. We anticipated explanations based on unbalanced carbon flows into the atmosphere. The natural carbon flows between oceans/atmosphere and vegetation/atmosphere should be recognized as balanced. It should become clear that it is not the amount but the balance of the carbon flows that matters.

Students who adhered to the conception *natural vs. man-made CO_2* were given the following narrative to read (adapted from Levi,1975; published in Niebert, 2009). In this narrative, Levi describes the carbon cycle by the cycling of a virtual carbon particle:

"Our character lies for hundreds of millions of years, bound to three atoms of oxygen and one of calcium, in the form of a limestone. In 1840 a man's pickaxe sent it on its way into the world of change…"

Box 2
Excerpt from the narrative of a carbon atom.

The students were then asked to model the carbon cycle presented in the story in the container-flow model. In addition, students who used the natural vs. man-made schema were asked to reflect the schema in the story and model. The story's intent was to communicate that CO_2 is a natural compound of the atmosphere and that CO_2 from burning and respiration is identical in structure and quality.

4.4. Thinking pathways on the carbon cycle in climate change

To analyse if and how the learning environments influence students' conceptions, we evaluated them in teaching experiments, an empirical method that allows combining interview situations (investigational aspect) with teaching (interventional aspect) (Riemeier & Gropengießer, 2008; Steffe & D´Ambrosio, 1996). This provided information on the students' pre-instructional conceptions as well as their development during the teaching process. The role of the researcher is, on the one hand, to be an interviewer and to identify the students' conceptions and, on the other, to be a teacher and organise learning activities depending on students' conceptions. In the teaching experiments, students were confronted with learning environments matching their conceptions. Each teaching experiment was carried out by the first author in small groups of 2 to 3 students on the premises of the Leibniz Universität Hannover. The teaching experiments were videotaped for a process-based analysis of students' conceptual development.

4.4.1. From man-made CO_2 to anthropogenic imbalance

The following example shows a student who reconstructs her conceptions by changing her argumentation based on the natural vs. man-made schema (*man-made CO_2*) to the balance schema (*imbalanced carbon cycle*).

Interview at the beginning of the teaching experiment

Tina: It is not possible to reduce the CO_2 concentration to zero, because of the industrialisation. The only way it would be possible is using renewable energy solely.

Marie: But there has been CO_2 even before man was there.

Tina: Yes. But the anthropogenic CO_2 has more effect than the natural CO_2.

At the beginning of the teaching experiment, Tina refers to the thinking pattern *man-made CO_2*, where CO_2 is produced solely by burning fossil carbon (cf. Table 2). Her conception implies the idea that only using renewable energy can reduce CO_2 emissions to zero. After a spontaneous intervention by her classmate Marie, Tina thinks her conception over, remembers that CO_2 from respiration is a natural compound of the atmosphere and formulates concepts which can be related to the thinking pattern *natural and man-made CO_2*. In her latter conception, there are two different kinds of CO_2 that react in different ways.

Modelling the carbon cycle

> **Tina:** Carbon enters the atmosphere from the organism by respiration and photosynthesis captures it again. Carbon from the oceans enters the atmosphere, but the same amount goes back into the oceans. There is a natural, a balanced cycling. By deforestation more CO_2 enters the atmosphere. And deforestation decreases photosynthesis because there are fewer trees. The carbon from deforestation stays in the atmosphere, because it cannot get down again. With the carbon from coal and oil it is the same. It stays in the atmosphere not because it is different, but because it is too much.

By modelling the carbon cycle, Tina argues based on the thinking pattern *anthropogenic imbalance*: there is a natural balance in the carbon cycle between the stocks oceans/atmosphere and vegetation/atmosphere. This balance is disturbed by deforestation and burning of fossil carbon. While modelling the carbon flows with containers and balls, Tina argues the causes for climate change by transferring balls from the containers representing the vegetation and fossil carbon into the container representing the atmosphere. First and foremost, her argumentation is no longer based on the natural vs. man-made schema but on the balance schema. This reflects a scientifically adequate perspective on the carbon cycle.

Modelling the carbon cycle with containers and balls seemed to help Tina reconstruct her conceptions: in her argumentation at the end of the teaching experiment, she traces global warming not to a special kind of CO_2 but to too much CO_2.

The process-based analysis of the teaching experiment allowed us to follow Tina's argumentation in the carbon cycle. It also enabled us to analyse the effects of spontaneous interactions, like Marie's intervention. Thus, we were able to model a thinking pathway of Tina's conceptual development (Figure 3), which illustrates Tina's conceptions and their development by the planned and spontaneous interventions. The thinking pathway shows the conceptual development in relation to the scientific adequacy of the concepts.

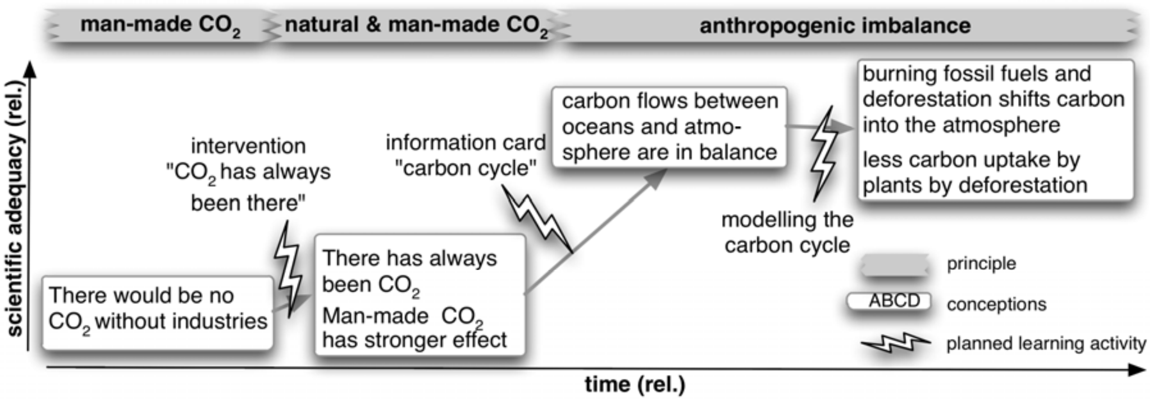


Figure 3
Tina's thinking pathway on the carbon flows in global warming

At the level of the thinking pattern used, Tina reconstructs her conceptions from *man-made CO_2* via *natural vs. man-made CO_2* to *anthropogenic imbalance*. During the teaching experiment, Tina worked out the idea of a combination of balanced and imbalanced carbon flows and the cause of climate change.

4.4.2. From man-made matter via man-made process to man-made cause

The following example shows a student who reflects the ontological category on which he bases his argumentation on climate change.

Interview at the beginning of the teaching experiment

Gustav: It is a fact that the CO_2 emitted by burning has another structure than the CO_2 emitted by respiration. Thus the CO_2 from burning cannot be captured again by photosynthesis.

Phillip: But the CO_2 from burning is CO_2, too.

Gustav: Yes. But it has another structure.

Phillip: CO_2 has three atoms. How shall they be ordered in a different way?

Gustav: I don't know how this happens. But it is possible.

At the beginning of the teaching experiment, Gustav argues with the thinking pattern *natural vs. man-made CO_2*. He refers his conception of different properties of the two kinds of CO_2 to their different molecular structures. His classmate Phillip argues that it is not possible to have different structures of CO_2. This intervention gives Gustav no reason to change his conception, he insists on his idea of two different kinds of CO_2 with different structures. To account for his conception, he argues not only on the experience-based level of schemata but also on the molecular level, with a different structure of the CO_2 molecule where the atoms are ordered differently. Thus the adaptation of the natural vs. man-made schema to CO_2 as matter is very plausible for Gustav: there is no cognitive conflict and thus no reason for a conceptual change.

While modelling the story

Gustav: My idea with the natural and man-made CO_2 was humbug. Because in the story, the carbon, which was burned, is captured again by photosynthesis. And if the tale is right, the idea of a natural and a man-made CO_2 with different properties must be wrong. It is not the matter. The cause of emitting CO_2, the burning is man-made. The emission of CO_2 by respiration is natural.

After reading the narrative about the carbon cycle, Gustav rejects the conception of one natural and one man-made CO_2. The reason for this conceptual development is the experience imparted in the story "*CO_2 is CO_2*", where CO_2 emitted by burning is–like CO_2 emitted by respiration–fixed again by photosynthesis. But the natural vs. man-made schema still plays an important role in Gustav's argumentation: after modelling the carbon cycle in a container-flow schema he assigns the natural vs. man-made schema not to the matter (CO_2), but to the cause for the carbon flow (burning, respiration).

Modelling the carbon cycle presented in the story induces a conceptual reconstruction. In his argumentation on global warming, Gustav changes the ontological category from matter, to cause of the process. Gustav's conceptual development reveals the following thinking pathway:

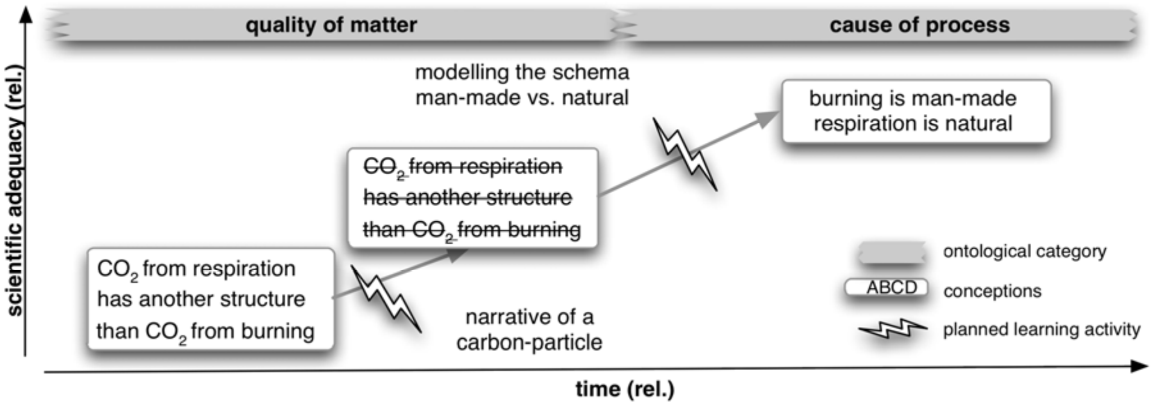


Figure 4
Gustav's thinking pathway on the carbon flows in global warming

4.4.3. From natural vs. man-made CO_2 to anthropogenic imbalance

The following example shows a conceptual development induced by modelling the carbon cycle.

At the beginning of the teaching experiment

Fritz: There is a difference between CO_2 emitted by burning oil and CO_2 emitted by respiration. Perhaps the one from burning is radioactive? It is not good at all. Perhaps they are different like ^{14}C-atoms and ^{16}C-atoms?

At the beginning of the teaching experiment, Fritz describes the cause of climate change based on the thinking pattern *natural and man-made CO_2*. Like Gustav, Fritz ascribes the natural vs. man-made schema to the quality of CO_2 and argues on a molecular structure by assuming different isotopes as the cause for the difference. In Fritz's argumentation, an appraisal of the natural vs. man-made schema can be found: Fritz appraises the man-made CO_2 as not good.

Modelling the carbon cycle in a container-flow model

Fritz: The flow of carbon from the container fossil carbon into the atmosphere is the problem. Without this flow there would be no climate change. If the carbon is in a solid state it has no effect. But when it is gaseous it causes climate change.

Interviewer: Please describe the carbon cycle with the help of the model.

Fritz: The carbon flow between atmosphere and oceans is in balance, respiration and photosynthesis, too. There is an imbalance caused by deforestation and burning fossil carbon.

Interviewer: Initially you said there are two kinds of CO_2.

Fritz: Yes, but it is not the CO_2 itself, the amount of flowing carbon is natural or man-made. The balanced cycling is natural. A change in the carbon flow or its intensity, the imbalance, is man-made.

After reading the text about the carbon cycle, Fritz describes the movement of carbon from the container fossil carbon to atmosphere as the cause of climate change. He has the concepts *burning is transforming, solid carbon does not cause climate change* and *gaseous carbon causes climate change* to describe the transformation of carbon from a solid into a gaseous state as a cause for climate change.

By modelling the carbon cycle with balls and containers, Fritz describes the carbon flows atmosphere/oceans and atmosphere/vegetation by photosynthesis and respiration as balanced carbon fluxes. Deforestation and burning fossil carbon causes imbalances in the carbon flows. On being asked by the interviewer, Fritz names balanced carbon fluxes as natural and a change in these fluxes and thus a resulting imbalance as man-made. So Fritz combines the use of the balance schema with the use of the natural vs. man-made schema: balanced fluxes are natural and imbalanced fluxes are man-made (cf. Figure 5).

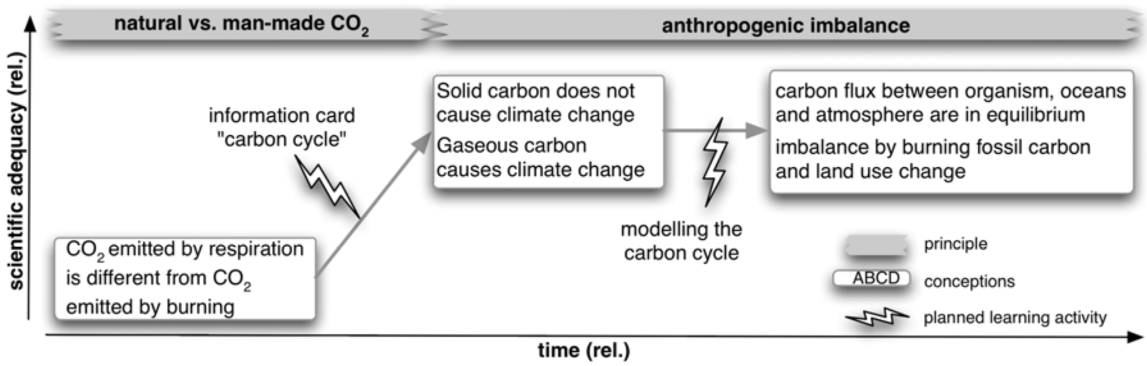


Figure 5
Fritz's thinking pathway on the carbon flows in global warming

5. Discussion and conclusions

Guided by experientialism, different thinking patterns about the carbon cycle were found in students' and scientists' conceptions. Following the model of educational reconstruction, these conceptions were taken as the basis for developing learning environments on global warming. These learning environments were evaluated in teaching experiments. The conceptual development was analysed by tracking students' learning pathways. The results can be interpreted as follows.

5.1. Different conceptions–same schemata

Students' and scientists' conceptions of the carbon cycle can be related to different schemata, which are rooted in experience. Following the theory of experientialism, it is not surprising that scientists and students use metaphors and metaphorical schemata when thinking of the carbon cycle: The carbon cycle is not accessible to direct experience and therefore metaphors are essential to understand it. Interestingly students' and scientists' conceptions of global warming refer to the same schemata, but conceptualise them differently in the target domain "carbon cycle". The container-flow schema provides the basal schema for thinking of carbon flows between different carbon stocks. The container-flow schema is substantiated by the natural vs. man-made and balance schemata. While the latter is an indicator of scientific or at least science-oriented conceptions, the former can be conceptualised on different ontologies: the substance (*CO_2*), the process (*burning*) or the cause for the process (*burning by man*).

5.2. Learning about the carbon cycle by reflecting on schemata

Due to the fact that students and scientists refer to the same schemata as the source domain for their conceptions of the carbon cycle, learning about the carbon cycle can be facilitated by a reflection on the schemata:

- *Broaden the perspective on containers and fluxes*

  Working with a container-flow model in coordination with information about the carbon cycle presented in a science-like and narrative context helps students develop more scientific conceptions. After the teaching experiments, they are able to base their idea of a carbon cycle on more containers and on a change of carbon fluxes instead of different kinds of CO_2.

- *Changing ontology*

  Students referring to the conception *natural and man-made CO_2* conceptualise the natural vs. man-made schema in a scientifically inadequate way onto the container-flow schema. Working with the "container-flow" model and thereby reflecting the application of the natural vs. man-made schema to the different parts of the model helps students reflect their conceptions. Based upon educationally reconstructed learning environments, a development of conceptions from *man-made CO_2* via *man-made carbon flow* to *man-made cause of carbon flow* and thus a change in the ontological category *matter* through *process* to *cause* can be seen. This result is in accordance with Chi (2008) who explained learning science as a categorical shift.

- *Experiencing and reflecting on the dynamic equilibrium*

  The everyday experience and scientific notion of balance are related, but not identical. While the former is based on maintaining and losing balance by stumbling, the latter is the idea of a dynamic equilibrium, where inputs and outputs of a system are balanced on longer time scales, so that the stock of the system stays nearly identical.

Substantiating the container-flow schema by the balance schema and the natural vs. man-made schema is very popular for students–and scientists: in textbooks and articles on climate change, it is very common to read phrases like "*balanced carbon flow*", "*disturbed balance*" or "*perturbed carbon cycle*". The combination of schemata indicates the conception of a natural carbon cycle, which is balanced, and an unbalanced carbon cycle caused by man. This conception is scientifically incorrect: nature knows no absolute balances, just dynamic balances as a result of a series of imbalances. The presented learning environments helped students shift their argumentation on global warming to an adequate ontological category. Further learning environments are needed to help students–and scientists–reflect on the role of balances and imbalances in nature.

5.3. Reflecting framework instead of changing concepts

Learning about the carbon cycle can be interpreted by Vosniadou's framework theory (Vosniadou, Vamavakoussi, & Skopeliti, 2008), which describes content theories as based on framework theory. There are parallels between Lakoff's definition of source and target domains and Vosniadou's definitions of framework and content theories: like schemata which act as source domains, framework theories are built early in infancy and consist of certain fundamental ontological and epistemological pre-suppositions. The content-specific theories describe the internal structure of an abstract conceptual domain, like the target domain. In this theoretical framework, the carbon cycle can be seen as the content-specific theory and the schemata on which the conceptions are based as the framework theory.

Vosniadou et al. (2008) describe learning at the level of the framework theory to be the most difficult type of conceptual change. Learning is difficult, when the content-specific theory as well as the framework theory have to undergo changes to reach more scientific conceptions. In our study, experientialism proved to be a helpful theory to gain access to students' conceptions, and provided means to reconstruct specific theories as well as framework theories. Based on our theoretical approach guided by experientialism, we are able to define learning about the carbon cycle not as conceptual change but as conceptual reconstruction: students do not change their conceptions, but they reconstruct the source-target mapping of the schemata on which their conceptions are based. This result is in accordance with the theory of constructivism, which describes learning as a construction of knowledge based on knowledge that already exists in the individual cognitive system.

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29 DEVELOPMENT AND APPLICATION OF THE FINE FRAMEWORK FOR LEARNING IN NATURE

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Abstract

Field trips (FTs) in natural environments are popular worldwide. Following Brody (2005) and Storksdieck (2006) who, respectively, suggested schemes for understanding learning in nature and assessed means of evaluating FTs in environmental education, we developed the Field Trip in Natural Environments (FiNE) framework, which consists of four dimensions: planning, pedagogy, activity and outcomes, and a rubric that enabled consistent assessment of the FT components. We applied the framework to 22 FTs to nature parks for 4th through 6th graders. Our findings indicate limited preparation in school and almost no communication between the teachers and the nature-park facilitators. We found limited deliberately enhanced social interactions, almost no discussion of goals with the students, and reasonable reference to the actual environment. There was good alignment between how the students and the researchers perceived the learning and physical activities. Overall, the FiNE framework was found to be a coherent framework based on general principles to assess FTs in different settings. It allows comparing and discussing pedagogical principles and their impact on learning.

Keywords: field trip; FiNE framework; nature; learning; outdoor

1. The rationale of the study

School field trips (FTs) to museums, zoos, aquariums and nature parks have always been an important means of schooling, as evidenced by a long history in education. FTs are usually arranged by schools, have educational purposes, and take place in engaging and interactive settings (Dillon et al., 2006; Hofstein & Rosenfeld, 1996; Rickinson et al., 2004), all of which have been shown to increase interest, motivation and environmental knowledge and awareness. It is widely agreed that all out-of-school learning environments yield a variety of cognitive, affective, social and behavioral impacts that make significant contributions to learning. The common perceived potential of the FT is to provide the learners with an opportunity for sensory experiences through a gradual shift from using simple concepts to more complex ones, direct experiences with tangible phenomena and materials, and direct experiences in the construction and amplification of abstract concepts (Falk, Martin, & Balling, 1978; Orion, 1993). Other benefits, highlighted by sociocultural theory, which are widely discussed in the literature are the contextualization of learning, promoting dialogues and interactions with fellow learners and adults, and lifelong learning (Ash & Wells, 2006; Bamberger & Tal, 2008; Falk & Dierking, 2000). As an experiential learning activity, the FT enables students to engage with real phenomena in a relevant context, and allows the instructor to bridge school content with authentic expressions of more abstract ideas (Knapp & Barrie, 2001). Among the great variety of out-of-school learning environments, the FT in nature is different in many ways than a museum, a planetarium or a science center visit, as it allows direct experiences with real natural phenomena and wildlife. It also confronts the participants with discomforts and fears of, for example, insects, heights, dirt, caves, etc. More than any other out-of-school setting, the FT in nature has the potential to enhance pro-environmental behavior and awareness of conservation (Ballantyne, Packer, Hughes, & Dierking, 2007). Despite the many outdoor education programs for schools worldwide, and agreement on their value (Knapp & Barrie, 2001; Orion, 1993), relatively little research has focused on identifying and assessing good outdoor-education practice. Our study suggests a general framework to assess and design an entire FT event that can be applied in a variety of settings.

2. Objectives and research questions

In studying FTs to nature parks in Israel, we attempted to develop a theoretical and practical framework for evaluating the FT to natural environments, and applied the evaluation scheme to a variety of FTs, assessing their constituents and outcomes. The research questions were: (1) What are the characteristics of FTs to nature parks in Israel? (2) What are the learning outcomes of such FTs? The Field Trip in Natural Environments (FiNE) framework was constructed based on the research literature and the data collected in the study.

3. Methods

3.1 Context and data collection

The 22 monitored FTs took place in nature and archeological parks in northern and central Israel. The 4- to 8-hour FTs were carried out by professional facilitators employed by a well-established environmental organization. We followed diverse school groups from grades 4 through 6 (ages 9-12) from urban, suburban and rural schools, that represented diverse socio-economic status. There were 20 to 30 students per group, and each group came with at least one accompanying schoolteacher, commonly the homeroom teacher, and one or two chaperones. The FTs included walking along nature trails, describing the geography, history and wildlife and performing demonstrations. Sometimes there were activities and/or games, run by the facilitator. All of the FTs took place in the outdoors.

Data collection included *Observations* conducted on all 22 FTs and *Interviews* with 41 students from seven schools before the FT and a day or two afterward. Observations were carried out by the first author after a few joint observations that yielded an acceptable inter-rater reliability of 85%. In the interview, the students were asked about their expectations and about the extent to which they were fulfilled. They were also asked about the preparation in school, the FT program, the most and least enjoyable features, the activities they remembered, what they learned, their adventures, and their thoughts and beliefs about nature.

3.2. Framework development

Based on the informal science education literature, we identified the following major components that contribute to learning in out-of-school settings: preparation in class (Jarvis & Pell, 2005; Orion, 1993; Rennie & McClafferty, 1995); teacher-facilitator collaboration

(Tal, Bamberger, & Morag, 2005; Tal & Steiner, 2006); connecting the FT content to the school curriculum (Bogner, 1998; Dillon et al., 2006; Orion, 1993); connecting the FT content to everyday life (Bamberger & Tal, 2008; Brody, 2005); active and free-choice learning (Ballantyne & Packer, 2002; Brody, 2005; Falk, 2005; Rickinson et al., 2004); the facilitator's role (Griffin & Symington, 1997; Price & Hein, 1991); physical/adventure activity (Ash & Wells, 2006; Bamberger & Tal, 2008; Brody, 2005; Rickinson et al., 2004); multiple outcomes (Brody, 2005; Falk & Dierking, 2000; Knapp & Barrie, 2001; Orion, 1993; Rickinson et al., 2004). These components represent four phases or planes of the FT: (a) planning and preparing for the FT, (b) the pedagogy employed on the FT, (c) learning and physical activities, and (d) outcomes of the FT. In developing the framework, these phases and components guided our analysis of the observation data. In the analysis of the students' interview data, we looked for alignment to the above components. Capturing the different perspectives of the facilitators, teachers and researchers was a main concern in this study. Particular information on some aspects could be gathered only by talking to the teacher and the facilitator. Information regarding activities could be obtained from all of the participants, and evidence for student learning could be provided only by the students.

The cyclic form of the framework (Figure 1) consists of four rings representing the different phases and data sources. The various components are described in the following.

Planning. The outer ring, which addresses *coordination, connection to the curriculum,* and *preparation* includes: (1) classroom preparation (by a teacher or facilitator); (2) communication and collaboration between the organization/facilitator and the teacher; (3) connection of the FT topic/content to the school curriculum. Information about preparation was gathered mainly from the teacher and the facilitator, and by observing the FT. Additional information was obtained from the interviewed students.

Both the teacher and the facilitator described the coordination of the FT and whether they discussed its detailed program or merely provided essential technical information. Connection to the curriculum was reported by the teachers, and was observed by the researchers as well.

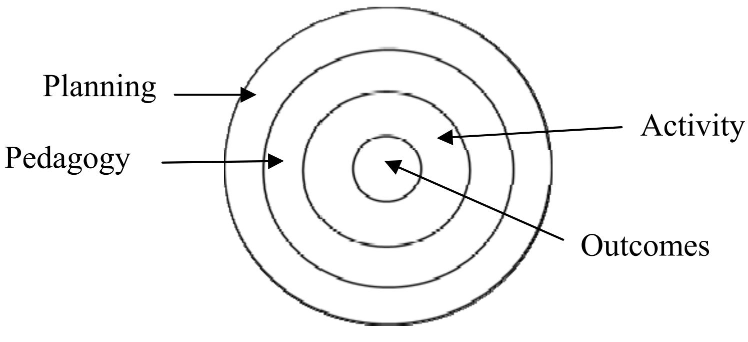

Figure 1
The rings of the FiNE framework

Pedagogy. The second ring addresses the *pedagogy* employed on the FT, as understood and interpreted by the researchers. This ring includes: (1) clarifying/discussing the FT goals with the students; (2) addressing the environment (referring to specific objects and features seen and found in the field); (3) making connections to everyday life; (4) enhancing learning by social interactions; (5) the facilitator's overall function.

Activity and action. Based on our experience and the importance attributed by the research literature to students' active learning in general, and to physical activity and hands-on experiences in authentic out-of-school learning environments in particular (Grabinger & Dunlap, 1995; Kahn, 2002), a separate ring for students' activities and actions was justified in the framework, despite its association with pedagogy. The data sources for the variety and extent of activity were the students' statements in the interview and the researchers' observations.

Outcomes. The FT outcomes, represented by the inner circle, were reported by students in in-depth interviews. In the analysis of the interview transcripts, we identified statements that addressed (1) learning and understanding of phenomena and ideas, and (2) views, values and beliefs.

4. Data analysis: scoring the rings' components

4.1 The planning ring

(1) Preparation. As suggested by many researchers (i.e., Falk et al., 1978; Orion, 1993), preparation for a FT is required to reduce novelty and enhance learning. Proper preparation includes geographical, psychological and cognitive aspects. Students should know what to expect in terms of physical challenges and learning activities. They should know where the FT is taking place, how to dress, what to bring or avoid bringing. They should also know the learning activities and task(s) that they are supposed to perform. The preparation category was scored as follows:

[0] No preparation aside from collecting a permission slip from the parents which included mainly technical information	**[1]** Partial preparation: teaching about the region in general	**[2]** Thorough preparation: teaching relevant content and addressing the FT program. Discussing expectations and proper behavior

(2) Communication and collaboration between the organization/facilitator and the school/teacher is needed to discuss the learning goals and mutual expectations (Dillon et al., 2006; Kisiel, 2005; Tal & Steiner, 2006). The teacher can either take an active part by contributing his/her own knowledge or reflecting upon school-based learning, or function only in monitoring behavior and safety. Collaboration was assessed on the following scale:

[0] The facilitator is solely responsible for the event. No connection was made with the teacher prior to the FT	**[1]** Partial collaboration: a telephone call the night before the FT, during which some information was shared	**[2]** Full partnership: a telephone conversation conducted in advance that enabled appropriate arrangements. Details of the students' needs, the curriculum and teacher's preferences were discussed

(3) Connection to the school curriculum is required to support learning and use the field experiences to help the student understand abstract phenomena (Anderson, Lucas, Ginns, & Dierking, 2000; Orion, 1993). In this category, we emphasized consistent planning of FTs with respect to the curriculum. While the extent of prior communication is reported by the teacher and the facilitator, an expert observer can determine the extent to which the facilitator addressed the school curriculum and ideas learned in school. This category was scored as follows:

[0] No connection	**[1]** Implicit connection: topics could be connected but there was no attempt to point out these connections	**[2]** Explicit connections were made during the FT

4.2 The pedagogy ring

To allow engagement and social-knowledge construction, teachers must shift from traditional pedagogies to more child-centered approaches, and change their role from delivering knowledge to mediating learning. Students should have the opportunity to choose, discover and construct their own understanding of phenomena (Falk & Dierking, 2000; Hein, 1998; Price & Hein, 1991). The components of the pedagogy ring included:

(1) Clarifying and discussing the goals with the students. This is important in classrooms as well as outdoors. Students should know if they are expected to participate in learning activities, listen, and answer the facilitator's questions. They should be aware of social and behavioral objectives as well. The following scale was used to assess whether the FT goals were transparent:

[0] No goals were mentioned	**[1]** The facilitator briefly mentioned goals	**[2]** The facilitator referred to specific goals that he/she and the teacher had discussed prior to the FT

(2) Addressing the environment. It is obvious that in the outdoors, facilitators are referring to the environment. However, objects and phenomena can be addressed in a general manner, or with an emphasis on students' discoveries. The following two levels expressed what we found with respect to how facilitators used such objects:

[1] Superficial. Explanations given in specific sites	[2] Using occasional artifacts found by the facilitatoror students for explanation, investigation or discussion

(3) Connecting to everyday life experiences is widely discussed in the literature as a variable that contributes to learning in informal settings (Ballantyne et al., 2007; Falk & Dierking, 2000). Even abstract phenomena can be tied to simple experiences such as watching TV, playing outside, previous family or school FTs and so forth. We found a range of connections that were scored as:

[0] No connection made	**[1]** Few or superficial connections made	**[2]** Many meaningful connections made

(4) Social interactions are needed for meaningful learning to take place. Such interactions can occur among students, and between students and adults (Ash & Wells, 2006). Outdoors, social interactions naturally occur when students walk or gather to listen. Therefore, we referred mainly to explicit instruction given by the facilitator to "do or discuss things together" in small groups. In the following three levels, we deliberately distinguished between natural/random interactions and deliberate activity-enhanced interaction that is planned to enhance social interaction.

[0] No interactions enhanced by the facilitator	**[1]** Weak, random interactions: social games, quizzes	**[2]** Meaningful, strong interactions, based on planned tasks

(5) The facilitator's function is crucial to the success of the FT. Beyond all of the previous components, this category includes three aspects: (a) interpersonal relationships with the students and the teacher, patience, tolerance, showing empathy and addressing all students equally; (b) didactic skills: using suitable and understandable language, demonstrating, telling stories and sharing personal experiences, and (c) maintaining a suitable pace. The degree to which the facilitator demonstrated these characteristics determined his/her score:

[0] Impatient, does not treat the students equally, does not show empathy, hardly uses demonstrations, uses language/terms which are not understood, poor pacing: breaks that are too long or too short, makes the students hurry, does not complete the program	**[1]** Inconsistent functioning in the relevant aspects	**[2]** Patient, shows empathy, treats the students equally, uses appropriate language and explains terms, enthusiastic, shares experiences, tells stories, uses demonstrations, and if the facilitator already knows the students–uses this knowledge in positive manner, good pacing

4.3 The activity and action ring

Active learning is recommended across contexts of learning. Brody (2005) puts special emphasis on students' actions, arguing that individuals must interact directly with the physical setting, and that this interaction must involve all possible senses. He also argues that for meaningful learning to take place, individuals must interact with other people.

Accordingly, in this ring we encompassed two aspects of activity: learning activity and physical activity, and two points of view: the researcher's and the student's. By learning activity, we mean any planned activity that engages the students in meaningful and independent construction of knowledge. Since walking is a fundamental activity in nature, which occurs on all FTs, we considered walking as a baseline. Other activities that enhanced the adventure and the physical experience included rolling down a sand dune, crawling into a dark tunnel, walking inside an ancient aqueduct, etc. Activity was scored as follows:

Physical activity

[0] Walking along the trail with no special or additional activity	**[1]** The trail requires special activity such as climbing, jumping, crawling	**[2]** The facilitator amplifies physical experiences and encourages the students to do things to activate their senses and feelings

Learning activity

[0] None: "walk and talk" pattern	**[1]** Demonstration or quiz. The facilitator demonstrates phenomena with some help from a student or two. All others observe and listen	**[2]** Small group or individual assignments that require the students to explore, play a game, collect items, etc.

The students' views of activity, as obtained by the interview, were classified into:

[0] No activity	**[1]** Statements about physical and/or learning activity	**[2]** Statements about physical and/or learning activities which are connected to new knowledge, feelings or social aspects

"Each one got a task, a concept that was there, which we had to find and explain. I and my friend had to find a canal and explain about it" (G', Y-5-0507)	"We had to uncover a secret code. We got a key and that's how we decoded this letter. We worked in teams and each one did something. I wrote, and someone else told me the next letter. It's fun when everyone works and together we got a result" (Y', N-0307-6)

4.4 The outcomes circle

The inner outcomes circle consists of two hemispheres that reflect the outcomes reported by the interviewed students: (a) knowledge and understanding and (b) perceptions, beliefs and affect. As the total score of each of the two hemispheres was different, we standardized them both to a 1-10 scale.

(1) Knowledge and understanding. Each relevant student statement was scored from 0 to 3 as follows, and then an average score was calculated for each student and for each FT event.

0	**1**	**2**	**3**
None	Incorrect, simplistic, concise	Correct, draws simple connection between cause and effect	Correct, detailed, addresses a scientific process, points to cause-effect relationships, adds examples
	"Oak trees provide air" (A', K-0307-5)	"Everywhere on that hill, if you dig you can find an ancient mosaic and other things as well. This is how they found the synagogue floor" (L', T-1106-6)	"I understood that porcupines are hunted although it's forbidden since they are endangered. If they become extinct the whole food web will be harmed because then leopards will not have food and other animals as well. Eventually it will harm us. Once, my dog found a porcupine and began barking, so I took it away and let the porcupine go away" (E', Z-0509-4)

(2) Beliefs. In this category we included all statements that conveyed beliefs, attitudes, feelings and views. Each of the following views was scored 1, allowing a maximum score of 4.

- Nature as resource for humans (air, water, land for crops, materials…)
- Nature as a spiritual and aesthetic feature
- Nature as needing protection (wildlife, ecological systems…)
- Nature as a factor in human health

In addition, 1 to 2 points were given to affective statements as follows (allowing a maximum score of 6):

1 - any statement that referred to feelings toward nature

2 - expression of deep feelings or many repetitions of affective statements

Figure 2 and Table 1, respectively, present the FiNE framework components. The color scale beneath the table represents the three performance levels of each component. In the inner ring, a total score of 0 to 3.3 represented the low level; 3.3 to 3.6 the medium level, and 6.6 to 10 the high level of performance.

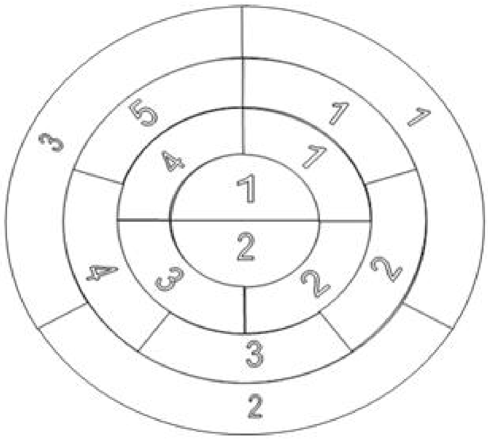

Figure 2
FiNE framework rings

Table 1
FiNE framework components

Planning			Pedagogy					Activity				Outcomes	
1	2	3	1	2	3	4	5	1	2	3	4	1	2
Classroom preparation	School-organization collaboration	Connection to curriculum	Clarifying the goals	Addressing the environment	Connection to everyday life	Social interactions	Facilitator performance	Active learning–observer	Physical activity–observer	Active learning	Physical activity	Beliefs, views & values	Knowledge & understanding
Low (red)				Medium (yellow)					High (green)				

The framework was discussed at length with leading educators at the environmental organization, who strongly agreed with the following findings. However, they suggested further research to refine the Facilitator Function component and to continue to a large-scale study that will enable development of quantitative measures for the outcomes circle.

5. Findings

As indicated, we employed the FiNE framework to assess 22 FTs; of these, seven included in-depth interviews represented in the inner circle and in one hemisphere of the activity ring.

Table 2 presents the distribution of the FTs with respect to planning. It is evident that the facilitators had sole responsibility for the program, that good preparation was executed by a minority of teachers, and that the linkage between the FT and the school curriculum was either implicit or nonexistent.

Table 2
The planning components' distribution

Level	Preparation in class	Organization-school communication	Connection to the school curriculum
0	8	17	10
1	8	1	11
2	6	4	1

Table 3 resents the pedagogies employed in the field. For almost all FTs, no goals were presented or discussed with the students. For most of the FTs, there was a limited attempt to connect the content to the students' everyday lives. Social interactions were especially enhanced but only to a limited extent. In only four FTs did we identify an explicit effort to encourage meaningful interaction among students as part of a planned activity.

Table 3
Distribution of the FTs by the components of the pedagogy ring

Level	Clarifying the goals	Addressing the environment	Connecting to everyday life	Social interactions	The facilitator's function
0	21	Not relevant	14	9	2
1	1	7	4	9	9
2		15	4	4	11

Table 4 presents the observable component of the activity ring. It is surprising that we identified an additional physical activity on only 10 FTs and that this activity was empowered by the facilitator in only four of them. In half of the FTs we recognized some kind of learning activity, but in most cases these activities were demonstrations. Substantial activity that involved all students was detected in eight FTs.

Table 4
The observable dimension of the activity ring

Level	Physical activity	Learning activity
0	12	3
1	6	11
2	4	8

As indicated, student interviews were carried out in seven schools. Figure 3 presents the complete pattern of six FTs (due to space limitations). The different colors represent three levels: red - low; yellow - medium; green - high. The outer rings reflect the results shown in Tables 2 to 4. For example, in the planning ring, good preparation in school was only carried out in school 2, and alignment to the school curriculum was poor for all FTs. Collaboration between the facilitator and the teacher varied. In the pedagogy ring, it is apparent that there was no clarification of goals, but the other components showed considerable variation. The activity rings of only two schools (1 and 5) are mostly green indicating substantial learning and physical activity as perceived by both students and researchers. On the FTs of schools 3 and 4, this ring is mostly red, indicating passive listening to the facilitators. On school 6's FT there was medium to low activity. The students and researchers differed in how they viewed the activity only for school 2's FT, with students being more critical. Overall, for five FTs, one-quarter of the activity ring was scored higher by the researchers, implying that more action should be enacted for the students to acknowledge it the day after the FT.

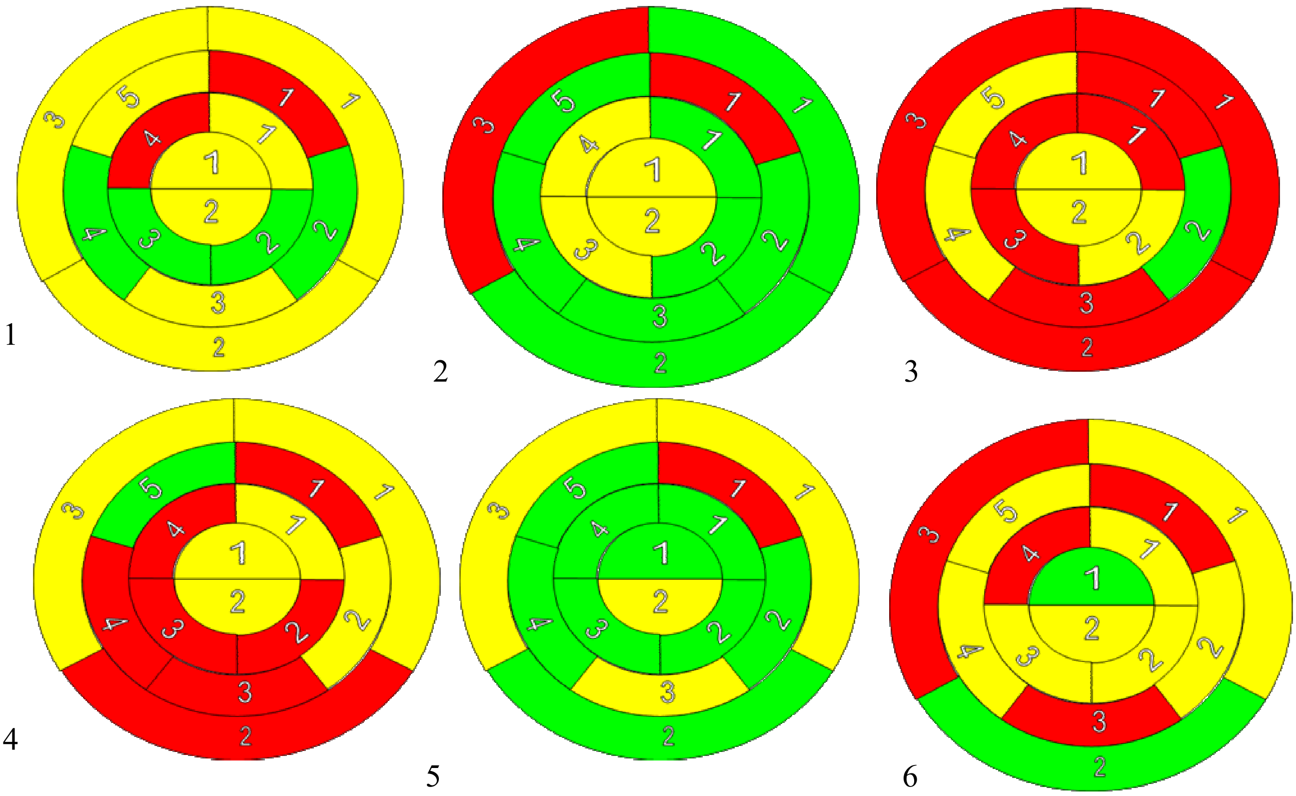

Figure 3
FiNE frameworks

Despite the opportunity provided by the FiNE framework to describe and reflect upon the characteristics of the FT, we are aware of its limitations. The extent to which the inner circle reflects the qualities of the FT is not clear enough; other factors not taken into account, such as students' previous experiences, have an impact as well.

6. Discussion

Since educational activities in nature are important in many countries, models that contribute to evaluating the quality of such activities and to guiding their design are expected to be of interest to the educational community.

The FiNE framework captures the planning phase's components and the pedagogical aspects of the guided FT, such as discussing the goals with the students, enhancing social interactions among learners, using the actual environment as a source for learning and the facilitator's overall function. Following ideas of active learning in general and Brody's (2005) notion of action in particular, we highlight the importance of learning activities and other forms of action.

The 22 monitored FTs enabled application and refinement of the FiNE framework, which indicated that (a) good preparation is not common, (b) communication between the FT facilitators and the teachers and mutual planning are rare, (c) content is occasionally connected to the school curriculum, (d) goals are barely discussed (or even defined), (e) social interactions occur naturally in the outdoor environment but are barely recognized as a means for learning, (f) the facilitators make use of the environment, but too often with no special emphasis on students' discoveries, (g) connecting the FT experiences to the students' everyday lives is not common, and (h) most of the facilitators show empathy, treat the students with respect, encourage them, use demonstrations to explain phenomena, and attempt to teach the students about the park. To assess the FT's merit, we were interested in the students' reflections on the knowledge they acquired and in their views and feelings toward nature in general and toward specific issues they encountered in particular. The interviews of 41 students provided valuable information on the outcomes of the FT. We learned that the students are able to address scientific processes, draw relationships between processes and outcomes, provide correct examples that support their claims and address many facts and ideas they encountered. In the beliefs and values domain, the students addressed their perceptions of nature, and were eager to report on their feelings in and toward the outdoors. Orr (1992), who attributed great importance to outdoor experiences in one's self development and as part of formal education stated: "experience in the natural world is both an essential part of understanding the environment, and conductive to good thinkers" (p. 91). Such experiences should be cognitive, experiential, active, aesthetic, and spiritual.

Overall, our findings reveal the multifaceted nature of the FT experience, and suggest an applicable instrument that allows capturing multiple views of the FT in nature, as well as a comprehensive examination of its structure and pedagogy. In a follow-up study based on the interview data, we plan to develop a questionnaire that will allow detecting the outcomes of the FT more efficiently.

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30 USING COMPANION MODELLING ON AUTHENTIC TERRITORIES IN THE TEACHING OF BIODIVERSITY

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Abstract

Companion modelling associates simulation using a multi-agent system, a geographical information system and role-playing to create a model and simulate the dynamics of eco-socio-systems. A computer model maps out the evolution of the territory according to the interactions between the stakeholders and different elements of the given authentic territory. The use of companion modelling in the classroom is the subject of this research. Students, participating in role play, use the modelling approach to apprehend sociological, economic and ecological dynamics and the importance of dialogue between stakeholders. A computerised simulation confronts them with the impact of their decisions. Educational research insists on the centrality of values and emotions in Environmental learning and on the importance of developing empathic attitudes towards the living, human and non-human. With the help of conceptual frameworks used in psychology and socio-linguistics, we analyse the attitudes expressed by four students during an experiment. Although role play can encourage the expression of empathic attitudes, we also observe identification and reversal processes which are detrimental to learning. The role played by the student must offer the affective and cognitive distance necessary for him/her to appropriate it without sparking identification processes.

Keywords: environmental education; attitude; empathy; biodiversity; role play

French agricultural education deals with issues relating to the joint management of heritage and natural resources in a specific part of the course, concerning the concept of heritage management (Ollagnon, 1984, 1989). As a mediation tool, based on a democratic participatory approach, the aim of introducing companion modelling into teaching is to develop an “eco-citizen” attitude.

1. **Rationale of the study**

Like every other education, biodiversity education seeks to encourage changes in attitude (Lebeaume & Lange, 2008). Role-playing is considered, particularly by certain authors (Arnaud & Serdidi, 2001), to play a potentially major educational part in acquiring new attitudes. Games offer a transitional space between the ego and the non-ego (Winnicott, 1971). The student’s attitude during the game is therefore a transitional attitude which is, at

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least in part, the result of an identity attitude (an attitude developed in real life) and the epistemological stance of the game.

The notion of attitude has been defined in many different ways in the literature (Michelik, 2008). It can be considered one-dimensional (Petty & Cacioppo, 1981), expressing only positive or negative affective responses, or three-dimensional, expressing cognitive, conative and affective responses (Rosenberg & Hovland, 1960). However, attitude is not a subject of direct observation; rather, it is deduced from individual verbal or non-verbal assertions. To analyse the students' attitudes towards the human and non-human, we used the conceptual frameworks of Searles, Descola, Anscombre and Ducrot.

Searles (1960) clarifies the importance of the dialectical relationship between human and non-human environments in the development of the "self". On a psychological level, he proposes that the individual presents different types of relational modes pertaining to fusion, separation or association. The latter stage, considered to be the most mature, results in the perception of a structural connection with non-human elements, while maintaining the perception of the individuality of being human. The state of fusion is defined as the sense of becoming one with the Other (human or non-human). The state of separation is defined as the desire to protect oneself against any feeling of association with the Other.

Descola (2005) considers this relation to the human and non-human from an ethnological point of view. He identifies observed *modes of attachment* towards both the human and the non-human. He distinguishes six major modes of attachment: reciprocity, giving, predation, production, protection and transmission.

The semantic unit theory (SUT), developed by Anscombre and Ducrot, is another way of accessing attitudes. Lescano (2008) observes that it belongs to the field of discursive argumentative semantics. Considering that all utterances are argumentation, the theory helps describe an argumentative content conveyed by utterances. According to SUT, the argumentative content may be structured around elements such as "consequently, because, if…then, therefore, thanks to" (e.g. "I'm from a farming background, *consequently* I want to become a farmer"), a so-called "normative" linking, or around elements like "however, in spite of, even if, although" (e.g. "I'm from a farming background, *however* I don't want to become a farmer"), a so-called "transgressive" or conflicting linking. According to the founders of SUT, these forms of argumentation reveal the speaker's "point of view", or "mini ideology".

2. Objective and research questions of the study

Companion modelling–the representation of stakeholders and of other elements interacting in a given territory–is designed to help guide the stakeholders when making decisions on issues concerning biodiversity management. Designed as a simulation of authentic environmental situations associated with role plays, companion modelling was examined here for its relevance to encouraging students to express their attitudes or even to change or acquire new attitudes which are respectful of the human and the non-human, such as empathy. Under particular scrutiny are empathic attitudes, the acquisition of which certain authors (Berenger, 2007; White & Stoecklin, 2008) consider to be a key objective in environmental education and in respect for others. In the area of psychology, empathy has been defined in many different ways. We chose to concentrate on the empathic attitude which focuses attention on the Other, towards a communicative projection (Rosenfeld, 1990); this approach enables making contact with the feelings and thoughts of the Other, to experiment and understand what happens to that Other.

The following questions were therefore analysed: Are the attitudes towards humans and non-humans the same in real life and during role plays? Do the role plays used in companion modelling enlighten attitudes towards the human and non-human? More specifically, do they enable the development of empathic attitudes?

3. Methods

The method involved comparing students' discourse during role plays (discourse which gives access to their transitional attitudes) and the discourse resulting from their life stories (giving access to their identity attitudes).

3.1 Didactic material and processes

The observed model simulates the dynamics of conifer planting in the "Causse" Méjean, limestone territory in the south of France. Pine trees can disperse their seeds all over the territory but their occurrence is more or less frequent, depending on the socio-economic context, namely the acts of farmers and foresters, the evolution of certain elements of natural heritage such as the Little Owl (*Athene noctua*) and the Stone Curlew (*Burhinus oedicnemus*)' a wader. A computer chart shows the ecological units of the territory, the distribution of these protected species and their evolution according to the actions carried out within the territory. Different stakeholders take part in the role play: a forester, three farmers, a naturalist, and the Little Owl which is considered a player in its own right. Each player has a role, with his/her activities defined on a role card. Depending on the stakeholder in question, different activities can be carried out: pathway management, deforestation, conservation, restoration, creation of natural habitats.

The role play was organised by two teachers with five to seven groups of six 19- to 20-year-old students at school. They were given the following instructions: "try to live without upsetting the biodiversity of the territory". The players were free to act as they saw fit and to exchange points of view. The Little Owl had the right to talk with the human stakeholders in order to defend its own interests.

3.2 Sample and collection of data

Two role plays were chosen at random and recorded. The exchanges between the student players engaged in the process of dialogue were then transcribed.

Four students (Amélie, Aurélien, Arold and Iannis) were selected during the observation phase of the role plays with a view to subsequently studying their identity attitudes and their transitional attitudes towards the human and non-human. The following criteria were chosen for this study: (1) attitude towards the human and non-human as revealed during the role play, (2) level of involvement in the role play, (3) role played. The aim was to obtain a variety of profiles according to these criteria. At the end of the role play, the four students were interviewed individually using the semi-directive method. We had two objectives: (1) to understand how the person defends his/her attitude during the game, (2) to identify the person's attitude regarding his/her relation to the human and non-human, as conveyed in comments on his/her "life story".

To conduct the interviews, we used the themes proposed by Dominicé (1979) to broach the question of an educational biography: the pathways to independence and the acquisition of autonomy regarding the original family, the school curriculum, the process of choosing a career, the development of a professional identity, roots and moving elsewhere. Use was also made of events which could explain the emergence of a particular relation to the human or the non-human (e.g. Have you ever worked with your father? Do you have a pet?), as suggested by Bliez-Sullerot (1999).

3.3 Data analysis

The transcribed corpus was then analysed in three stages:

1. We qualified and enumerated all of the comments which confirmed a *mode of attachment* to the human or non-human (giving, reciprocity, predation, production, protection and transmission). We compared the *modes of relation* expressed during the role play and during the interview.

2. We identified the argumentative aspects linked with the relation to the human or non-human in the interviews and role play. We organised these aspects into semantic units expressing *points of view*.

3. We defined the modes of relation in accordance with Searles' theory. We grouped together the comments expressing a feeling towards the human or non-human in the game and in the life-story interview and determined the dominant feeling of attachment for each student.

Finally, we compared the attitudes during the game and during the life-story interview in terms of the states of the ego, the modes of attachment, the modes of relation and the points of view.

4. Results

Amélie played the part of a farmer in the role play. Table 1 presents the dominant aspects in the modes of attachment in Amélie's case (when they exceeded 20% of the comment) along with her views and modes of relation towards the human and non-human.

Amélie shows a transitional attitude which can be reduced to certain aspects of her identity attitude. Very few new indicators emerged during her transitional attitude (only predation towards the human) compared to those she expressed during the interview. Two points of view expressed in the role play "*no* interest in agriculture *consequently no* biodiversity protection" and "*no* interest in environmental protection *consequently* conservation of the farming system" are similar to the points of view expressed during the interview "respect for the environment *however* defends farmers". Amélie expresses a respect for the environment in the interview but she no longer thinks in these terms during the role play.

Aurélien played the part of the Little Owl. Table 2 presents the different aspects dominating the modes of attachment in Aurélien's case (when they exceeded 20% of the comment) along with his views and modes of relation towards the human and non-human.

Table 1
Indicators of Amélie's attitude towards the human and the non-human in the role play and during the life-story interview

Indicator	Towards the human		Towards the non-human	
	In real life	**In the role play**	**In real life**	**In the role play**
Mode of attach-ment	Protection of farmers	Predation towards the other stakeholders	Love and protection of the agricultural milieu, agricultural production	Protection of the agricultural milieu, agricultural production
Point of view	-has farming roots *consequently* understands farming - of traditional agricultural origin *consequently* in defence of traditional agriculture -respect for the environment *however* in defence of farmers	- *no* interest in agriculture *consequently no* protection of biodiversity - *no* interest in protecting the environment *consequently* conservation of the farming system -production *consequently* in need of help -production *consequently* creation of agricultural areas	-sensitive to environmental damage *however no* action -respect for the environment *however* defends farmers	- *no* interest in agriculture *consequently no* biodiversity protection
Mode of relation	Partial fusion regarding farmers and farming	Fusion regarding farmers and farming	Partial separation regarding nature/environ-ment detrimental to agriculture	Partial separation regarding the aspects of biodiversity which are detrimental to agriculture

Aurélien adapts to the role of the Little Owl which leads him to express two new modes of attachment (predation and giving) which he does not show in his identity attitude. Aside from these changes, his transitional attitude is reduced to certain aspects of his identity attitude. The identity point of view "interest in man *consequently* maintaining biodiversity in terms of species of game" is part of the same semantic unit as "managing the Little Owl which is detrimental to the stakeholders in the game *consequently no* protection".

Arold played the part of a farmer in the role play. Table 3 presents the different aspects dominating the modes of attachment in Arold's case (when they exceeded 20% of the comment) along with his views and modes of relation towards the human and non-human.

Table 2
Indicators of Aurélien's attitude towards the human and the non-human in the role play and during the life-story interview

Indicators	**Towards the human**		**Towards the non-human**	
	In real life	**In the role play**	**In real life**	**In the role play**
Mode of attachment	Reciprocity	Predation Giving	Protection Predation Production	Protection
Point of view	-has farming roots *consequently* wants to be a farmer -hunter, fisherman *consequently* loves/manages/ protects nature -intervention of hunters *consequently* maintaining biodiversity for the sake of game animals -interest in man *consequently* maintaining biodiversity in terms of species of game	-management of the Little Owl detrimental to the stakeholders in the role play *consequently no* protection	-has farming roots *consequently* wants to be a farmer -hunter, fisherman *consequently* loves/manages/protects nature thanks to the intervention of the hunters *consequently* maintaining biodiversity for the sake of game animals -interest in man *consequently* maintaining biodiversity in terms of species of game	protect the Little Owl *consequently* manage its habitat -management of the Little Owl detrimental to the stakeholders in the role play *consequently no* protection
Mode of relation	Association regarding the human	Association regarding the human	Association regarding the non-human	Association regarding the non-human

Arold shows marked differences in attitude in the role play and in his life-story interview. In the role play he develops a new mode of attachment towards the human, of the "production" type, and a new mode of relation of the "association" type; his mode of relation towards the non-human falls into the category of fusion in his life-story interview and alternates between separation/association in the role play. The points of view are different and difficult to compare.

Iannis played the part of a forester in the role play. His attitudes were analysed differently because he did not make any comments during the role play. What was analysed was what he said after the role play, during a specific interview. This was then compared to comments relating to his life story. Table 4 presents the different aspects.

Table 3
Indicators of Arold's attitude towards the human and the non-human in the role play and during the life-story interview

Indicator	Towards the human		Towards the non-human	
	In real life	**In the role play**	**In real life**	**In the role play**
Mode of attach-ment	Giving Reciprocity Predation	Giving	Protection	Production Protection
Point of view	-in conflict with the farmers *consequently* understanding them -farmer *however* respect for the environment -parents love animals *consequently* I love them -discover nature *consequently* become more human	- *no* interest in biodiversity *consequently no* biodiversity management - *no* interest in biodiversity *however* biodiversity management - elements of nature are beautiful *consequently* management of these elements -people in need *consequently* give help - *no* interest in production *consequently no* management of natural areas	-ecological wealth of the territory *consequently* love it -parents love animals *consequently* I love them -discover nature *consequently* become more human -living with animals *consequently* paradise -constraints of managing animals *however* pleasure	- *no* interest in biodiversity *consequently* no biodiversity management - *no* interest in biodiversity *however* biodiversity management -elements of nature are beautiful *consequently* management of these elements - *no* interest in production *consequently no* management of natural areas
Mode of relation	Separation regarding farmers, hunters, naturalists	Separation/ association regarding the human	Fusion regarding the non-human	Separation or association regarding elements of biodiversity

Iannis seems to develop new modes of attachment of the "giving and "predation" type. He expresses a mode of relation which goes from fusion to association towards the natural non-human in the role play.

Table 4
Indicators of Iannis's attitude towards the human and the non-human in the role play and during the life-story interview

Indicators	Towards the human		Towards the non-human	
	In real life	**In the role play**	**In real life**	**In the role play**
Mode of attachment	Defence	Giving Predation	Protection	Protection
	- respectful of the environment *consequently* respectable human - *no* interest in the environment and nature, in the family *however* interest in nature	- forester *consequently* economic rationale in the forestry sphere -forester *however* ecological rationale	- respectful of the environment *consequently* respectable human - *no* interest in the environment and nature, in the family *however* interest in	-biodiversity protection *consequently* management of natural habitats

Indicators	Towards the human	Towards the non-human	
Point of view	- the wealth of nature *however* disrespect - ignorance, unawareness, omnipotence of man *consequently no* respect for nature - *no* environmental quality *consequently* people's non-well-being - aware of environmental problems *however no* action - interest in different people *however* uneasy in their presence	nature - the wealth of nature *however no* respect - ignorance, unawareness, omnipotence of man *consequently no* respect for nature - *no* environmental quality *consequently* people's non-well-being - aware of environmental problems *however no* action	
Mode of relation	Separation regarding the human	Separation regarding an artificial non-human area but fusion towards natural areas	Association towards biodiversity

5. Interpretation

As a tool for teaching empathy, role play can be used either to make students aware of their attitudes to the human and the non-human or to try to get them to modify their attitudes. The educational stance is not the same in both cases. To enable students to become aware of their attitudes, they must express an attitude during the role play which is very close to their own in real life. If we are expecting to achieve a change of attitude in the students, the role play must help them develop one or two decent attitudes, such as an empathic attitude towards the stakeholder whose part they are playing, towards the other stakeholders and towards aspects of biodiversity.

If as Winnicott (1971) proposes, games facilitate self-knowledge, the role play enabled Amélie to express opinions that she would never have allowed herself to express in other school contexts. This in itself means that she learned something. An analysis of her attitudes could help her get to know herself better. The parts played by Aurélien and Arold may shed light on certain aspects of their identity attitudes, but the mirror image is distorted because new attitudes are expressed within the context of the role play. We may also question whether there is a risk of the game reinforcing certain attitudes that result in a commitment effect taking root in the student (Joule & Beauvois, 2002): in this sense the game enables Amélie to express her mini-ideology and to strengthen her pro-farmer and anti-biodiversity commitment. Such identity reinforcement could well become an obstacle to a critical analysis of her attitude.

If the role play aims at encouraging the expression of a more empathic attitude, one question must be asked: does the person express a transitional attitude which is different from his/her identity attitude? In other words, does the person project a large part of him or herself into the role play or on the contrary, does that person try to distance him or herself in order to understand the Other?

Amélie expresses few new attitudes in the game; she adopts a position of identification rather than a position of empathy. Aurélien partially changes his attitude in the game. He therefore tends more towards an empathic attitude. He also partly expresses an attitude of identification which leads to showing an anthropomorphic line of reasoning regarding the Little Owl. He says : *"as she [the owl] is in the lowlands, towards the prairies, when there's water the field mice and all that leave the place or get drowned…they go into the forest…the owl can't do this because there aren't any "clapas" (rocky heaps)…the forest is perhaps not near enough".* Iannis decides not to talk during the role play which, as he explains later, revealed his lack of desire to engage in any sort of empathic relationship with his role. Arold adopts a transitional attitude which is different from his identity attitude. He appears to develop an empathic attitude. However, he expresses certain important contradictions during the role play. We can identify two contradictory semantic units: "no interest in biodiversity *consequently* no biodiversity management" and "no interest in biodiversity *however* biodiversity management". The role he decides to play is not very stable. Sometimes he plays the part and sometimes he pretends to be playing the part, sometimes he leaves the game to meta-communicate on his role; he will say, for instance, *"me, I'm a stupid farmer".* His position, in the game, is sometimes emphatic, sometimes stereotyped. The role play is more likely to confirm his stereotypes than to challenge them.

How can we explain that, contrary to Aurélien and Arold, Amélie shows a transitional attitude which partially reflects her identity attitude? How can we explain that Aurélien and Arold partly change their attitudes during the role play? There appear to be three decisive factors: an internal factor which is the identity attitude itself and two external factors, the issue dealt with in the role play and the assigned role.

Amélie has an identity attitude which manifests itself as partial fusion towards the human, i.e. with the farmer, and as partial separation towards the non-human, which would be detrimental to farming. The issue dealt with in the role play questions the farmer-biodiversity relationship and leads her to activate a point of view which seems particularly important in her identity attitude "respect for the environment *however* defends farming and farmers". Amélie, in her own words, chose the role with which she identifies the most. Amélie's plan for the farmer in the role play is to maintain and even develop her autonomy. Figure 1 summarises the dynamics of the issue-role-identity attitude triptych, in Amélie's case.

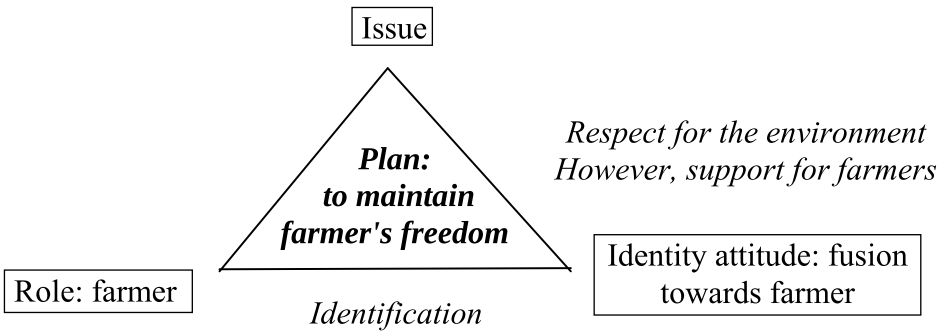

Figure 1
Expression of the issue dealt with in the game-identity attitude-role triptych, in Amélie's case

Arold, who is particularly interested in animal conservation, has an identity attitude that reveals itself as separation towards the human, namely farmers and hunters, and fusion towards the non-human. The issue in the role play activated the following points of view:

"conflict with farmers consequently understanding them" and *"farmer however respect for the environment"*. The role of farmer was imposed; he says that he is satisfied with it because it will help him better understand farmers. Even if he partly engages in an empathic relationship with the role he plays in the game, at the same time he associates certain identity attitudes and projects his own stereotypes into the role. The game leads him to a *reversal* (a process of identifying a subject with another subject who makes him suffer). Arold plans, in the role play, to become involved in a process of biodiversity management and in parallel to this, to develop the stereotype of a farmer who is anti-biodiversity. Figure 2 summarises the dynamics of the issue-role-identity attitude triptych in Arold's case.

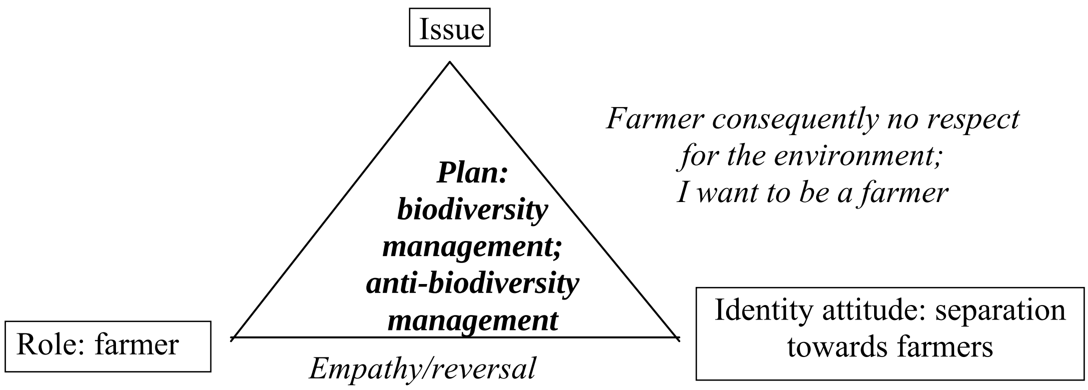

Figure 2
Expression of the issue dealt with in the game-identity attitude-role triptych, in Arold's case

Aurélien, a hunter in real life, expresses a feeling of association in his identity attitude. The issue dealt with in the game activates an identity point of view which is *"hunter, fisherman consequently loves/manages/protects nature"*. The Little Owl role leads him to express this partially, but also helps him develop an empathic attitude. The interaction between the part he plays and his identity attitude encourages him to partially assume an empathic position. His plan is to protect the owl while taking into account the other stakeholders. Figure 3 summarises these dynamics of the issue-role-identity attitude triptych.

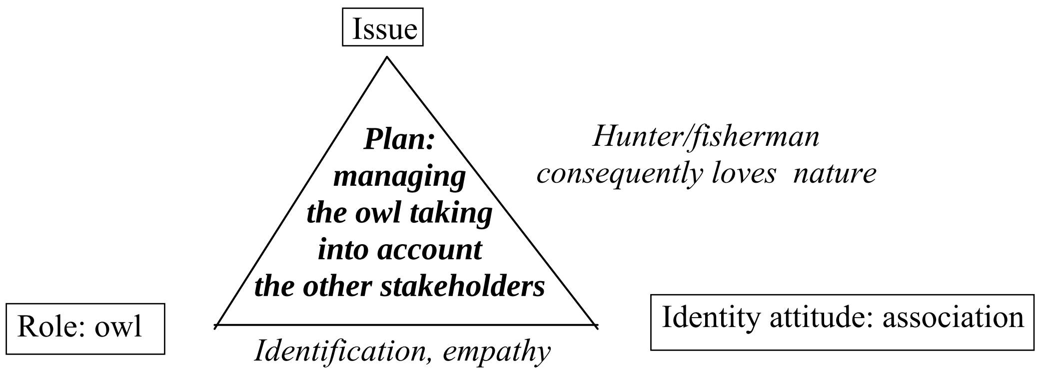

Figure 3
Expression of the issue dealt with in the game-identity attitude-role triptych, in Aurélien's case

Iannis, who is concerned with environmental protection, has an identity attitude which expresses itself in a separation from the human. The issue and the part he played did not really spur him to action. Iannis did not choose his role and the part he had did not enable him to get involved in the game. He did not have much knowledge of the role he played (he will say: *"I know practically nothing about forestry management"*) and referring to the affective relationship he invents (he says: *"If I'd had the choice…I would have chosen to be the naturalist"* and *"even if I am playing the part of the forester, I am still a naturalist at heart").* His plan is not to get involved in the game. Figure 4 summarises these dynamics of the issue-role-identity attitude triptych.

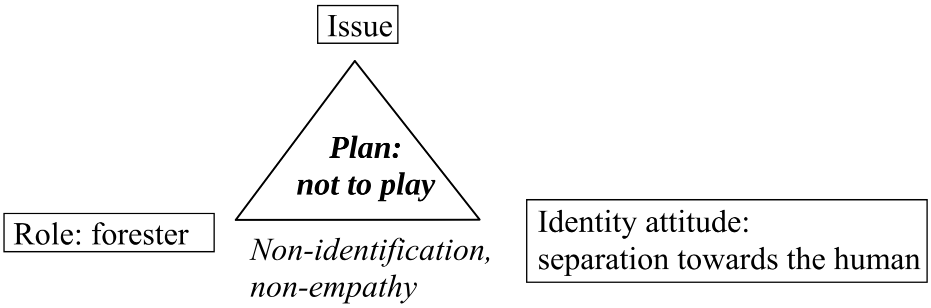

Figure 4
Expression of the issue dealt with in the game-identity attitude-role triptych, in Iannis's case

The issue-role-identity attitude triptych has an influence on transitional attitudes, encouraging empathy or non-empathy, identification or non-identification, or reversal. According to the educational aim of the role play, this triptych can be a catalyst or a barrier to learning.

Simonneaux and Simonneaux (2009) demonstrate that, when dealing with socio-scientific issues, if the situation presented to the students goes against their values, the affective dimension can hinder critical reasoning and create resistance. The issue can activate certain attitudes, favourable or detrimental to the educational aim, depending on whether the objective is to encourage identification or foster empathy with the other.

The part played seems to be a decisive factor as well. The role of forester is far removed from Iannis's cognitive and affective sphere. The role played by Arold activates his identity attitude which expresses separation towards farmers and leads to certain stereotypical attitudes but also to attitudes that approach empathy. Amélie is, on an affective level, close to her role as farmer and this fact results in her identifying with the part. Although an affective closeness may be desirable on an educational level to enable identification, this proximity is detrimental to the adoption of empathic attitudes. In the case of the latter, an optimal affective and cognitive distance is to be sought, a distance which is neither too great (creating a lack of interest in the role) nor too small (sparking the identification processes).

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31 RESIDENTIAL FIELDWORK: CONTRIBUTIONS TO SCHOOL SCIENCE FROM A FIVE-YEAR INITIATIVE FOR INNER-CITY STUDENTS IN THE UK

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Abstract

There is a great deal of interest in many countries in the value of residential fieldwork for school students. This paper draws on the evaluation of a distinctive fieldwork initiative resulting from a collaboration between several of the main fieldwork providers across the UK. The providers created an extensive programme of residential courses for 11-14 year olds in London schools from 2004 to 2008. Some 33,000 students from 849 schools took part. Data were gathered by questionnaire, interview and observation of field courses from 2706 students, 70 teachers and 869 parents/caregivers from 46 schools. The evaluation revealed that collaborative interactions between students improved and relationships between students and between students and teachers were strengthened and taken back to school. Benefits for students in the social and affective domains emerged, in conjunction with high levels of conceptual engagement. Some evidence for cognitive gains was apparent. Over the 5-year programme, courses combining adventure activities with curriculum foci proved to be popular with the students and their teachers, and provided opportunities for learning science in ways not usually accessible in urban school environments.

Keywords: fieldwork; learning science; affective; social; urban

1. Introduction

It is a long-held belief that learning outside the classroom is a positive educational experience for young people and to a certain extent, this notion has been substantiated by research. Such experiences have been cited as contributing positively to students' enjoyment of science (Cerini, Murray, & Reiss, 2003). As curriculum authorities the world over try to promote the study of science beyond compulsory years (Schreiner, 2006; USA National Academy of Science, 2007), inspirational approaches to motivating young people to continue with science are vital. Traditionally, many school curricula have placed importance on the provision of out-of-classroom learning activities such as fieldwork in subjects like geography, environmental science and science itself (Braund & Reiss, 2006; Scharfenberg, Bogner, & Klutke, 2006).

In the UK, science educators and outdoor education providers became increasingly alarmed at the beginning of the twenty-first century by the demise of fieldwork in science, in particular in biology (Lock & Tilling, 2002). Several factors contributed to this decline (Lock, 2010). School senior managers were becoming reluctant to sanction science fieldwork visits in the midst of increasing pressure from the content-laden science National Curriculum for England and Wales (Department for Education and Skills, 1995). If a more positive environment for school students' participation in science fieldwork is to be established in the UK, teachers, senior managers and parents, as well as curriculum authorities and governments, need to be convinced of the benefits of fieldwork in the wider context of students' education.

The purpose of this paper is therefore to explore the expectations for, and perceived benefits of, residential fieldwork for 11- to 14-year-old students from London, UK, participating in a distinctive out-of-classroom programme led by the Field Studies Council (a major UK provider of residential fieldwork) from 2004 to 2008.

2. The potential impacts of fieldwork in school science

Braund and Reiss (2006) argue for the potential of learning outside the classroom to improve school students' attitudes towards studying science, as well as to afford school science greater authenticity. They state that alongside learning science, there are opportunities for other potential benefits, such as socialisation and building self-confidence.

Learning outside the classroom takes place in many contexts: traditional biology or geology fieldwork usually involves a few days of immersion in a rural environment with students taking part in observation, data collection and analysis. Given the examination-oriented nature of much of the biology fieldwork in the UK, one could argue that the focus on 'what is being learnt' dominates other possible questions about the benefits of specific experiences. Falk and Dierking (2000) challenged the 'what has been learnt?' scenario in the context of their research into learning in museums. They asserted that this kind of question is fundamentally flawed and that a much more meaningful inquiry would involve discovering how an out-of-classroom experience contributes to what a person 'knows, feels, believes or is capable of doing' (p. 13).

The ways in which people come to new understandings of concepts are clearly complex. In 2004, a review of international research (published in English) into the impacts of fieldwork was summarised in a report for the UK-based National Centre for Educational Research (Rickinson et al., 2004). Four key developmental domains were highlighted: cognitive, affective, social/interpersonal and physical/behavioural. These domains were used to initiate an analytical framework for our data analysis. Several studies cited in the Rickinson et al. (2004) meta-analysis take a rather limited view of the definition of learning, that is, the learning of subject-related facts and skills related directly to curricula. Instead, Brody and Tomkiewicz (2002) applied Falk and Dierking's (2000) learning model in their study of learning gains by visitors to Yellowstone National Park in the USA. They confirmed some of the close links between the personal, socio-cultural and physical contexts that people bring to learning situations. Brody (2005) went on to propose a valuable framework for analysing learning in environmental settings which highlights the intertwined nature of the impacts outlined by Rickinson et al. (2004).

In 2003, the London Challenge initiative (a government-funded inner-city project) announced a pledge to provide a fully funded residential experience for all 11- to 14-year-old state secondary school students in London. There were three main categories of fieldwork courses in the London Challenge programme:

- curriculum (traditional fieldwork in ecology or geology, for example)
- adventure

- combined curriculum-adventure.

Three types of science curriculum courses were available: seashore ecology, seashore ecology with geology, and animal and plant ecology. Adventure courses typically included climbing, canoeing or hill walking. In combined courses, students most commonly climbed, abseiled, sea-level traversed and built rafts or shelters, linked with ecology or geology fieldwork.

3. Research questions and methodology

We report the findings of the London Challenge programme explored through the following research questions:

1. What is the nature of 11- to 14-year-old inner-city school students' learning during residential fieldwork experiences?
2. When examined from different perspectives–the students themselves, their teachers and their parents–how are the potential benefits of residential fieldwork perceived? What relative importance is placed on the different kinds of impact?
3. What evidence is there to show that students develop an understanding and awareness of environmental issues during a short fieldwork intervention in the immediate term?

Approximately 33,000 11-14 year olds from 849 schools took part in the London Challenge residential initiative between 2004 and 2008. Our study sample included 2706 students participating in 77 field courses, their teachers and their parents. The courses took place at 20 different field centres across the UK. The methods used for data collection with respect to the 77 courses were:

- pre- and post-course student questionnaires containing a range of attitudinal and cognitive questions
- post-course small-group student interviews at school (n=170, from 35 courses) from 2 to 8 weeks after the course (according to teacher and student availability)
- pre- and post-course teacher interviews (n=70, face-to-face or by telephone)
- pre- and post-course parent questionnaires (n=869, phases 2-6)
- observational visits to 17 courses by one of the authors.

3.1 Questionnaire design

Student and parental surveys were a mixture of closed and open questions. Student questionnaires were typically 28-item instruments: the first 14 questions used a 4-point Likert-type scale to gauge attitudes towards school subjects, as well as social, affective and physical issues pertinent to the out-of-classroom learning environment. The next four free text response items were more open, asking students for their expectations, enjoyment and 'best memories' of the course. The next three or four items addressing cognitive gains and understanding were open; respondents were given no prompts. These items were varied according to course type and content. For example, to assess environmental awareness, a typical item was: "if you can, write down an example of a problem affecting the environment".

A further six items (closed and open) then explored the other learning domains. The student survey instrument was trialled during the pilot first year (428 students). Limited physical space on the questionnaire (two sides of an A4 sheet to assist with ease of administration) was likely to lead respondents to restrict the range and depth of their written responses. Experienced science teachers and Field Study Council tutors judged the content validity of the cognitive questions. Cognitive questions were designed to explore broad ideas related to course activities, but the depth and specificity of the questions was limited by the requirement to gather data from a wide range of courses. In addition, the evolving nature of the London Challenge programme over 5 years led to continual modification of research instruments. In the pilot first year, students were simply asked to describe new science ideas or skills learnt during the field courses. Their responses framed more specific questions where possible from then on. All instruments are available from the first author.

Pre-course student questionnaires were sent to lead teachers approximately one month prior to field courses. Neither of us was present during the completion of the questionnaires but teachers were asked to ensure individual completion, in confidence, and to allow sufficient time for the task. Post-course questionnaires were to be completed 4 to 6 weeks later.

Parental questionnaire surveys were seven-item instruments distributed to 55 groups of students (where teachers were willing to administrate). Students took the questionnaires home to their parents, and then returned them to the lead teachers. Two items required parents to describe three expectations of, or gains made during the field courses; responses were not prompted. A number of schools requested parent questionnaires in languages other than English (and these were provided in Urdu, Punjabi, Turkish, French and Portuguese). Students occasionally acted as scribes for parents.

3.2 Student and teacher interviews

Student and teacher interviews were semi-structured, encouraging students to offer their own unprompted evidence throughout. Student interviews began with the interviewer asking:

"Tell me about something new, something different that you didn't know before, or can you do something that you couldn't do before, as a result of going on your fieldwork course?"

The aim of this question was to prompt non-directed, self-reported cognitive impact responses, prior to asking more specific, science-related questions. To further explore the opening question on the second side of the student questionnaire, in which respondents were asked to record their two 'best' memories, interviewees were prompted to elaborate on expectations and outcomes other than those they considered to be personally most significant.

Teachers were asked for their expectations and perceived impacts of the courses for the students, before more specific questions pertaining to cognitive, affective, social and physical impacts were addressed if these were not brought up by the teachers themselves.

3.3 Observational visits

One of us took extensive field notes, sampled students' work and journals, took photographs and a small number of video/audio recordings during visits to 17 courses: 7 science curriculum, 2 'other' curriculum, 3 adventure and 5 combined curriculum-adventure.

3.4 Data analysis

We used the four developmental domains–cognitive, social(/interpersonal), affective and physical/behavioural–identified by Rickinson et al. (2004, p. 12) as an initial analytical tool for categorising the impacts of the residential experiences on students. We adopted the key Rickinson et al. definitions within the four domains to create our data analysis framework:

- cognitive: concerning knowledge gain, understanding and inquiry skills
- affective: encompassing personal attitudes, values, beliefs and self-perceptions
- social(/interpersonal): including communication skills, leadership, friendship and teamwork
- physical/behavioural: relating to physical fitness, motor skills, personal behaviours and actions.

These initiated the development of a more fine-grained analysis in which we began to code and categorise our findings based upon emergent themes from all survey and interview data. The Rickinson et al. framework provided us with an analytical framework with which to explore the wide range of possible outcomes pertaining to the diverse field courses in the programme.

Data from questionnaire items (excluding the attitudinal data), transcripts of interviews, video/audio recordings and observational field notes were coded and categorised according to the four developmental domains. Coded data for students and parents were collated from pre- and post-questionnaires by frequency analysis using the statistical software programme SPSS, and for students and teachers from the transcripts of pre- and post-interviews. All coding was carried out by one of us and checked by research colleagues. Inter-rater reliability across sampled questionnaire items and interview data was 0.78.

Fifty-two different fine-grained categories of impact emerged during this process (Table 1). These represent the full range of coded categories which emerged from the three sample groups. For example, some parents stated that they wanted students to 'learn research skills' or to 'learn experimental skills' (under cognitive domain) without specifying exactly what they meant by those terms. Students worked on 'literacy skills' such as oral communication and presentation. Inquiry skills included observing, collecting and analysing data. The codings in Table 1 therefore represent the response language of the sample groups.

For example, the following was given in response to the interview item 'give an example of a new science idea or skill you learnt during your field course':

"we are doing habitats now in science in my class; and when we were there [on the field course] we saw a hawk, and its habitat is a cave" (student, school 25).

This response was assigned three codings in the cognitive domain, thus:

- knowledge gain: learn about science/nature (student appreciates that the habitat of a hawk can be a cave)
- understanding ideas: display 'real world' understanding (the understanding about the hawk's habitat was gathered on an actual field trip, not from a textbook)
- inquiry skills: explore the real world (the student undertook observation at a natural site, rather than examining images/resources at school, for example).

Another interview response showing evidence of social development:

"On the challenges, like climbing and the night walk, they were encouraging one another when they saw each other struggling. I see that in PE at school, but other staff were pleasantly surprised!" (teacher, school 16).

Table 1
Fine-grained data analysis categories for the four Rickinson et al. (2004) developmental domains: questionnaire and interview data

Cognitive domain	**Affective domain**	**Social/interpersonal domain**	**Physical/behavioural domain**
Knowledge gain	Personal attitudes	Communication skills	Physical fitness
- learn about science	- do their best	- listen well to others	- face challenges
- learn about nature	- develop independence	- listen well to instructions	- participate fully in a hike/expedition
- learn about recycling	- improve motivation to learn	- discuss ideas effectively	- build stamina
	- have fun (whilst learning)		
	- persevere		
Understanding ideas	Personal values	Leadership skills	Physical/motor skills
- understand scientific ideas	- appreciate opportunities	- show initiative	- develop climbing skills
- display 'real world' understanding	- appreciate new places	- accept responsibility	- learn to abseil/zip wire
- raise achievement in science back at school	- respond to eco-centric issues	- develop time-management skills	- learn to canoe/raft/swim/surf
	- live without electrical appliances	- encourage team-mates	- learn to go-kart/cycle
Inquiry skills	Personal beliefs	Team-work skills	Personal behaviours
- map reading/ orienteering skills	- show concern for environmental issues	- participate well	- behave well
- research skills		- cooperate well	- look after self well
- experimental skills		- share ideas	
- literacy skills		- be supportive/helpful	
- explore the real world	Self-perceptions	Building relationships	Social actions
	- build self-esteem	- make friends/be friendly	- live well with others
	- build self-confidence	- build teacher-student relationship	- look out for each other
	- develop self-belief	- build student-other adult relationship	- look after the living environment
	- overcome fears	- be away with friends positively	

It was coded as:

- teamwork skills: be supportive.

Results are reported from the perspectives of students, their teachers and their parents.

4. Results

From the 77 groups in the study, 1685 (62%) pre-course and 1177 (43%) post-course student questionnaires were returned. Great effort was made to maximise the return rate of the questionnaires as busy teachers, and students with other priorities, were not always willing or able to support the survey. We received 608 (70%) pre- and 261 (30%) post-course questionnaires from parents in the 55 groups to whom they were sent. Schools were identified by number (1 to 46) in chronological order of taking part in the programme.

4.1 The nature of experiences during the London Challenge residential fieldwork

Of the participating students, 32% had not had a prior residential fieldwork experience, making their impressions of the quality of this first experience potentially influential on future participation. Teachers and parents/caregivers were overwhelmingly supportive of the field courses:

“The opportunity to take difficult students from challenging backgrounds away on a fieldwork residential course is invaluable; it has the potential to change things” (teacher, school 1).

“I think this is a really good experience for my son to try things he wouldn’t get the chance to do otherwise” (parent, school 2).

Of the responding students, 83% stated that they had enjoyed their fieldwork experience.

4.2 Specific evidence for gains in the four main developmental domains

Whilst recognising that learning experiences cannot be neatly compartmentalised, we analysed data by developing Rickinson et al.’s (2004) framework. The data were coded reflexively to identify evolving themes and ideas. Codings were then tested iteratively against the data. Coded data from questionnaires, interviews and observational notes confirmed that all three sample groups (students, teachers and parents) were most highly focused on expectations for, and impacts in, the social and affective domains. Physical impacts were commonly linked to challenging activities such as climbing and hiking; teachers cited behavioural impacts most often. The expectations and impacts that emerged in the four Rickinson et al. domains are shown in Table 2, in rank order of ‘respondent importance’, from the perspectives of students, teachers and parents, respectively. In other words, all data from questionnaire items in which students and parents stated their ‘most important’ expectations and memories/gains, together with all data from the ‘most important’ expectation/impact responses in the student and teacher interviews were collated and the most frequently stated for each of the sample groups was compared. Overall, eight categories of impact emerged as most important for students and teachers, compared with six similar categories for parents, as shown in Table 2 (a ranking of 1 indicates highest importance, 8 lowest importance).

Table 2

Ranked importance of pre-course expectations for, and post-course reported gains from fieldwork experiences within the four Rickinson et al. (2004) developmental domains

Developmental domain	Expectation / reported gain	Student pre	Student post	Teacher pre	Teacher post	Parent pre	Parent Post
Cognitive (C)	Learning new ideas	*	*	5	8	2	3
Affective (A)	Having fun	4	4	-	-	6	-
A	Building self-esteem	-	6	3	5	-	-
A	Building self-confidence	-	5	-	4	4	5
A	Developing independence	-	7		6	5	4
A	Improving motivation to learn	-	-	4	7	-	-
A	Seeing new places	5	8	6	-	-	-
Social/ interpersonal (S)	Improving cooperation	6	-	7	2	-	-
S	Improving teamwork	-	3	1	1	3	1
S	Building relationships	1	1	2	3	1	2
S	Being away with friends	3	2	-	-	-	-
Physical / behavioural (P)	Trying (a variety of) new activities	2	1	-	-	-	6

*Only a handful of students voluntarily offered examples of wanting to learn/having learnt new ideas in the interviews; hence those categories did not feature in the students' highest eight expected/reported impacts. Data were drawn from 1685 student questionnaires, 170 student interviews, 70 teacher interviews and 869 parent questionnaires.

There is only one 'cognitive impact' reported in Table 2 ('learning new ideas') because this represents all of the diverse responses related to 'knowledge gain' (Table 1). Indeed, several categories in Table 2 represent collapsed fine-grained coding of data to summarise overall expectations and impacts from Table 1. For example, 'improving teamwork' encompasses 'participate well; cooperate well; share ideas and be supportive/helpful' (during group tasks).

Overall, analysis confirmed that all sample groups were in broad agreement, i.e. **developing teamwork skills** and **building relationships** were the most important gains made during the fieldwork courses:

"Friendships grew and students are now interacting back at school; the trip initiated this" (teacher, school 2).

This teacher was a pastoral Head of Year for 170 12-13 year olds and she hoped that the residential experience would help heal an all-too-familiar pattern of social division amongst her students.

4.3 Cognitive gains and impacts on environmental awareness

Measuring students' attitudes toward environmental issues has long been an area of research interest (Brody, 2005), although measurements of attitude changes have often been inconclusive. The majority of field centres in the London Challenge programme are run to promote ecological sustainability, and students therefore actively participate in recycling materials and 'saving' energy. Some did demonstrate changed behaviours and attitudes when they returned home:

"Now if I go upstairs, I make sure I do turn the light off again; if I hear my brother's telly, I'll turn it off. And I'll check taps are off".

"Yes, I'm saving electricity and telling my Mum to switch off lights as she goes from one room to another".

(in school) "I think it's quite wasteful, like in French, it was a sunny day, we had the curtains open but we still had the lights on; we didn't really need them" (interview conversations, students, school 27).

For courses focusing on environmental issues, students gave a wider range of post-course responses to the questionnaire item 'Give an example of an environmental problem happening at the moment': pre-course, 48% of respondents (n=150 from 7 schools) suggested 'global warming' and 29% 'pollution'. After the course, 30% stated 'global warming' but now 14% 'littering', 4% 'deforestation' and 2% 'energy waste' (n=146) were also mentioned. It is likely that these three new issues were directly related to course inputs where students were required to pick up the litter and so forth. Their experiences at the field centres therefore had some immediate influences on personal behaviours.

Questionnaire items revealed cognitive gains; student responses were compared pre- and post-course to explore whether they had made progress in using scientific terms accurately, or had assimilated new ideas, using simple chi-squared associations. For example:

1. Where exactly will you find living things on a rocky shore? Compare reference to under/on a rock/in a rock pool ($\chi^2 = 6.11$, df = 1, p = 0.01).
2. Name, if you can, three plants/animals that live in a woodland/forest/field in the UK. Compare frequency of non-farm animals/pets cited ($\chi^2 = 28.26$, df = 1, p = 0.0001).

However, authentic learning emerged for individual students as a result of unique personal experiences. Such experiences for students in school 46 illustrate some typical findings. Whilst we acknowledge that a small sample of 36 students on an environmental eco-adventure course in Northern Ireland cannot provide generalisable data, the impacts of the field course can be illustrated in greater depth than for the whole sample.

School 46 is in North West London and has an ethnically diverse population, of which the fieldwork group was representative. A small group of nine boys and girls was interviewed at school afterwards. The students were positive about the more informal and adventure-based content of their course. They undertook several curriculum activities, including beach ecology and exploration of coastal erosion and caves. None stated that the cognitive learning goals within activities had stronger impacts than their social, affective and physical experiences. However, when questioned directly about scientific ideas explored during their fieldwork, students were able to offer accurate examples for questionnaire items and during interview conversations. Responses from students in school 46 are given in Table 3.

Table 3
Students' recollections of cognitive gains and skills learnt during an eco-adventure course in Northern Ireland (school 46, nine students, post-course interview)

Student	Gender F, female M, male	Example of learning something new	Detail	Developmental domain (some reference to)
A	F	Looking at rocks in caves	Rock formations; limestone caves, useful in science geography	Cognitive
B	F	Exploring the rocky shore	Found living things, we haven't done much at school on sea creatures	Cognitive
C	M	Saw 'Dracula's fangs' in a cave	Examples of stalactites; calcium sulphate comes out of the water as it drips down, and 'sticks' to other particles	Cognitive
D	M	Exploring the rocky shore	Different animals live on different parts of the beach, depends upon how much water they need	Cognitive
E	M	Map reading	How to locate a specific site using a map (during orienteering)	Cognitive
F	M	Paddling a kayak	You have to twist the paddle, not just put it straight in	Physical / behavioural
G	F	Exploring the rocky shore	Identifying starfish and sea plants using an identification chart	Cognitive
H	F	Looking at rocks in caves	There were other rock formations like the angel's wings	Cognitive
I	F	How to help the planet	We learnt what to recycle and how; how to treat things and people with respect	Cognitive, Social/ interpersonal

During the interview, it was evident that students were more focused on social and affective impacts. The lead teacher expressed surprise at the students' low prioritisation of their experiences on the rocky shore:

"I was amazed at the impact of being on the rocky shore. The students were all there, bottoms in the air, discovering starfish and all sorts. Every single kid was totally focused on what they were doing, so different from being in the classroom" (teacher, school 46).

These short extracts illustrate a pattern that emerged in the data amassed over the 5-year period: students valued social and affective impacts more highly than cognitive, and to a lesser extent, physical ones. However, students readily gave evidence for cognitive gains during interviews, as well as in response to direct questionnaire items.

5. Discussion and implications

The four-domain developmental framework derived from Rickinson et al. (2004) provided an effective context for our assessment of participants' experiences during the 5-year evaluation of the London Challenge residential fieldwork programme. Almost without exception, teachers, students and parents gave testimony on the important impacts in the social and affective domains, over and above impacts in the physical, and particularly cognitive domains. This same predominance has been observed during fieldwork courses in other countries (American Camp Association, 2005; Brody, 2005; Eshach, 2007). Some teachers and parents did cite the importance of cognitive gains but these were secondary to social and affective benefits.

It is perhaps not surprising that participants tend to focus on social and affective outcomes during out-of-classroom experiences. The novelty of being outside, away from home and learning in a less formal way than in school may create a sense of well being and excitement in participants which then stimulates stronger memories. In an attempt to explain these memorable feelings, Falk and Dierking (2004) drew on the thoughts of psychologist Csikszantmihalyi who describes people who pursue certain kinds of intense activity (such as rock climbing) as thriving on a kind of 'flow experience': the total immersion in a high-demand situation gives an immediacy of feedback that in itself sustains motivation. Perhaps the field courses gave students a 'flow experience' of a kind, more so than could readily be achieved in school. School science in a classroom or laboratory setting, for all its central value to science, can too often fail to engage students at a more than superficial level.

We believe our study indicates that, in the context of residential fieldwork, learning in the social and affective domains made valuable contributions to students' educational experience in the London Challenge residential programme. Conceptual engagement was high. In terms of cognitive benefit, there were clear opportunities for students to make progress with knowledge gain and skill development which had the potential to support their learning back at school. There was evidence of students taking those opportunities. Others have also reported the overlapping nature of learning in several domains during fieldwork (Brody, 2005; Eshach, 2007).

It is promising that most of the teachers who took part in the London Challenge programme were inspired by the fieldwork activities and gained confidence in organising and leading residential courses. We also suggest that science teachers and field course providers take into account the potential successes of fieldwork that incorporates adventure activities alongside curriculum activities–the combined courses. The value of social and affective impacts needs to be fully recognised in terms of underpinning learning in out-of-classroom contexts.

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