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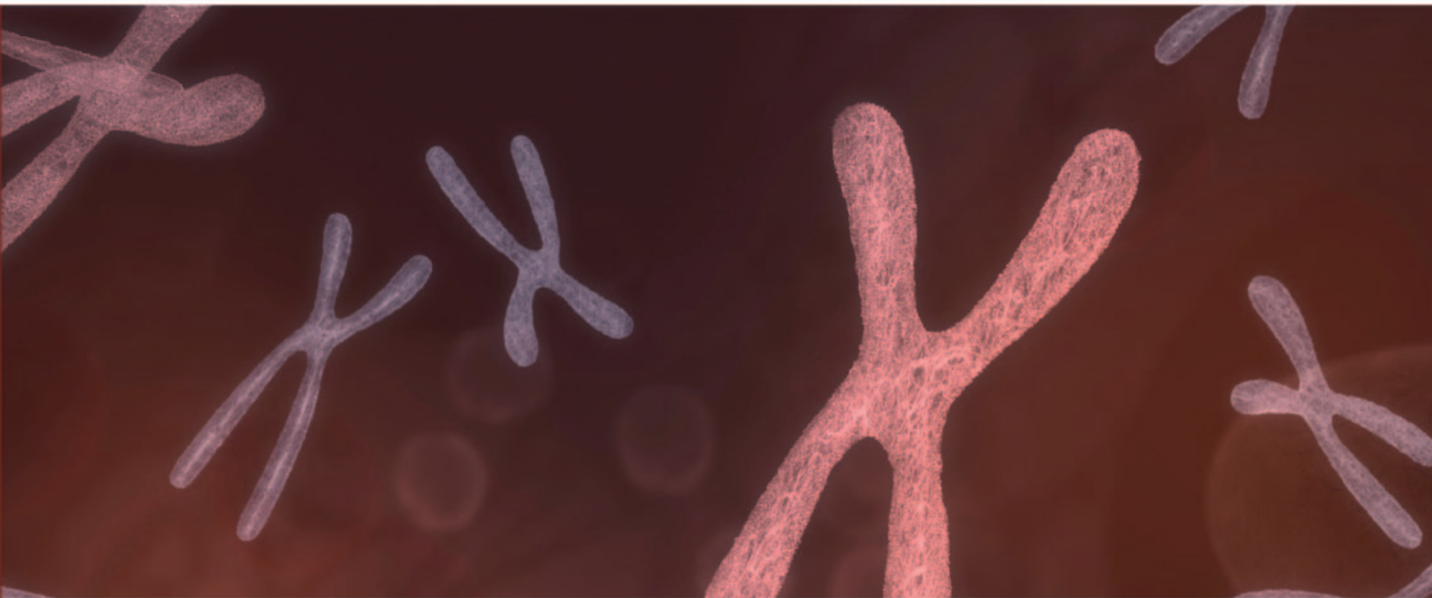
Biology in Context

Learning and teaching for the twenty-first century



Edited by
Marcus Hammann
Michael Reiss
Carolyn Boulter
Sue Dale Tunnicliffe

A selection of papers presented at the VIth Conference of European Researchers in Didactics of Biology (ERIDOB)

Biology in Context

Learning and teaching for the twenty-first century

This volume presents the empirical findings of 31 original studies in biology education with extended discussions of the implications for classroom practice. The studies addressed the following issues:

- student conceptions and conceptual change
- student interest and motivation
- student values, attitudes and decision-making
- student reasoning, scientific thinking and argumentation
- teaching strategies, teaching environments and educational technology
- health education
- social, cultural and gender issues
- practical work and field work.

Most of the studies presented here share an interest in contexts, which are being more frequently used in biology education because they have been shown to increase students' interest and motivation, provide personal relevance to biological topics, and create situations for decision-making and discussing socio-scientific issues.

The studies were presented at the sixth biennial conference of ERIDOB – European Researchers in Didactics of Biology – at the Institute of Education, University of London in September 2006. Founded in 1996, ERIDOB is devoted to empirical research in biology education and reflects the growing interest of teachers, researchers and science educators in evidence-based teaching practices. In an introductory chapter in this volume Randal Keynes, British author and great-great-grandson of Charles Darwin, addresses the relationships between the ERIDOB research strands and Charles Darwin. His historical contextualisation of research in biology education is inspiring because it challenges the community of biology teachers, researchers and educators to continue the fascinating but difficult endeavour to improve the pupils' interest in biology and their understanding of biological issues in modern society.

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11–15 September 2006
Institute of Education, University of London, UK

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Preface

Two trends characterise the bi-annual conference of European Researchers in Didactics of Biology (ERIDOB): the considerable increase in the number of research-active participants and the growing internationalisation of the conference. Since it was first established in Kiel, Germany, in November 1996, the conference has grown continuously, which reflects the increasing importance of empirical research in biology education. At the VIth ERIDOB Conference held at the Institute of Education, University of London (11–15 September 2006), there were 46 paper presentations (compared to 31 paper presentations in 2004) and 87 poster presentation (compared to 43 in 2004), which made it necessary to introduce parallel paper sessions for the first time in the history of the conference. Also, the number of participating countries increased. While there were almost one hundred researchers from 17 different countries who actively contributed to the Vth ERIDOB conference in Patras (2004), there were 160 researchers from 23 countries who shared their research at the VIth ERIDOB conference in London in 2006: Argentina, Australia, Brasil, Chile, Cyprus, England, France, Germany, Iceland, Israel, Italy, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, South Africa, Tunisia and Turkey.

The title of the VIth ERIDOB conference 'Biology in context: learning and teaching for the twenty-first century' indicates the growing importance of contexts for biology instruction. Contexts have been shown to increase students' interest and motivation, to provide personal relevance to learning biology, and to allow for applying knowledge and discussing contentious issues. Moreover, contexts increase students' awareness of the social and technological implications of biology. Thus, socio-scientific issues, which are always context-based, play an increasingly important role in biology education (see section 7). Generally, there is an on-going international trend towards contextualised curricula, context-led teaching approaches (e.g. SNAB in the UK, BIK in Germany) and context-based assessment (e.g. PISA 2006). The 31 papers presented at VIth ERIDOB in London and published here, which were selected after independent reviews by two members of the academic committee, reflect the importance of contexts. The papers are grouped into eight sections, which represent the main research strands of the conference. The relationships between the papers, as well as their recognition of contexts, will be spelt out in the following description of the contributions.

The first contribution is by Randal Keynes, British author and great-great-grandson of Charles Darwin. In his inspiring talk, he explores the links between Charles Darwin and the ERIDOB research strands. The following papers are devoted to research on student conceptions and conceptual change. Addressing a new perspective in research on student conceptions, the first paper analyses anthropomorphic student conceptions that emerge in a number of studies conducted within the framework of educational reconstruction (Kattmann). Other papers focus on students' conceptions of hearing (West, Andersson and Lustig), ecological units in nature (Jelemenská and Kattmann) and patients' conceptions of rheumatism (Sander and Krüger). The final pair of papers in this section is devoted to the development of student concepts and conceptual change. Anita Wallin reports on a study investigating the extent to which students continue to use scientific concepts of biological evolution one year after teaching. Using a test with the famous cheetah problem as one of his probes, Clas Olander reports on the development of student conceptions concerning evolutionary change in grades 5–9.

Section 2 reports on empirical findings concerning students' interest and motivation. Both studies in this section are devoted to the context of biotechnology. The starting point for the first study (France and Buntting) is the fact that interest is an important prerequisite for a student's decision to pursue a career in biotechnology. Three biotechnologists' narratives about significant educational episodes thus shed light on how teaching influences career choices. In the second paper, Gillian Kidman investigates topics of interest to students and teachers in biotechnology education and identifies mismatches between students' interests and teachers' decisions in biotechnology classes. The study shows that students are interested in topics of personal relevance, whereas teachers tend to favour topics that can be easily taught.

The third section focuses on research on students' attitudes, values and decision making. One of the papers focuses on the context of biotechnology (Klop and Severiens), whereas the other two look at the contexts of genetically modified organisms (Ekborg), and pest control (Nicolaou, Korfiatis, Evagorou and Constantinou). The first two papers in this section are united by the attempt to know more about the ways in which students form attitudes and make decisions. Thus, gender and values (Klop and Severiens) as well as biological knowledge (Ekborg) are investigated as potential factors for explaining students' attitudes. The final paper in this section studies the effects of teaching decision-making skills to students by providing a kind of scaffolding for developing criteria, identifying alternatives and selecting between them (Nicolaou, Korfiatis, Evagorou and Constantinou).

Section 4 combines papers on student reasoning, scientific thinking and argumentation. The six papers in this section focus on different contexts, for example biotechnology (Gilbert and France, Dawson), organ trafficking (Braund, Lubben, Scholtz, Sadeck and Hodges), the ecology of a park lake (Ergazaki and Zogza) and seed germination (Ehmer and Hammann). The section begins with a paper that puts forth a model of communication about biotechnology which includes the community's awareness of the nature of science, key concepts, risks, beliefs and attitudes towards biotechnology (Gilbert and France). The following papers address a range of specific aspects of argumentation, in particular patterns of argumentation about biotechnology (Dawson), the nature of student interactions in argumentation classes (Braund *et al.*), students' engagement in argumentative reasoning (Ergazaki and Zogza), the gradual transformation of children's everyday language into scientific language (Gomez and Sanmarti) and student reasoning and argumentation about disconfirming data (Ehmer and Hammann).

Section 5 is devoted to the teaching of biology. There are seven papers in this section that address a broad range of issues. The first two studies share a common focus on teaching and assessing systems thinking. Defining context as a social activity, the first paper reports on a concept-activity-context approach that was used to teach students systems thinking by authentic practices (Westra, Boersma, Savelsbergh and Waarlo). The second study is devoted to the formative assessment of primary school children's systems thinking after teaching the ecology of waterways (Hipkins, Bull and

Joyce). In the third paper, the focus lies on the ways in which genetic diseases are presented in French secondary school biology text books (Castéra, Bruguière and Clément). The following study analyses the teacher's pedagogical content knowledge about cell biology (Cohen and Yarden). The next study is an analysis of 600 tasks from biology tests in Germany, which revealed a strong emphasis on reproductive knowledge (Germ and Harms). Differently structured tasks are analysed in terms of their cognitive and affective consequences (Wilde and Urhane) and the needs of blind and visually impaired students in biology classes are studied (Fraser and Maguvhe).

The sixth section is devoted to health education. The two studies foreground attitudinal aspects of sex education. The first study is an analysis of Portuguese primary school teachers' attitudes to and conceptions of potentially controversial issues in sex education (Anastácio, Carvalho and Clément). One of the main findings of this study is an identification of the areas in which teachers' attitudes form obstacles to teaching sex education. The second study is an interesting companion piece because it portrays teacher attitudes towards sex education issues in Greece (Papadopoulou, Kartsoglou and Athanasiou). The study also includes policy makers' attitudes and an analysis of Greek textbooks.

The papers in Section 7 are united by a common focus on socio-scientific issues. The research is concerned with different contexts and highlights a range of problems related to teaching and understanding socio-scientific issues in biology classes. The first paper analyses the ways in which therapeutic cloning is presented in scientific papers and newspapers and investigates students' ability to identify central claims in newspaper articles (Federico-Agraso and Jiménez-Aleixandre). The second paper studies the roles of teachers in controversial socio-scientific issues and sheds light on their views of the interactions between science and society (Simonneaux and Simonneaux). The third paper is an analysis of the ways in which knowledge and values are used to construct the concept of human race in biology textbooks (Santos, Selles and Ferreira).

The final section is devoted to practical work in biology instruction. The two papers address the two different modes of experimentation and vivisection. The focus of the first paper is on assessment. The study addresses the question as to whether multiple choice items can be used to construct a test with reliable scales for the dimensions 'forming hypotheses', 'planning experiments' and 'analysing data' (Phan, Hammann and Bayrhuber). The second study analyses students' attitudes towards dissection in South Africa and discusses advantages and disadvantages as well as alternatives (de Villiers).

Darwin and ERIDOB research strands

Talk for ERIDOB dinner given by Randal Hume Keynes

CHARLES DARWIN TRUST

RHKeynes@aol.com

Thanks for your welcome. It is a privilege for me to talk to you all this evening with your special commitment to the fascinating but taxing issues of teaching biology. I've been most interested to look through your very full programme and see all the issues you've been dealing with in your papers and posters. It is striking how many of them bear directly on major issues for today, reaching out to the importance of human understanding for survival!

I'm involved in making good use of Darwin's heritage and have read your programme with Darwin in mind. I'd like to offer you some suggestions on each section, some serious because I feel they're important, and some trivial because the day's work is over and this *is* after all the after-dinner spot!

I'll take the themes in my own order.

Research Strand: Teaching: teaching strategies, teaching environments and educational technology

I was fascinated to see the mention of the role of narrative in understanding. The first kind of narrative in science education is the narrative of discovery. Darwin's with the Beagle voyage and all that followed is one of the most familiar. There are so many others, and it's so clear that they have a value, but they're tricky in many ways and the stories so often get distorted for different reasons. All people with an interest in the history of science and its uses will be glad to see that you're looking carefully at these accounts.

Research Strand: Student interest and motivation

Darwin recognised what every teacher knows about interest, how the best interest stems from the learner's focus and engagement. Darwin's family were devotees of Pestalozzi and equipped the school they built for the poor of their neighbourhood with his learning aids. One of Darwin's sons said of their father: 'He never tried to make us take an interest in science. When however we freely exhibited any wish to learn, there was no amount of trouble which he would not take, and the result was of course far more powerful than if it had been at his urging.' Darwin wrote once to a friend that 'giving specimens to children in order to give them a taste for natural history would tend to destroy such taste. If I had a collection of English lepidoptera, I would be systematically most miserly and not give my boys half a dozen butterflies in the year. Youngsters must *themselves* be collectors to acquire a taste.' Darwin said it. You know it.

Research Strand: Student values, attitudes and decision-making

These are fascinating topics – about student attitudes and values as factors that need to be recognised and can be taken into account in helping them to learn. I can offer one touching point on this about the young Darwin. He picked up from his elder sisters a deep concern about cruelty to animals. It was bound up with their Christian values although he didn't fully understand that at the time. His values got him into difficulty when he acquired a passion for collecting insects, because he rather commendably felt he should put his sisters' moral concerns above his ambitions as a collector. He decided that he could only allow into his box of specimens any beetles and butterflies he could be sure had died a natural death! He got nowhere of course with this high-minded approach, and made what may have been the first moral compromise of his life just to get on with his collection.

Research Strand: Student reasoning, scientific thinking and argumentation

Darwin wrote that *The Origin of Species* was 'one long argument'. At times he tried to emphasise the purely empirical nature of his research but he knew he was driven by ideas. When you discuss all the aspects of fact and theory and weighing ideas against each other, do remember Darwin's comment as one who knew from the sharpest experience: 'All observation must be for or against some view if it is to be of *any* service!'

It is wonderful to see that one of you in your talk looked at 'unexpected outcomes'. Darwin would have been so pleased to hear about an approach to biological education based on 'unexpected outcomes'. Some of the best of his outcomes, some of the most interesting ones, were utterly unexpected. The point for Darwin was what to do next. Open your mind to the possibility that you were wrong in your approach, obviously, but also follow the puzzling facts in *any* direction that may be interesting. You've been discussing methods of teaching biology that have to do with the whole experience of investigation together with the knowledge gained. Darwin is with you in your emphasis on how to explore, how to find out.

Research Strand: Student conceptions and conceptual change

Yes indeed! How embedded they are, how often they aren't understood, how we always need to be thinking about the learners' value systems and how our own match them. I remember talking at a conference in Tokyo about Darwin's insights into the struggle for existence. One senior person I spoke to, a guru for the others, didn't like to dwell on Darwin's idea of the struggle for existence. It was essential for him that nature is good, in balance, in harmony, etc. But Darwin wrote in *The Origin of Species*, 'Nothing is easier than to admit in words the truth of the universal struggle for life, or more difficult – at least I have found it so – than constantly to bear this conclusion in mind. Yet unless it be thoroughly engrained in the mind, I am convinced that the whole economy of nature, with every fact on distribution, rarity, abundance, extinction and variation, will be dimly seen or quite misunderstood. We behold the face of nature bright with gladness, we often see superabundance of food; we do not see, or we forget, that the birds which are idly singing round us mostly live on insects or seeds, and are thus constantly destroying life; or we forget how largely these songsters, or their eggs, or their nestlings, are destroyed by birds and beasts of prey.' We must find the truth behind appearances and beyond assumptions. We must all always remember the strength of our and others' preconceptions as obstacles to true understanding.

Research Strand: Social, cultural and gender issues in biology education

On this theme I can give you one piece of Darwin trivia. Who apart from Darwin read the whole text of *The Origin* before it was published? We all imagine he gave it to his closest scientific colleagues – the geologist Sir Charles Lyell surely, and 'Darwin's bulldog', Thomas Huxley. But no, Darwin gave it to only two people, his wife and a close friend of hers. Two ladies, neither scientists. Why? Because he trusted them most as general readers, and he was writing for everyone prepared to open their mind to the extraordinary possibilities he wanted to explain. Writing for the general reader was the best discipline; understanding how different backgrounds and beliefs come into play.

Research Strand: Environmental education and biology education

This is a key issue. You know the responsibility you have to encourage environmental awareness. It takes efforts of thought and imagination to understand about loss of biodiversity and all its consequences. If people don't understand, we just can't expect them to care. Thinking of places that Darwin cared about; I'm impressed by the scientists in Galapagos today. With all the threats the islands now face, especially of invasive species with the ever-growing numbers of tourists, the scientists see that the children in Galapagos need to learn with their teachers' help how the web of life, their life, hangs together. If the people who live and work in Galapagos don't understand about the links, how they work and how easily they can be destroyed, if the people don't join the conservation effort, it won't succeed. Helping the children of Galapagos and everywhere around the world to understand themselves what needs to be protected, and why, is simply essential.

Research Strand: Health education and biology education

This topic has a special importance to me for my book about Darwin and his daughter, who died of tuberculosis at the age of 10. In my book, I've written about Darwin's understanding of disease, its nature, its spread and its effects. To cope with it, we need an understanding of how life works. One book that shows the value of a Darwinian, evolutionary perspective, is Burnet and White's *Natural History of Infectious Disease* (1972). In Darwin's time, tuberculosis was endemic and treatments were ineffective. He was powerless to save his daughter and her death brought home to him how little power medicine had. Scientists developed the germ theory of infection in the years after Annie's death. In 1877, Darwin's German friend, Professor Ferdinand Cohn at the University of Breslau, sent him copies of Robert Koch's first photographs of anthrax bacilli with Koch's suggestion that they were the cause of that fatal disease. Cohn suggested to Darwin that they were 'the least but also perhaps the mightiest living things'. Darwin replied that he well remembered saying to himself in the years after Annie's death 'that if ever the origin of any infectious disease could be proved it would be the greatest triumph to science; and now I rejoice to see the triumph.' Yes, the greatest triumph to science.

Research Strand: Practical work and field work in biology education

I don't need to add anything this evening to all you have been discussing about practical work and field studies. But I can give you a glimpse of Darwin in the field, always modest, always ready to laugh at himself. On 5 June 1855, he had just started on a survey of the plant diversity of a field at the end of his garden, a survey that was to prove historic. He was not a botanist and was having to learn how to identify plants as he worked. That day, he wrote in triumph to his botanist friend Joseph Hooker, 'I have just made out my first Grass, Hurrah! Hurrah! . . . It is a great discovery. I never expected to make out a grass in all my life!'

There he was at 46, well over 16 years after he had first worked out the idea of natural selection as the key to evolution, the great scientist, identifying his first grass! We can all be inspired by Darwin, but we can also be reassured. He saw the need, the compelling need, for fieldwork. He was learning, learning as he went, and enjoyed it all intensely. Let's help our pupils to as best we can!

1 Student conceptions and conceptual change

1 Learning biology by means of anthropomorphic conceptions?

Ulrich Kattmann

INSTITUTE OF BIOLOGY AND ENVIRONMENTAL SCIENCES, UNIVERSITY OF OLDENBURG, OLDENBURG, GERMANY

ulrich.kattmann@uni-oldenburg.de

In biology lessons, anthropomorphisms are traditionally avoided in order to exclude anthropomorphic conceptions from scientific approaches. Since Ulrich Gebhard put the question: ‘Are children allowed to animate living things?’, the pedagogical aspect of anthropomorphisms has been opened up, especially when considering the emotional relationships of students to animals and plants. Accordingly, a co-existence of scientific and anthropomorphic views of organisms has been proposed. On the basis of the results of studies within the frame of educational reconstruction, this paper demonstrates that anthropomorphic thinking and speech are an unavoidable part of human understanding of nature and that – under certain circumstances – they can even promote learning.

1. INTRODUCTION

> Plants breathe in carbon dioxide and oxygen out – I know, I should not say ‘breathe’, but this way I can remember it better.
>
> (Female student, biology major, 20 years old.)

This statement illustrates the main aspects of the issues considered in this paper. Firstly, it demonstrates that breathing is understood anthropomorphically as the intake of gases into the body. Secondly, it refers to the technical distinction between photosynthesis and biological oxidation. Lastly, the expression to ‘remember it better’ reflects the psychological link between everyday concepts and sustainable learning.

2. CURRENT STATE OF RESEARCH AND RESEARCH QUESTIONS

Former studies have shown that students tend not only to express their knowledge anthropomorphically but also to misinterpret biological processes teleologically. Teachers themselves tend to accept these statements as biologically correct (Jungwirth 1975). Nevertheless, biology educators have traditionally proposed that anthropomorphisms and teleological expressions should be avoided or even sanctioned by the teacher in order to eliminate the corresponding conceptions as scientifically false and detrimental. A new perspective was opened up by Ulrich Gebhard (1990) when he asked: ‘Are children allowed to animate living things?’ Since then, emotional and ethical aspects of anthropomorphising plants and animals have been considered more deeply. It has been suggested that scientific and anthropomorphic conceptions should be used side by side in biology teaching. It was also postulated that the rotation between ‘objectifying’ and ‘anthropomorphising’ should lead to discussion in two languages – a scientific one and a colloquial one. Thus, teaching should aim to transform an intuitive anthropomorphism to a reflected understanding, in which common features of man and animals are acknowledged along with the modest place of man in nature (Gebhard 2003: 108). It has been stated that, particularly with respect to attitudes towards animals, not only should emotional bonds be considered but also an adequate treatment of the species concerned. Anthropomorphic conceptions must therefore be corrected by factual information about the biology of the species concerned (Etschenberg 1994). On the other hand, it has been pointed out that anthropomorphisms can have a cognitive effect emerging from the illustration and imagination that is given by (anthropomorphic) metaphors (Gebhard 2005; Watts and Bentley 1994; Langlet 2004). Studies in Israel went a step further, where it was shown that 'the anthropomorphic formulation of scientific knowledge facilitates students' learning and understanding of biology' (Zohar and Ginossar 1998; see also Tamir and Zohar 1991). Taking into account the results of this research, anthropomorphic conceptions seem to be an obvious mental tool of learning and it should be tested whether they are suitable for use in the teaching of biology.

The research questions that we asked were:

1. Which anthropomorphic conceptions relevant to biology education are used by the students?
2. What clues can be deduced from results of empirical studies concerning the question of whether anthropomorphic conceptions may be prerequisites for and specific means of learning biology?
3. How should anthropomorphisms be treated in order to promote biology learning?
4. How can the controversy between anthropomorphic thinking and science be converted into a fruitful cooperation in learning biology?

These questions were answered by a cross-case study of contributions to educational reconstruction, which was conducted by the Oldenburg Biology Education Group (see below).

3. THEORETICAL BACKGROUND

Generally, conceptions are merely cognitions, i.e. thoughts or mental constructs concerning a phenomenon or a field of subjects. Our understanding of learning is based on a constructivist position, which stands in contrast to an instructional view of learning and teaching. Whilst the majority of teachers and researchers disagree with this view, it is still prevalent in schools. Even constructivists tend to voice this backlash because instructional thinking is deeply imprinted in our minds. Nearly every metaphor of teaching and learning corresponds to an instructional understanding, as Gropengießer (2004) has shown.

In biology teaching, the students often develop and use concepts that strongly deviate from scientific ones. Lijnse (1995) pointed out that – at least from the perspective of a constructivist – it is decisive for learning to link the conceptions of the students to the scientific concepts in such a way that they are meaningful to the students and can be used fruitfully. Accordingly, in this study, learning is not understood as the change of pre-instructional conceptions for scientific ones, but rather their modification, enrichment and differentiation. By using terms such as 'conceptual change' or 'conceptual growth' (Posner *et al.* 1982; Strike and Posner 1992), the underlying process of learning is characterised unsatisfactorily. If the active role of the students is considered, the term 'educational reconstruction' seems more adequate (Watts and Bentley 1994: 94; Demastes *et al.* 1995: 638: 'conceptual restructuring'). The term 'conceptual reconstruction' indicates that conceptions are rebuilt during learning using old and new components for the new construction of the building of thoughts. Pre-scientific conceptions therefore should be treated not so much as constraints but as instruments and aids of learning (Baalmann *et al.* 2005).

In this context, we reject the commonly used phrase of 'bringing the students from the point where they are standing'. 'Bringing' can be applied adequately to a person who is waiting. We cannot expect that the students are waiting for us. Furthermore, students do not stand but move. It should be worth accompanying them on their way. This means that students are not asked to abandon their pre-scientific conceptions or leave them at the side of the road. Rather, these conceptions are prerequisites for and instruments of further learning. Without using them, learning will be in vain and no goal will be reached.

The (pre-scientific) conceptions of everyday life, which are more obvious to the students and easily developed by them, can be interpreted by the 'experiential theory of understanding' (Lakoff and Johnson 1980; Gropengießer 2003). The idea is that our conceptions are formed by means of basic experiences with our own body, as well as from interactions with the social and natural environment. Such experiences are mainly made in early childhood. General distribution and availability and the inter-subjectivity of everyday conceptions emerge from this common ground of experience of nearly all human beings. The character of these perspectives is emphasised by the term 'embodied conceptions' (Gropengießer 2003). They are expressed through general schemata of human acting and by central metaphors. From this view of an experiential theory of understanding, it can be deduced that conceptions – founded in and organised by basic human experiences – are unavoidably anthropomorphic.

The generally anthropomorphic character of conceptualising the world implies that an anthropomorphic conception may be either adequate or inadequate but in either case is an instrument of understanding. This perspective overcomes the traditional belief that anthropomorphisms can or should be avoided. In accordance with the anthropomorphic character of basic conceptions, in this study the terms 'anthropomorphic' and 'anthropomorphisms' are used in a wide sense.

4. FRAMEWORK OF RESEARCH AND METHODS: CROSS-CASE ANALYSIS

In accordance with the understanding of pre-scientific conceptions, our studies were conducted in the research frame of the 'model of educational reconstruction'. In this model, students' conceptions are systematically linked to scientific ones in order to use the correspondences for fruitful scientific learning (Kattmann *et al.* 1997; Duit *et al.* 2005).

The intimate interplay between clarification of the structure of the science subject matter and the investigation of students' perspectives forms the heart of the model. Investigations of students' perspectives should include issues of development of the constructed ideas towards the scientific point of view, i.e. should comprise issues of possible instruction of the science content in question. It is therefore important to explicitly integrate another component into the model of educational reconstruction, namely the design of learning environments. The dynamic interrelationships between these issues are shown in Figure 1.1.

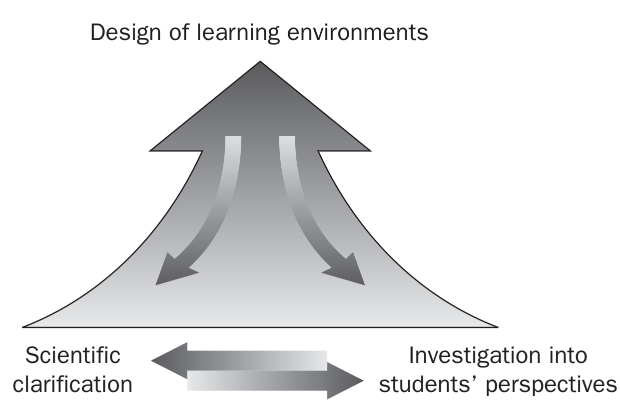

Figure 1.1 The three components of educational reconstruction

To answer the research questions outlined above, several studies that were conducted in Oldenburg under the frame of educational reconstruction were re-analysed in a cross-case study. In the original studies, problem-centred interviews were conducted with students in grades 5–12 (10–18 years old), each study comprising five to ten interview partners. The interviews were audiotaped and interpreted by qualitative content analysis (adapted from Mayring; see also Gropengießer 2001). The studies comprised a wide spectrum of biological subjects (microbes: Hilge 1999; Hörsch and Kattmann 2005; genes and genetic processes: Frerichs 1999; Kattmann *et al.* 2005; visual perception: Gropengießer 2001; behaviour of animals and humans: Kamelger 2004; evolution: Baalmann *et al.* 2004; Biebricher 2002; Papenfuß 2002; ecology: Huff 2002; Sander *et al.* 2006; Jelemenská 2006; Jelemenská and Kattmann, Chapter 3, this volume; physiology of the human body: Focken-zum Buttel 2004; Schwegmann 2004; Sturm 2004). In the cross-case analysis, anthropomorphic conceptions identified in the studies were compiled, compared and generalised. The reanalysis was made easier by the fact that all of the studies were conducted within the frame of the model of educational reconstruction by which students' conceptions and principles are formulated in the same manner and can therefore easily be compared. The clarification of corresponding scientific conceptions provided a solid basis to answer in particular the third and fourth research questions adequately.

5. RESULTS: ANTHROPOMORPHISMS REVISITED

5.1 Common ground in students' conceptions

A number of anthropomorphic conceptions that were common ground in the understanding of several interview partners were identified. These basic conceptions could be formulated as 'principles', as described below. According to the theory of experiential understanding, the anthropomorphism of these principles is based on experience and relies on embodied schemata (see Table 1.1).

It should be noted that the statements of the students that are documented below are anchor quotations. They exemplify the principles that were deduced by systematic qualitative analysis from the problem-centred interviews, rather than from a single statement or expression. Some quotations did not come from our interview, but were chosen in addition to passages from the interviews as they demonstrate the anthropomorphic conception very clearly. These quotations show that these conceptions go far beyond the limits of the set of empirical studies.

5.1.1 Evidence and existence

This principle emerged directly from the human perception that: 'Plants are living because they are just there' and 'Ecosystems exist because they can be recognised in the landscape by the look of the vegetation.' These statements express a naïve realism that is 'self-satisfying': the facts serve as a sufficient and comprehensive explanation of the phenomenon, as the following anchor quotations show:

> Why do bacteria cause diseases? Likewise, you can ask: 'Why does the heart beat?
> (Wilhelm, 11th grade)

> The growth of plants is probably similar to that of humans. They become older and stronger and therefore they must grow, of course.
> (Hans, 5th grade)

5.1.2 Constancy

The assumption of constancy is grounded in our experience that things are stable and present until disposed of and that they will not change without a cause. This principle is typically applied to genes and ecological ideas:

Table 1.1 Main principles, colloquial statements, pre-scientific conceptions and basic experiences

Principle	*'Colloquial statements' and pre-scientific conceptions*	*Basic experience*
Evidence/existence	'It is as I see it.' Naïve, self -evident realism Topographical sorting	Perception and awareness of the self Perception of one's own body and experience of the social and natural environment
Constancy	'There will be no change.' Preservation of species Preservation of genes Preservation of nature Equilibrium or balance	Repeated experiences with one's own body and the environment Keeping a balance
Continuation	'There is nothing new under the sun.' Transfer of stimuli and information Circles Hidden inheritance	Identity of caring persons and stability of objects in the environment Self-identity
Coherence	'We belong together.' Heirlooms Life community Natural harmony	Personal relationships Home Security, dependence, family and social bonds
Tendency	'They lived happily ever after.' Wisdom of the body Wisdom of nature Adaptive action Egoism of genes	Intention Purposeful, goal-directed action Effort Success
Valuation	'There are two sides to a coin.' Good and bad bacteria Good and bad genes Struggle for existence/reciprocal support Natural enemies Dominance of genes	Well-being/illness Reconciliation/conflict Reward/punishment Victory/defeat

> At a friend of mine's, the rabbits had young ones. Because the mother is black and the father is white, there can be at most a white rabbit with black spots. There were no real deviations. If there had been a red one among them, there would have been something wrong.
>
> (Alan, 9th grade)

> After swinging, the balance will always be reached again, because it is quite good for the environment that the balance will be maintained if possible.
>
> (Ben 11th grade)

5.1.3 Continuation

Compared with constancy, continuation is distinguished by interruption or change in small steps. Continuation will be also assumed, if – for a period – the object or process cannot be perceived. This principle is grounded in the experience that people or phenomena will return regularly or will last permanently:

> Stimuli [not impulses] are propagated to the brain: 'hidden' traits will re-appear in following generations.
>
> (Summarised student statement)

> With flash-like velocity and without detours, pheromones generate surprising effects in the brain.
>
> (Quote from a popular journal)

> This is my conception of the origin of the white gorilla: genes can be passed on ahead of a generation. I can, for example, inherit my grandfather's eyes. I assume that the parents of the gorilla were not albinos. But perhaps his great-grandfather was an albino, and so his genes were handed down to him. So he got his white fur.
>
> (Alan, 9th grade)

5.1.4 Coherence

This principle is deduced from the analogy of social experiences and relationships; for example: 'Traits are heirlooms of the family' and 'Animals of a community live peacefully side by side.' The significance of nature for human life is interpreted particularly in such a way:

> Plants are relevant to me because they look so nice. They bring fun into the world with their various colours.
>
> (Hans, 5th grade)

> Nature is also important for humans because it provides human beings with nutrition, fresh air from lots of woods, and you can relax there too . . . If no trees existed, there would be no apples, no bananas, no peas, no fruits and no vitamins. And then you would soon die.
>
> (Franz, 10th grade)

5.1.5 Tendency

This principle refers to purpose and teleological assumptions. The conceptions are formed by analogy with the experience of purposeful and goal-directed actions of one's own; for example, 'The body knows what will be good for it' and 'Living organisms adapt to the environment in order to survive.' This principle is so strongly embedded in the thoughts that learnt scientific conceptions are easily modified and integrated into pre-scientific conceptions. Typical examples can be found in the context of evolutionary adaptation:

> There are many white apes there who find out that they all get eaten (they are an easy prey). Somehow the information enters their heads: 'White is no good for us.' The apes look around and see: 'Everything around us is dark, so we must also become dark, so as

> not to stand out so much.' An unconscious information takes place, which somehow passes into the genes, and the next generation will be black.
>
> (Alan, 11th grade)

Nature is given intention, motives and wisdom:

> Influenza is installed by nature as a factor of selection in order to maintain the biological equilibrium in a biotope.
>
> (Statement in a written final leaving examination)

> But nature surely would not have produced bad bacteria if they were not useful for anything. If there are no bad bacteria, humankind would sometimes be overcrowded. Bad bacteria thus make the world a little bit larger again.
>
> (Gereon, 7th grade)

5.1.6 Valuation

The principle of valuation corresponds to human experience and the need to evaluate things and actions, especially by producing dichotomies; for example, 'The dominant gene suppresses the weak gene' and 'Bad – illness-generating – bacteria fight against good bacteria.'

> There are bad and good bacteria. The bad bacteria have hostile relationships towards humans. Thus they attack the body.'
>
> (Gereon, 7th grade)

This evaluation shows the need for harmony and thus also refers to the principle of tendency:

> Interspecific competition should be avoided under natural conditions, in order to maintain balanced conditions of life for all.
>
> (Insa, 13th grade)

5.2 Types of anthropomorphism

On the basis of our studies, three different types of anthropomorphism could be distinguished: animals, plants and the non-visible. The differences between these were only gradual and no clear cut definition was possible, but the three types represented typical examples. In the formation of anthropomorphic conceptions within these three domains, perception, social experience and imagination appeared to play different roles: animals were mainly conceptualised empathically, plants metaphorically and invisible things or processes purely imaginatively, with abstract entities (such life or nature) and invisible causes of processes (such microbes, genes and molecules) envisaged as acting like goal-directed people with their own will (personification).

With respect to animals, the common ground with humans was perceived as a result of overt similarities (evidence). Consequently, the traits of animals were mostly equated with human features, and social relationships among animals were presumed to be like those among humans. Differences between human and animal behaviour were hard to detect, as was shown previously in the interviews of Kamelger (2004) with 11–12-year-old students.

If plants are also acknowledged as living things, then they too can be seen to be similar to humans and consequently are anthropomorphised empathically (Cypionka 2005). In agreement with the results of Tamir and Zohar (1991), who studied 17-year-old students, Sieke (2005) show that even 13-year-old students were able to differentiate in their anthropomorphic expressions between the processes of plants and humans. She reported that when students suggests that ‘the plants drink’, they are aware that they are talking metaphorically, because they explain: ‘The plants do not drink like us, but they take water into their body.’ In general, it was obvious in their explanations that they understood the anthropomorphisms metaphorically.

With respect to invisible things and abstract processes, there are no features available that can be perceived by the senses as either similarities (as applies to animals) or persuasive differences (with respect to plants). Conceptions that have been formed primarily by direct experience and perception of the visible were therefore transferred into the non-visible, without immediately being understood as metaphors. These anthropomorphic conceptions corresponded to several of the reported basic principles (especially coherence, tendency and valuation). Abstract entities (such as life and nature) and effectors of (unexplained or little understood) processes (such as organisms, organs, genes and molecules) were personified and appeared as goal-oriented actors (see the following references for examples of microbes: Hilge 1999; Hörsch and Kattmann 2005; genes: Frerichs 1999; Kattmann *et al.* 2005; adaptation of organisms: Baalmann *et al.* 2004; Biebricher 2002; Huff 2002; the ‘wisdom’ of nature: Jelemenská 2006; Sander *et al.* 2006; the ‘wisdom’ of the body and organs: Focken-zum Buttel 2004; Schwegmann 2004; Sturm 2004). Anthropomorphic ideas about non-visible things and abstract processes seems to be necessary in order to make the non-concrete understandable. The lack of perception implies that anthropomorphisms are formed purely by imagination only.

6. CONCLUSIONS FOR LEARNING: ADEQUATE USE OF ANTHROPOMORPHISMS

The findings of the cross-case study can be discussed in several ways. On the basis of this study, it seems most appropriate to draw conclusions for the learning of biology. The three modes of anthropomorphic understanding lead to different consequences for learning and teaching of biology.

6.1 In the light of evolution

Empathically formed anthropomorphisms need not be a constraint to biological understanding, if the similarities between humans and animals are interpreted and differentiated evolutionarily. In his work, Charles Darwin made extensive but reflected use of anthropomorphisms in order to illustrate evolutionary continuity and the relationships between humans and other organisms (Kamelger 2004). In this way, Darwin’s anthropomorphic conceptions were limited to and justified by phylogenetic aspects. ‘Insight’ and ‘understanding’ as an ability of humans may well be applied to anthropomorphic apes, which can be justified by recent comparative studies of behaviour. This mode of using anthropomorphisms could also be applicable in biology teaching, if anthropomorphic pre-scientific conceptions are not immediately regarded as being inadequate, but are reflected in the light of evolution.

6.2 Metaphorical understanding

A metaphorical understanding of the processes taking place in plants can be an aid to learning: a reflected use of anthropomorphic terms may promote a view of plants as living beings and may even increase the students’ interest in plants by linking to the empathic aspects. Furthermore, the students should also be helped to reflect on their anthropomorphic understanding in other domains as an illustrative ‘as if’. On this basis, even empathically formed conceptions can be used to promote learning of scientific concepts. Thus, they can look at the naïve/realistic view and reach an epistemologically reflected knowledge (Jelemenská 2006). In this way, metaphorical understanding of anthropomorphisms should be an important aim of teaching (Langlet 2004: 56).

In aiming towards this goal, it will be necessary to substitute metaphors that are misleading in a certain biological context by more adequate ones. The reflected use of metaphors and terms is even more important with respect to emphatic and imaginative anthropomorphisms.

Conceptions of 'equilibrium', for example, are of special importance in biology and psychology. This is due to the fact that the necessity of maintaining balance is one of the basic and deeply imprinted experiences of humans. Who likes to lose equilibrium or balance? Therefore, it is understandable that ecological equilibrium has to be maintained. Scientifically and factually, the so-called ecological equilibrium is a series of disequilibria ('patch dynamics'; Sander *et al.* 2006). Oxygen-breathing organisms such as humans owe their existence to a long disequilibrium in the history of the earth when there was an imbalance in the production (photosynthesis) and mineralisation (bio-oxidation). As a consequence, large amounts of oxygen were released into the atmosphere (Sander *et al.* 2004). The importance of disequilibria can be demonstrated by a short exercise: 'Stand up and distribute the weight of your body equally on both of your feet (state of full balance or equilibrium). Keep the balance and move!' Keeping the balance totally, one cannot move at all. For walking, a series of slight disequilibria must be created. Metaphors qualifying the concept of equilibrium are 'movement', 'competition' and 'interaction'.

7. IMPLICATIONS FOR TEACHING

We cannot learn at all without anthropomorphic conceptions. Anthropomorphisms should not thus be excluded or set apart, but should be used in the teaching of biology. Nevertheless, teachers should recognise that – in a chosen context – some anthropomorphisms and metaphors are merely constraints, whilst others are more appropriate to promote the learning of biology. A real constraint in using anthropomorphisms lies in the verbal and direct misunderstanding of the metaphors so that they can lead to reification of knowledge: abstract mental constructs then take on a material existence as part of the reality of nature (Jelemenská 2006). This misunderstanding is also connected with some technical terms (Chew and Laubichler 2003). A suitable choice of metaphors and terms can be a decisive aid for sustainable learning (Watts and Bentley 1994). In this context, narratives are also suitable instruments for reflecting anthropomorphic imagination and factual biological knowledge (Nissen and Probst 1997; Cypionka and Cypionka 2004).

The 'speech' of genes gives an excellent example: because they cannot be perceived, they are easily personified. This is true for students and teaching, as well as for scientific books and technical terms (e.g. gene egoism, gene action and expression, etc.). Furthermore, genes are described with features they do not possess. We read and hear of 'diseased' and 'defective' genes, as well as 'dominant' and 'recessive' genes. In spite of this, genes and their traits must be strictly distinguished. The distinction of genotype and phenotype is essential for an adequate understanding of genetics: genes do not have the characters of the traits they determine: a gene that determines that a person gets blue eyes is not a gene with blue eyes. This misunderstanding can be scientifically corrected. Nevertheless, scientifically correct but abstract statements often remain without a sustainable effect for learning and teaching (Kattmann *et al.* 2005). A colloquial statement that provokes anthropomorphic imagination is more easily remembered: 'Genes are lacking in character.'

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2 Ten- to 13-year-old pupils' conceptions of hearing

Eva West, Björn Andersson and Florentina Lustig

DEPARTMENT OF EDUCATION, GÖTEBORG UNIVERSITY, SWEDEN

Eva.West@ped.gu.se

This paper reports on an investigation into pupils' conceptions of hearing before teaching, and is the first step in a project called 'Design and validation of a teaching sequence about sound, hearing and health' for pupils aged 10–13. There are a number of studies on pupils' conceptions of acoustic phenomena. However, very few take up the biological aspects of hearing. Ninety-two pupils were asked the question, 'What happens to a sound that has reached your ear?' They were asked to explain their thinking by drawing on a diagram and then explaining their drawing in writing. In addition, 26 of the pupils were interviewed. The method of analysis involved identifying and coding components of the answers, such as mention of the eardrum, parts of the middle and internal ear, nerves and the brain, as well as causal chains. This information was condensed into broader categories of description. It was shown that the majority of pupils included the brain in the process of hearing, even if they did not express any ideas about the structure of the ear and the mechanisms of hearing.

1. INTRODUCTION

High sound levels are becoming more and more frequent in young people's lives, and at the same time more and more people have impaired hearing conditions such as tinnitus. The problem is more serious among young people. The younger the child, the more sensitive they are to loud sounds. The National Swedish Board of Health and Welfare (Socialstyrelsen 2003) reported that children between the ages of 13 and 14 are more affected by high sound levels than those between the ages of 18 and 20. They proposed that precautions should be taken in order to maintain children's auditory health. There is a need for teaching at an early age, for example during the first two years at school, to support the possibility of children adopting an inappropriate attitude towards high sound levels and environmental noise. An additional report (Socialstyrelsen 2005) found that one in five 12-year-old Swedish pupils has suffered or suffers from some form of tinnitus after having listened to loud music or loud sounds. Many children and young people listen to equipment such as Mp3 players every day. As they do not always use them carefully enough, the hearing organs are often exposed to unnecessary stress. According to WHO (Berglund *et al.* 2000), the sound level of music that is listened to through headphones should not exceed 85 decibels.

In 2003, part of the Swedish national evaluation of compulsory schooling was a project investigating pupils' problem-solving skills (Kärrqvist and West 2005). One problem given to 12-year-olds was called 'the disco dilemma' and was about a disagreement about sound levels. Some pupils at a class disco wanted very loud music, whilst others wanted a more moderate sound. How could the dilemma be solved? In general, the pupils viewed the problem within a 'democratic' frame – how could they create justice and be fair to both groups? For example, they proposed that there should be one room with a very high sound level and one with a moderate level, or changes between high and moderate levels in the same room. They seldom questioned the aspect of health. Their problem-solving was not based on actual knowledge of the matter at issue, although part of the problem was a proposal to find out for themselves from various sources about the risk of damaging their hearing. In short, pupils did not seem to value scientific knowledge as being particularly important when they had to make decisions about sound levels. The question for this research was whether the pupils might have suggested other solutions if they had understood how the ear works and known about the sensitivity of the ear and the effects of sound levels.

Consequently, it is important that precautions are taken to make children conscious of the harmful effects of high sound levels at an early age in order to maintain their auditory health. Our hypothesis is that an understanding of the mechanism behind the sound phenomenon and the hearing process will make pupils more inclined to care for their auditory health. Thus, the teaching and learning of this subject are of great importance.

The question arises as to what methodology should be selected for this purpose. There is increasing interest in Europe in the 'design and validation of teaching sequences', and a special issue of the International Journal of Science Education (Meheut and Psillos, 2004) was devoted to this topic. Several groups in the world are now working on the development and improvement of this methodology, and we have adopted it for our work. Recently, Andersson and Bach (2005) and Andersson and Wallin (2006), researchers in our group, formulated some common steps in the design and validation of teaching sequences. According to these and other scientists, a prerequisite for the successful design of the teaching sequence and a good starting point is a deeper understanding of pupils' conceptions of the subject being taught.

This paper presents an investigation into pupils' conceptions of hearing. It is the first part of a project concerning the design and validation of a teaching sequence about sound, hearing and health for pupils aged 10–13 years. This teaching sequence is a Swedish contribution to the European project (2004–2007) in Comenius 2.1 Project with participants from six different countries.

2. BACKGROUND

There are a number of studies of pupils' and students' conceptions and learning of sound and hearing. Most have been concerned only with sound generation and propagation. Few have considered the mechanism of hearing, which requires the integration of several subjects for it to be understood. For example, Asoko *et al.* (1991) found, through interviews, that children and pupils between the ages of 4 and 16 lacked a general idea of the origin of sound, namely that sound is created by vibrations of a material object. The authors pointed out that such an idea is very important for the understanding of sound. However, they did not ask about the mechanism of sound propagation through the ear. Boyes and Stanisstreet (1991), in a study of pupils between the ages of 11 and 16, concluded that teaching is more effective when you put it into a system that consists of the source of the sound, propagation of the sound, and the structure of the ear, auditory nerve and brain. According to Driver *et al.* (1994), it is only when pupils understand that sound is vibrations of a material medium that they are able to understand the mechanism that governs hearing. To our knowledge, Watt and Russel (1990) are the only researchers who have provided explicit information about pupils' ideas of the process by which sound is perceived once it has entered the ear. The ear drum was mentioned by one-fifth of the upper juniors, aged 9–11 (n=84) and one-tenth of lower juniors, aged 7–9 (n=74). Some of these children mentioned vibrations set up in the eardrum. One pupil described bones within the ear. The apparatus contained within the internal ear to translate sound vibrations into neural impulses that travel to the brain was not mentioned in detail by any child. The brain was mentioned by one-tenth of lower and upper juniors.

3. RESEARCH QUESTIONS

The overall aim of this project was to determine to what extent a carefully designed teaching–learning sequence might improve pupils' understanding of the properties of sound, the function of the ear, and hearing and acoustic conditions that might cause damage. The study presented in this paper attempts to make a contribution to this overall aim by answering the question: What are 10–13-year-old pupils' conceptions of hearing?

4. METHODOLOGY

4.1 General methodology of the project

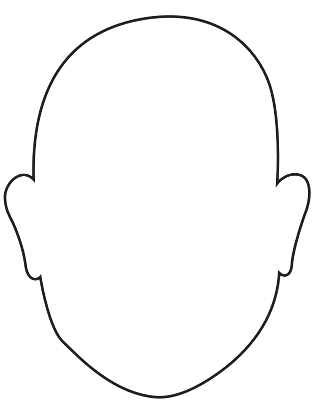
As indicated in the introduction, we used a methodology that is called 'Design and validation of teaching sequences'. One important step in the work is analysis of the pupils' conceptions, which in our work concerned the area of sound and hearing.

4.2 Pupils

Pupils from a middle-class school in a city on the west coast of Sweden participated in the study. The children had not previously had any formal teaching about hearing and the anatomy of the ear. There were 92 pupils, 47 aged 10–11 and 45 aged 12–13.

4.3 The present study

The teachers participating in our project distributed ten paper-and-pencil questions to the whole class and explained their need to learn what the pupils already knew about sound and hearing in order to plan further work. Most of the questions were in a multiple-choice format, followed by an invitation to the pupil to explain their choice. There was no time limit for doing this diagnostic pre-test. This paper deals with how the pupils answered one of the open-ended questions on the diagnostic pre-test, namely, 'What happens to sound that reaches the ear?' They were asked to explain their thinking by drawing on a diagram showing the contour of a head face-on, including the outer ears, and then trying to explain their drawing in writing (Figure 2.1).



HOW DO WE HEAR?

What happens to sound that reaches the ear? Draw what you think right now.

Write a short text to the picture that can explain how you were thinking when you were drawing.

Figure 2.1 The test question used in the study

In addition, 27 pupils were interviewed about what was going through their minds when they were answering the paper-and-pencil questions. There was a selection of pupils from different ability levels and from different age groups, and a balanced distribution of girls and boys. The purpose was to test the validity of the diagnostic pre-test. The interviews, of about 15 minutes each, were performed with one pupil at time and recorded with the permission of parents and pupils. The researcher and the pupil looked through the pupil's written answers and the pupil was asked to explain what the question was about. In addition, the pupil was asked to describe how they were thinking when trying to explain something in their own words. With reference to the actual questions, the same procedure was used concerning both the text and the drawing. The researcher was an active listener and, if necessary, asked for further clarification, but no new questions were introduced.

5. ANALYSIS

The analysis was based on both the written answers and the drawings. The drawings and the explanations were sorted and arranged in a ranked order that reflected different levels of understanding of the mechanism of hearing. Finally, we proposed five components that we could use to describe the pupils' answers. A particular answer corresponded to just one of these components or was a combination of two or more of them. The components were labelled A–E as follows.

5.1 Inclusion of the internal part/parts of the ear

Answers and/or drawings that included one or more parts of the middle or internal ear:

5.1.1 Component A: signs of anatomical structures

Answers that describe one or more part/parts of the middle and/or internal ear. This category also included answers or drawings where pupils clearly pointed out parts without mentioning the name of the part or where they put the wrong name for the part. For example:

- 'The sound comes into the ear into the eardrum which alarms the brain.' The pupil draws how a signal from a telephone passes through the eardrum and then proceeds to the brain.
- 'The sound comes into the ear and then it goes through the stable, and then the saddle and through the eardrum and the cochlea and then the sound is in contact with the brain.' There is a detailed drawing of all parts.
- 'The sound goes into the ear and reaches the eardrum and thereafter the ear bone and is caught.'

5.1.2 Component B: signs of transformation inside the ear from sound into impulses

Answers with an explicit idea of a mechanism where sound, described as 'vibrations', 'sound waves', etc., transforms into something else inside the ear such as 'signals', 'sent through nerves' or something similar. There are some simple explanations that give expressions of this mechanism; even if they do not use the correct scientific words, they are categorised here. For example:

- 'The sound goes to the eardrum, which sends signals to the brain.'
- 'The sound comes to your eardrum, which makes three small bones knock together, then this is sent through nerves to your brain.'

5.2 Inclusion of the brain in hearing

Answers and/or drawings that include the brain in hearing:

5.2.1 Component C: involvement of the brain in hearing

Answers where pupils draw or explain that the brain is involved in hearing. The brain is described in the sense of an anatomical structure or as a receiver. For example:

- 'The sound goes into the brain and then it disappears.'
- 'There are signals coming into the brain.'

The most elaborate answer allowed at this level was:

- 'The sound comes to the brain, which says what you have heard.'

5.2.2 Component D: signs of perception in the brain

Answers with explanations that indicate a process of perception in the brain. By this we mean that something is happening when a 'sound', a 'signal', a 'vibration' and so on reaches the brain. The answers clearly indicate something more than just hearing when the brain is involved. For example:

- 'The sound goes into the head to a place that tells the brain that someone is saying something. That place also says what voice the sound says.'
- 'The sound is captured by the ears and they send it further to the brain, which explains what you have heard.' This quotation is also illustrated by the pupil's drawing (Figure 2.2):

5.3 Component E: no answers or other answers that do not deal with hearing

Two of the researchers then separately and independently scored all of the drawings and the explanations that went with them. There was 84 per cent agreement of the scorings. In cases where

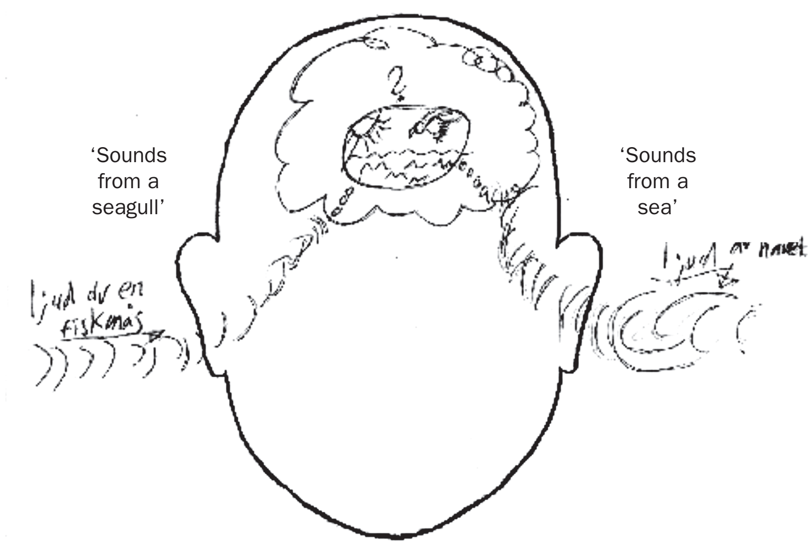


Figure 2.2 A seagull flying over the sea is drawn in the brain

views differed, each case was discussed until an agreement was reached. The differences were mostly about the interpretation of components B and D.

6. RESULTS

6.1 Components

All coded components are presented in Table 2.1, which gives an overview of the results.

Nearly two-thirds of the total number of pupils knew that the brain was involved in hearing (C). One-quarter mentioned or drew parts of the middle and/or internal ear (A), but there was a difference between the different age groups. Twice as many of the older pupils were aware of parts inside the ear. Few pupils had any idea about the transformation of sound inside the ear into something else, such as a signal (B). Three pupils showed signs of understanding the perception of signals in the brain (D).

6.2 Whole answers

Some answers could be described by just one of the four components, whilst others involved two or more components. This reflected going from a simple to a more advanced answer. The different categories of answers that we found are presented in Table 2.2.

Fifty per cent of the total number of answers only involved one component, mostly that the brain is involved in hearing (C only). It is likely that pupils in this category do not yet have any ideas of the importance of the internal parts of the ear. A typical drawing consisted of a line from the outer ear to some form of brain (Figure 2.3).

Table 2.1 How do we hear? Overview of the number of components in pupils' explanations (including drawings)

Component	*Age 10–11 (n=47)*	*Age 12–13 (n=45)*	*Total (n=92)*
A. Anatomical structures	9	17	26
B. Transformation of sound into impulses	3	3	6
C. Involvement of brain	29	30	59
D. Perception in brain	2	1	3
E. No/other answer	14	10	24

Table 2.2 How do we hear? Distribution by categories of number of answers

Category	*Age 10–11 (n=47)*	*Age 12–13 (n=45)*	*Total (n=92)*
A only	3	3	6
C only	23	17	40
A + B	1	2	3
A + C	3	11	14
C + D	1	1	2
A + B + C	1	1	2
A + B + C + D	1	0	1

Figure 2.3 This drawing shows the connection between the ear and the brain. Thus, the pupil means that the sound comes through the ear. The text written by the pupil translates as: 'The sounds come into the brain'

The older pupils were more often aware of the link between the internal parts of ear and the brain than the younger ones (A+C). See Figure 2.4 for an example.

There were a few pupils who also connected the brain to perception (C+D). About 10 per cent did not mention the brain at all; they thought only of parts of the ear (A only) or went a little further and showed signs of understanding sound transformation (A+B). You could say that, according to their answers, hearing ends in the ear. There were three answers that indicated a good understanding. Two showed a causal chain, including parts inside the ear, transformation of the sound inside the ear and a signal of some type that moved to the brain (A+B+C). The third answer, from an 11-year-old boy, also included the implication of perception in the brain (A+B+C+D): 'The sound/vibrations goes into the ear and then to the small bones and then the vibrations go through the cochlea, which sends a signal up to the brain, and then the brain finds out what the other person says.'

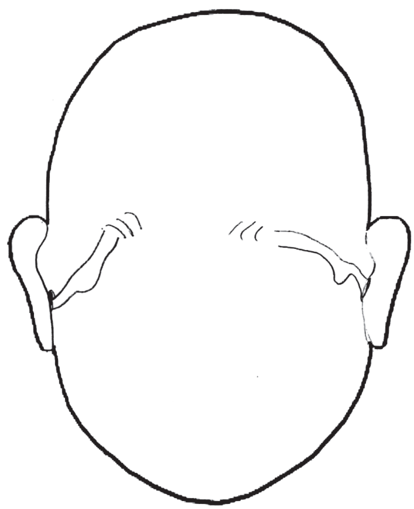
6.3 Anatomical structures

Those drawings/explanations that included parts of the middle and/or internal ear most often mentioned the eardrum. However, other parts were also mentioned (see Table 2.3 for an overview).

A quarter of all pupils were conscious of the eardrum, and of these there were twice as many in the age group 12–13 years. About 10 per cent in both groups included parts of the middle ear.

Hur hör vi?

Vad händer med ett ljud som har nått örat? Rita hur du tänker just nu



Skriv en liten text till bilden som kan förklara hur du tänkt när du ritat

Ljudet kommer in igenom örat och sen till trumhinnan
som reglerar ljudet och sedan vidare till hjärnan.

Figure 2.4 'The sound comes through the ear and then to the eardrum, which regulates the sound and then it goes further on to the brain.' The drawing concerns the eardrum, but the text also describes the connection with the brain

However, there was some confusion about terminology. In Swedish schools, the terms malleus, incus and stapes are not used. Instead, the Swedish words corresponding to hammer, anvil and stirrup are commonly used. This probably explains why some pupils described the malleus as a hammer and why some others claimed that there was a saddle and a stable in the internal part of the ear. One pupil described how the malleus hits a drum. These answers were categorised as 'everyday meanings'.

There were 12 per cent, mainly in the older group, who were aware of the cochlea. No one mentioned the sensory cells of the cochlea, the hair cells, although one pupil may have been aware of them; it was a question of interpretation. 'There are a lot of hearing things and if somebody screams very loudly it might happen that a thing is destroyed!' One pupil used the term nerve for the connection between the ear and the brain. There were other words and phrases for this connection such as 'flex', 'the sound goes', 'signal' and 'sound waves'. Most pupils showed the connection in their drawings using different illustrations, the most common simply being a line.

There were pupils who mentioned two or more parts and as a result they were included in the counts for each structure in Table 2.3. An example of an answer with several anatomical structures is given in Figure 2.5.

Three pupils said that there was a 'sound' or 'signal' back to the ear. This is actually true, as there are electrical signals from the brain to small muscles inside the middle ear and there are also some

Table 2.3 Number of pupils who mentioned different anatomical structures in the middle and/or internal ear in their drawings and/or writing

Anatomic structure	*Age 10–11 (n=47)*	*Age 12–13 (n=45)*	*Total (n=92)*
Eardrum	7	15	22
Ossicles generally	5	0	5
Malleus	2	2	4
Incus	0	0	0
Stapes	0	0	0
Everyday meaning of ossicles	0	5	5
Cochlea	2	9	11

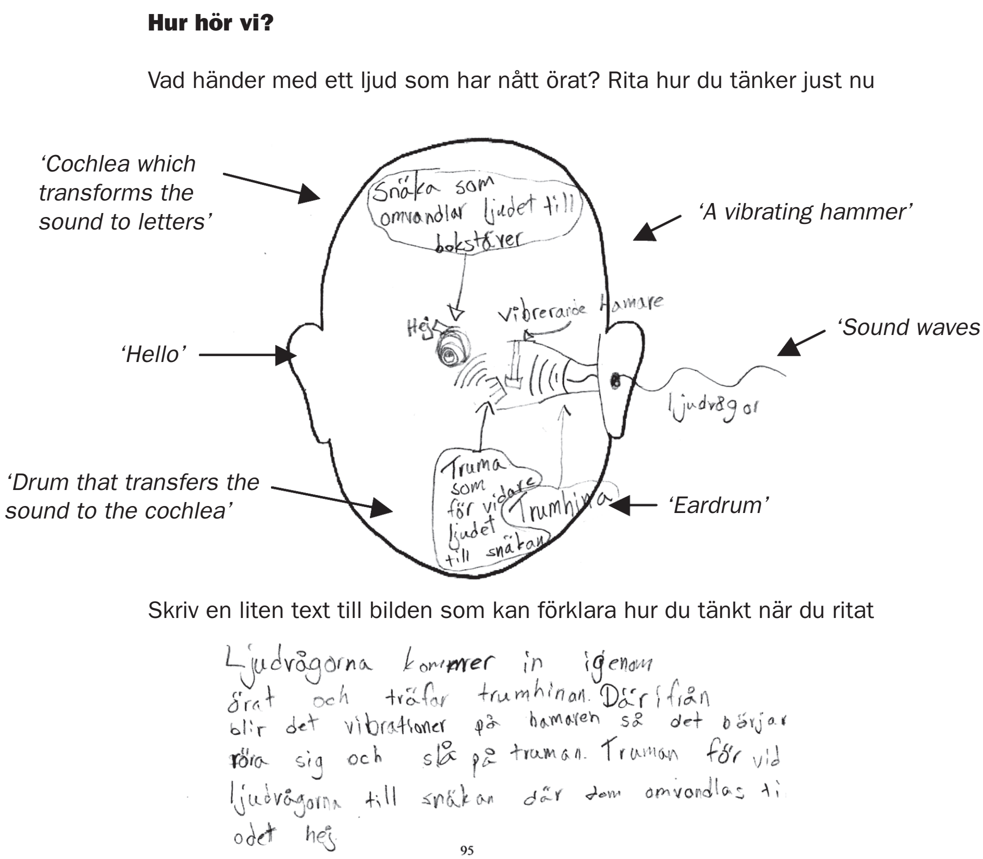


Figure 2.5 An example of a pupil who is aware of parts in the middle and internal ear, although there are expressions of some structures using words with everyday meanings. This pupil does not include the brain in the process of hearing

signals to the membranes of the hair cells in the cochlea. However, most signals go from the ear to the brain.

6.4 Interviews

The interviews showed that 77 per cent of the pupils (20/26) described exactly the same components as in their drawings and written explanations at the start. Three of the pupils, who had shown no ideas about hearing in the pre-test, expressed during the interview that they were in fact aware of the role of the brain in hearing. Two pupils, who initially only mentioned the brain, explained later that there were also structures in the ear that were important. One pupil started with structures in the ear, but in the interview he also added the brain.

We concluded that approximately three-quarters of all pupils could demonstrate a valid picture of their preconceptions concerning hearing and the mechanism of hearing in the paper-and-pencil test, whilst the rest probably knew more than could be seen from their pre-test results.

7. DISCUSSION

The problem-solving part of the Swedish national evaluation 2003 (Kärrqvist and West 2005) showed that pupils aged 11–12 generally do not take scientific knowledge into consideration when they have to make a decision about the sound level at a disco. A prerequisite for using scientific knowledge in this context is that the pupils have had an opportunity to learn something about sound, hearing and how to protect the auditory health of themselves and others. Socialstyrelsen (2003, 2005) pointed out the problem of tinnitus among young people, and they proposed teaching related issues at an early age. The results of our study indicate some key ideas about teaching this subject. To support the pupils' conceptions of hearing, there is a need for an understanding of the connecting link from external sound through the ear and into the brain. How can you understand why it is important adopt a cautious attitude if you do not know that there are structures inside the ear that you have to look after? Fifty per cent of the pupils in this study did not involve the internal parts of the ear in hearing, although they mentioned the brain. More pupils mentioned the brain in this study than in a study reported by Watt and Russel (1990), who showed that about 10 per cent of the pupils included the brain. A quarter of the pupils were conscious of the eardrum, and of these there were twice as many in the age group 12–13 years. About 10 per cent included parts of the middle ear. These results have scorings somewhat higher than the study of Watt and Russel (1990). There is no need for detailed knowledge of all anatomical structures, including their names, even though discussion of the terminology might be fruitful. Function is necessary before detailed knowledge.

None of the pupils mentioned the sensory cells in the cochlea. We believe that pupils who have learned that there are sensitive hearing receptors, hair cells, inside the internal ear might improve their awareness of auditory health. This part of the ear is crucial in issues of tinnitus, as the transformation of sound from vibrations into neural impulses occurs in these cells. It is important to have an idea of how vibrations from loud sounds are related to the risk of damage to the hair cells. Another significant piece of information is the fact that damage can occur without a feeling of pain. We do not mean that the teacher should discuss all of this at an advanced level at these ages, such as explaining the structure of cells or how neural impulses function. However, we regard an understanding of the function of the ear as one important contribution to supporting pupils' care for their own auditory health and that of others.

It might interest the pupils to include perception in the brain when learning about hearing. Very few pupils in our study were aware of this mechanism; rather, they thought of the brain as a receiver. Perception in the brain has in itself a subordinate importance compared with the understanding of hair cells to prevent tinnitus. We also believe, like Asoko *et al.* (1991), Boyes and Stanisstreet (1991) and Driver *et al.* (1994), that there is a need for pupils to learn about sound in the physical sense to be able to understand the mechanism that governs hearing, i.e. that sound is vibrations of matter and that these vibrations are propagated through the air and into the ear. The question of sound levels, and thereby the teaching of hearing, is in consequence a question of integration of different school subjects, but it is also a question of science for all and scientific literacy. In Sweden, teaching about the ear and hearing is generally separated from teaching about sound and sound propagation.

Our teaching–learning sequence integrates school subjects such as biology, physics and chemistry. Other subjects can also be included, for instance, music and technology. We believe that such integration into the field of sound, hearing and health is necessary in order to create a holistic picture. Our sequence is an example of applying a humanistic perspective in science education (Aikenhead 2006). Aikenhead includes such aspects as citizenship, preparation for the everyday world and moral reasoning integrated with values, human concerns and scientific reasoning.

The area of auditory health is an urgent societal issue, and work at school must also comprise discussions of high sound levels and the pupils' values within this area. If the pupils are given the opportunity to do this, we think their awareness of their own and other's auditory health will increase, as well as their inclination to take protective action when needed. Further studies will report on children's learning within this area, as well as their attitudes to high sound levels before and after teaching.

Acknowledgements

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3 Understanding the units of nature: from reification to reflection. A contribution to educational reconstruction in the field of ecology

Patrícia Jelemenská[1] and Ulrich Kattmann[2]

[1]NATIONAL INSTITUTE FOR EDUCATION, BRATISLAVA, SLOVAKIA;
[2]CARL VON OSSIETZKY UNIVERSITY OF OLDENBURG, OLDENBURG, GERMANY

patricia.jelemenska@uni-oldenburg.de; ulrich.kattmann@uni-oldenburg.de

This paper focuses on students' and scientific understanding of the concept 'ecosystem', its ontological status (objective-real or conceptually constructed) and the reflection of epistemological beliefs. The study was conducted within the frame of the 'model of educational reconstruction', which consists of three closely interrelated tasks: (1) investigation of students' conceptions; (2) scientific clarification; and (3) design of learning environments (Jelemenská 2006). The conceptions of scientists and students were not separated categorically as 'alternative' and 'scientific', but rather common ground and the reasons for conceptions were identified. By distinguishing in understanding between objective-real and conceptually constructed understanding, the common ground and the differences between the conceptions of students and scientists could be understood within an epistemological perspective: it was assumed that contrasting conceptions could be caused by (deficient) epistemological considerations. The results of the study showed that students' conceptions were essentially similar to the conceptions of the scientists. The principles (or ideas) of 'encapsis', 'self-preservation' and 'goal-directed development' were significant for the definition of the units of nature. Some scientists also showed reflected understanding of ecological units: this included a reflection on contradictions and values. This therefore can be treated as a general aim of teaching and learning. Thus, conceptions of reification should be taken as prerequisites for learning.

1. INTRODUCTION

Students' epistemological beliefs about the nature of science have long been a topic of science education. Furthermore, it has been shown that students' epistemological beliefs about the nature of science and methods have an important influence on their learning (Moss 2001; Urhahne and Hopf 2004). For teaching, the following questions are important: (1) What are the causes of the differences in the 'learning strategies' of the students? and (2) How do the students reach an understanding of the scientific knowledge as mentally constructed? An empirical study shows that it is useful to assess individuals' commitment to constructivist versus positivistic epistemological views: 'Learners who are more constructivistic in their epistemological orientation are also more likely to employ meaningful learning strategies than learners who are more positivistic in their orientation' (Novak 2005: 37). It is important to understand the extent to which instruction for learning can be conducive to self-reflection and the effect that this has on an understanding of the nature of science. In this paper, we consider the interrelationship between epistemology and scientific content in order to reflect on the consequences for both learning and teaching.

2. STARTING POINT OF THE STUDY AND RESEARCH QUESTIONS

The technical term 'ecosystem' is the one most used in ecology (Cherrett 1989), but its necessity is also questioned most frequently. Critics look not only at the multiple definitions but also at the criteria (e.g. topography, functional characteristics of homeostasis, ability to regulate, etc.) used in the formation of the concept (Jax 2002). The definitions of ecosystem depend on the perception of nature and this is reflected by technical terms. This can be shown by the following example. In textbooks, there are different definitions of the concepts of 'community' and 'ecosystem'. Usually, community is defined as 'all of the organisms living in an area', whilst 'the community and the abiotic components' together are said to constitute an ecosystem (e.g. Odum 1999; Campbell and Reece 2002). It is problematic to define an ecosystem as an area (biotope) if the connections between the organisms are being emphasised, as the organisms may go beyond the borders of the defined area (Jax 2002; Knight *et al.* 2005). Separation of the community from the abiotic components has also been criticised (Begon *et al.* 1996). Such criticism corresponds to the ideas of Tansley (1935). He criticised the holistic conception of the perception of nature and proposed an empirically based conception of the units of nature. In this perspective, Tansley introduced the technical term 'ecosystem' into ecology. However, from another point of view, this term becomes superfluous, as the community cannot be separated from the abiotic components of the environment (Begon *et al.* 1996).

Disagreement can be found not only in the concepts of an ecosystem, but also in the historical interpretations of the ecosystem concept. Golley (1993) interpreted this as a differentiation of the ecosystem concept, whilst Jax (2002) has criticised the holistic conceptions of, for example, Odum, Friederichs and Golley, and juxtaposes them to the ecosystem concept of Tansley. The approach of Jax is determined by his epistemological perspective. He differentiates between an epistemological belief (ecological units are mentally constructed) and an ontological belief (units are real entities).

Starting from this view, one should be aware of the interrelationship between epistemology and ontology; for example, the epistemological perspective of naïve realism determines the ontological beliefs concerning the reality of ecological units. Therefore, the connection between epistemological perspectives and statements about the ontology should be considered (Jelemenská 2006).

The meaning of the concept of 'ecosystem' can only be demonstrated in relation to other ecological units. Therefore, the interrelationships between the units must also be considered. It is important to understand how the epistemological beliefs influence the statements about 'ecosystem' and 'community'. Our research questions were thus:

1. What are the conceptions of 'biocoenosis', 'ecosystem' and 'earth as an ecosystem'?
2. What are the differences among these conceptions?
3. Which ontological status (objective-real or conceptually constructed) is connected with the (ecological) units?
4. Which epistemological understanding and values are connected with the (ecological) units?

The concept formation emerges from the perception of nature: it is evident that students construct preconceptions on their own before they receive scientific instruction (pre-instructional and pre-scientific conceptions). These conceptions are fundamental for learning. The results of this study should therefore lead to useful suggestions for the improvement of biology instruction in the field of ecology.

3. THEORETICAL FRAMEWORKS AND METHODS

3.1 Theoretical framework

The study follows the 'model of educational reconstruction' (Kattmann *et al.* 1997; Duit *et al.* 2005), which offers a theoretical framework for planning and conducting educational research. The components of the model are (1) an understanding of students' conceptions; (2) scientific clarification; and (3) design of learning environments. Students' conceptions are systematically related to scientific conceptions in order to develop learning environments for more effective learning. The aim of the study was to enhance ecological teaching to enable students to understand ecological concepts and their theoretical background adequately.

The model of educational reconstruction implies that the mutual relationships and the common ground of scientific and students' conceptions are a decisive basis for educational conclusions that will lead to a significant and fruitful understanding of the subject. If the common ground in epistemology of the scientists and the students can be identified, the validity and reliability of the ecological conceptions can be evaluated. We assumed that any common ground among the conceptions indicated the same basis of understanding.

From this point of view, we interpreted the common ground between students' and scientific conceptions as emphasising two kinds of knowledge formation: reification and reflection. For example, if the concept of ecosystem was understood as an area with visible boundaries, the concept in nature was reified: visible boundaries, that we can perceive or imagine, are taken as self-evident criteria for the definition of the concept 'ecosystem'.

'Reification of knowledge' was taken to mean equalisation of perception and reality. If the limitations and premises of the reifying perspective and processes were acknowledged, we referred to this as reflected knowledge.

'Reflection of knowledge' was thus taken to mean recognition that concepts are mentally constructed units. This cognition must be distinguished from reality. Ecological systems therefore are mental constructs and are not real units of nature.

3.2 Methods

For educational structuring, it is important to identify empirically the contexts in which students can reflect on their own understanding.

3.2.1 Scientific clarification

In this respect, the choice of scientific sources was important. Because formation of the concepts of 'ecosystem' and 'community' depends on the underlying epistemology, we chose sources with different argumentations. Karl Friederichs (1937) is a historical German ecologist, who offers a classical holistic view of the ecological units. The British ecologist Arthur G. Tansley (1935) criticised this point of view and introduced the term 'ecosystem' in the sense of an empirical research programme of interactions between the components. Eugen P. Odum (1999), a leading American ecologist, represents a cybernetic conception of ecosystems. Ecologists understand the concept 'ecosystem' mainly from a local perspective, e.g. forests and lakes. James Lovelock (1988) replaced this view by his global perspective of Gaia. The main emphasis of scientific clarification of the sources was laid on the research interest and the argumentations of the authors. In this respect, the source of Kurt Jax (2002), a German theoretical ecologist, was of special importance, in which several definitions of the units of nature are analysed from the view of constructivism in order to clarify the ecological muddle in terminology.

3.2.2 Comprehension of students' conceptions

To understand students' conceptions, a combination of qualitative methods was used: problem-centred interviews (PCIs) and concept-net interviews (CNIs, a modification of concept mapping; see below). For the interviews, guidelines were constructed that were oriented on the research questions and modified by preliminary results of the scientific clarification (Gropengießer 2001). The students were asked to describe the units of nature within the perspectives of space (levels of organisation) and time (history of the Earth). Interview partners were 16–17-year-old students. The investigation into students' conceptions was conducted in Germany and Slovakia in order to gain a deeper insight into the connections between the world of thinking and the world of speech, especially concerning conceptions of everyday life. In order to receive a wide spectrum of conceptions, students with different experiences of nature were chosen. In the qualitative study, six students were investigated using both methods (three from Germany and three from Slovakia).

The guidelines of the PCI included questions concerning the units of nature – described from a local (e.g. a forest) to a global perspective and from the current time back to the evolution of the Earth, i.e. comprehension of the meaning of terms such as 'community', 'ecosystem' and 'Earth as an ecosystem'. Pictures were used as materials in the interviews in order to clarify conceptions or technical terms. Three months after the PCIs, the CNIs were conducted. In theses interviews, concept nets were created with the student. The understanding of technical terms was checked explicitly.

The 'concept-net' procedure is different from that of concept mapping: the concept map is an instrument for measuring the differentiation of knowledge (Novak 2005). Consequently, the absence of knowledge is evaluated as a cause of a student's inability to solve a problem. The method of concept mapping focuses on scientific understanding, e.g. the holistic definition of ecosystem (e.g. Assaraf and Orion 2005). Reification of systems is not questioned using this method, because the method is adequate to analyse the knowledge of a student within the limits of a scientific theory. In contrast to this, in our study, a deeper understanding of the concepts and comprehension of students' epistemological orientations was required. The specificity of personal conceptions – and not only their differentiation in comparison with scientific ones – is important as a basis for future learning. For this reason, the method of creating a 'concept net' was developed. The students considered the relationships in nature and explained their understanding of the concepts. Using the concept net, the students' understanding of a concept could be visualised and explained. In this way, the personal ecological concepts could be shown, contradictions in certain contexts became obvious and the necessity of terms could be questioned. Students had the opportunity to challenge their own conceptions.

3.2.3 Processing

The data from the interviews were interpreted and evaluated using qualitative content analysis (Mayring 2000; modified by Gropengießer 2001). Using this method, the material ascertained in the interviews was condensed, interpreted and analysed in a systematic and verifiable way. The method of qualitative content analysis was also applied to the scientific clarification. After all interviews and the selected scientific literature had been analysed by the qualitative content analysis, the conceptions gained within this structure were compared.

3.2.4 Generalisation

The interpretation of conceptions could be generalised with respect to two aspects: firstly, similarities in the argumentations of students and scientists were identified to show the differences between reification of knowledge and reflection of knowledge; and secondly, the causes of the reification of knowledge were interpreted through the theory of empirical realism (Lakoff and Johnson 2003, as modified by Gropengießer 2003).

4. MAIN RESULTS

4.1 Students' conceptions

As described above, two types of interview (PCI and CNI) were used. Anchor citations (PCI) and concept nets (CNI) are provided below as examples to demonstrate the conceptions of ecosystem of two students (Martin and Ada) and to compare and contrast them.

Martin's conception of 'ecosystem' in the PCI was as follows:

> I termed it ecosystem because in the characterised region plants and animals are living under similar conditions . . . I can imagine that an ecosystem is a certain region in which selected plants and animals are living. At the margins of an ecosystem there may be a sort of transition . . . Earth is a large ecosystem that is composed of smaller ones. Actually an ecosystem is a larger region that has no fixed connection with the surroundings. Actually it is an autonomous and independent unit.

His concept net is shown in Figure 3.1.

Ada's conception of 'ecosystem' in the PCI was:

> I like to speak of an ecosystem as if there is a regulated circulation present, i.e. a circulation including living beings which live there regulated.

In the CNI, she produced the concept net shown in Figure 3.2 and stated that 'An ecosystem is a balance in ecology. You have got a regulated circulation of dependencies.'

The concept nets were particularly useful to illustrate the differences in argumentation of individual students. Both students linked the concept of 'ecosystem' to a *characteristic combination of species of plants and animals* living in it. However, there were also important visible differences. Martin viewed an 'ecosystem' as an ecological unit of a higher level, which is ordered in a sequence of systems with spatial boundaries and encapsis, i.e. the smaller systems are encapsulated within the larger ones. In contrast, Ada understood an 'ecosystem' as forming an ecological equilibrium of interdependent, regulated parts: in her concept net, this was shown as (a) smaller ecosystems, (b) groups of organisms and (c) organisms and environmental factors.

Most of the students interviewed believed that the concept of balance is a central feature of ecological units, especially of ecosystems. The interdependencies of organisms were stressed as a characteristic of ecosystems but even more as a feature of communities (of living things). The differences in the understanding of the students were caused by two divergent orientations: space and limits versus interdependence and balance. The conceptions of ecological units could therefore be related to two principles: 'container in a container and interaction' and 'preservation of life'.

In general, some data from the interviews were congruent with those of earlier studies and thus confirmed their results. The holistic view contained the following aspects: orientation on equilibrium

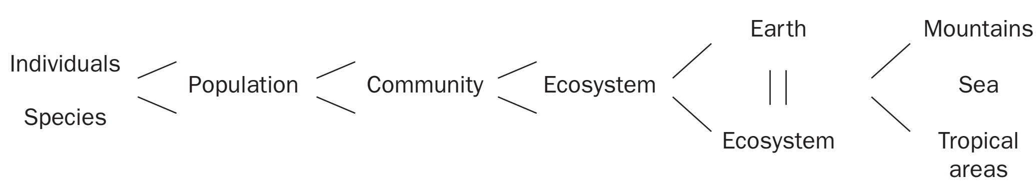

Figure 3.1 Martin's concept net for an 'ecosystem'

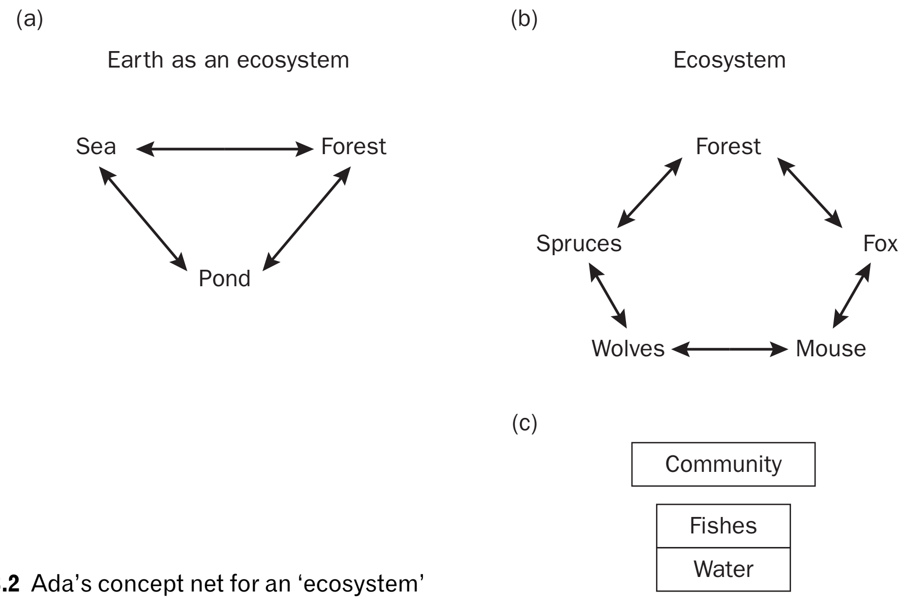

Figure 3.2 Ada's concept net for an 'ecosystem'

(Sander 2002), difficulties in grasping the nature of circulation, perceptions of abiotic components (Assaraf and Orion 2005), the aims of nature (Grotzer and Bell Basca 2003), anthropomorphisms (Leach *et al.* 1995) and difficulties in distinguishing the different concepts (Adeniyi 1985). We also found the following new and differentiated conceptions (Jelemenská 2006; Sander *et al.* 2006):

1. The students articulated differentiated conceptions concerning cooperation and interaction of the biotic and abiotic components, including dynamic processes caused by interaction of the components.
2. 'Earth' was understood as the global ecosystem. There were differences in understanding when students spoke about the Earth in the present time or the history of the Earth in terms of geology. Thus, the balance of nature was understood to preserve the present-day equilibrium of life, but natural change preserved life in the history of the Earth.
3. Reasons were given for the understanding of 'ecosystem' and 'biotic community' as synonyms, i.e. identical units.
4. Using a global perspective, nutritional relationships were complemented by the flow of matter. Thus, the autonomy of ecosystems was questioned. Using a local perspective, the students also qualified the autonomy of ecosystems by the distribution of animals.
5. The understanding of the students of the reification of the units of nature was apparent without exceptions: contradictions in their own conceptions were minimally reflected. The students defined ecosystems by space and boundaries, and they thought that life as it is today will not change, except as a result of the action of humans.

4.2 Common conceptions of students and scientists

Students' conceptions were essentially similar to the conceptions of the scientists studied. In all of the analysed sources (scientific ones included), views of reification were identified. The causes of reification were based on self-evident perception of nature and on self-evident correspondence with language (verbal interpretation of terms). In the following section, we discuss some of the similarities using four pairs of conceptions as examples (see Table 3.1).

The principles (or ideas) of ‘encapsis’, ‘self-preservation’ and ‘goal-directed development’ were significant for the *reification* of the units of nature. The conceptions of ‘encapsis and integration’ (scientists) and ‘container in a container and interaction’ (students) showed that the concepts of community, ecosystems and the Earth as an ecosystem were visualised as nesting within each other (see Martin’s example). Visual boundaries of a unit were used by both scientists (Odum and Friederichs) and students to back up the plausibility of the definitions of the ecological units. Odum used the metaphor of ‘china boxes’ and one student used the metaphor of a ‘body as a container’ to demonstrate their spatial container conceptions. The students distinguished the concepts of ‘community’ and ‘ecosystem’ on the basis of size.

The conceptions of ecological units were also connected with that of the ‘food chain’ and the ‘flow of matter and energy’. In this context, some differences between students and scientists could be found. Students expressed the relationship between organisms, as well as those of organisms with the biotope, as anthropomorphisms of ‘home’ and the ‘basic needs of life’ (similar to Friederichs 1937). For Odum (1999), the relationships in ecosystems were differentiated: the complete cycles of matter and the relative autonomy of ecosystems were important as central themes.

Reification was most clearly identified in the two conceptions of ‘preservation and homoeostasis’ (scientists) and ‘preservation of life’ (students). From the students’ point of view, the ecological systems were seen as units of nature: they overtly reified the systems. Furthermore, nature was personified by the students and their conceptions were linked to values and order: mainly, a purposeful cooperation of the components was taken for granted, serving to benefit the ‘whole’. This conception can also be found in Friederichs (1937).

In a modified version, this could be also identified in the conceptions of Odum (1999) and Lovelock (1988). They used technomorphic and physicomorphic (instead of anthropomorphic) analogies in describing or postulating ‘preservation and homoeostasis’ of systems.

Some students took the principle of ‘preservation of life’ into account to differentiate between the concepts of ecosystem and community. From this point of view, the concept of community could be seen as superfluous.

Table 3.1 Common ground in the conceptions of students and scientists

Knowledge	*Scientists’ conceptions*	*Students’ conceptions*
Reification	‘Encapsis and integration’ (central to Friederichs 1937, Odum 1999 and partly to Tansley 1935)	‘Container in a container and interaction’ (used by all students but one; central to Martin)
	‘Preservation and homoeostasis’ (central to Friederichs 1937 and Odum 1999)	‘Preservation of life’ (used by all students; central to Anne and Ada)
	‘Goal-directed development’ (central to Friederichs 1937 and Odum 1999 and partly to Tansley 1935)	
Reflection	‘Unity of biotic and abiotic components’ (Tansley 1935)	Anthropomorphic emphasis: ‘unity of biotic and abiotic components’ (used by all students; central to Tom and Martin)

Among the scientists, there were only a few epistemologically 'reflected' conceptions. Tansley (1935) came closest to a reflected understanding (but even he did not totally avoid reification; see Jelemenská 2006).

Tansley criticised the opinion of holism that the 'whole' is the cause of the features and dynamics of the entity. In this opinion, a system is not characterised by self-regulation. The causes of the development of plant communities should be empirically understood. To describe the processes of succession, one must think of the 'unity of biotic and abiotic components'. The biotic components can be isolated from abiotic ones only mentally. The factors that are important as causes of succession (e.g. fire, animals) must be identified empirically. For the new epistemological view, he introduced the new limitation of 'ecosystem'. Tansley emphasised that the unit 'ecosystem' can be understood only as a mental isolate (construct).

For the students, as well as for Tansley, the principle of 'unity of biotic and abiotic components' was important. Some students linked the biotic and abiotic components together but in an anthropomorphic manner. Oxygen was seen as a requirement for life in general (especially for humans); the habitat was understood as 'home'. The connection between the biotic and the abiotic components was interpreted as full dependence on each other.

5. DESIGN OF LEARNING ENVIRONMENTS

As a result of studies in educational reconstruction by the Oldenburg biology education group, we prefer to speak of 'conceptual reconstruction' instead of conceptual change or growth: the task of students is to repeatedly construct new conceptions, not to abandon or substitute their conceptions or to add new conceptions to the old ones. Further studies have shown the importance of the change in perspectives and the specific effects of the context or domain for the development of guidelines for education (spatial and temporal change: Sander *et al.* 2006; context of genetics and evolution: Baalmann *et al.* 2005). The idea of 'conceptual reconstruction' should also be shown in an epistemological perspective.

As a general aim of teaching and learning, we define reflected knowledge, which includes the reflection of reification, contradictions and values in scientific and students' conceptions. It is essential that the students also recognise the discrepancies within their own conceptions. Therefore, several interpretations of the concepts should be compared under different perspectives and applied to scientific problems. For teaching, contexts that facilitate acknowledging the concepts as mental constructs are the most important.

To illustrate how the overall aim can be reached, three of the guidelines developed for the teaching of ecology are presented below.

5.1 Guideline 1: From reification to reflection

Result: Students' conceptions are characterised by the reification of knowledge.
Aim: Students should understand the ecological concepts as mental constructs.

Reification and reflection of knowledge should be a topic of science instruction. The perception of nature as real and self-evident by Friederichs (1937) contradicted the arguments of Tansley (1935). Tansley demonstrated the limitations and implications of holistic conceptions. The students should acknowledge that the conceptions of Tansley and Friederichs were developed at the same time on the basis of different beliefs and that consequently the concepts of ecological systems are mental constructs.

Using the concept of ecosystem put forward by Odum (1999), it can be shown that this is oriented towards values relevant to society. The definition of the concept of ecosystem is important for the calculation of the productivity of ecosystems. This interest is analogous to the emphatic conceptions of students ('preservation of life'). The dependence on interests shows that the definitions of ecosystem do not provide one with an objective picture of nature.

Accordingly, the history of the concept of an ecosystem cannot be explained as an accumulation of knowledge. Instead, the continuity and the change in concepts can be shown historically by their individual, scientific and social acceptance.

5.2 Guideline 2: Let students experience the change in perspective and the selection of adequate terms (negotiation of meanings)

Result: Depending on the perception of nature, the students distinguished the concepts of community and ecosystem (size) or treated them synonymously (balance). Those students who treated the criterion of balance of ecosystems as important thought the idea of 'community' unnecessary.

Aim: By negotiation of meanings, the epistemological perspectives should be acknowledged and the nature of science demonstrated as a process of acquisition of reflected knowledge.

Controversies in ecology and the discrepancy of argumentations of students should be interpreted as effects of different perspectives. The method of creating a 'concept net' can be useful for the perception of discrepancies, implications and limitations of conceptions.

5.3 Guideline 3: Reflect the concept of ecosystem as an area with links across the borders

Result: Students take the area but also the connections between ecosystems into account. In their view, cooperation rather than predation is important for the 'preservation of life'.

Aim: The epistemological perspectives should be pointed out: objective views of nature are impossible.

The study of Knight *et al.* (2005) provides an instructive example of the limitations of the spatial concept of ecosystem. The authors showed empirically that the ecological effects of organisms can also have major consequences for community dynamics across ecosystem boundaries. The authors demonstrated that freshwater fish indirectly promote plant reproduction (see Figure 3.3).

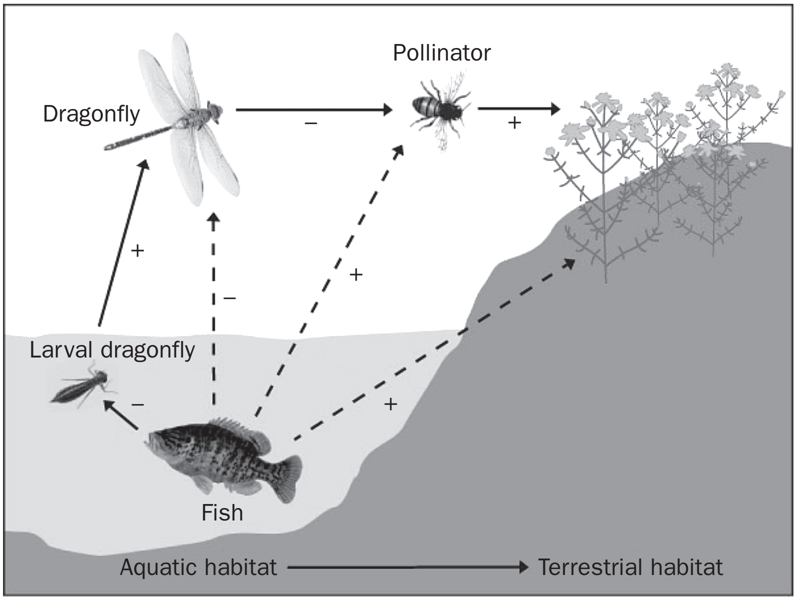

Figure 3.3 Synecological cascades across ecosystems (adapted from Knight *et al.* 2005)

A motivating introductory question might be: Do fish affect the pollination of terrestrial plants? The answer of the authors runs as follows: Fish predation often strongly limits the abundance of larval odonates (dragonflies) in aquatic habitats. The more fish, the fewer adult dragonflies. Adult dragonflies limit the population of pollinators. The fewer adult dragonflies, the greater the number of pollinating insects (bees and hoverflies). The more pollinators, the more seeds are produced by the pollinated plants. Plants near ponds with fish receive more visits from pollinators than plants near fish-free ponds. Result: Fish can affect the pollination of plants.

Instead of antagonistic interactions between species such as predation, this is a view on mutualism, which corresponds to the emphatic conceptions of the students. Instead of boundaries and balance in nature, the example emphasises dynamic relationships across the borders of aquatic and terrestrial ecosystems. By considering the changes in populations of several species, students can also learn more about the life history of the organisms.

These guidelines should be investigated and modified by further teaching.

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4 Rheumatic patients' conceptions of their disease: improvement of patient–physician communication

Cornelia Sander and Dirk Krüger

DEPARTMENT OF BIOLOGY, CHEMISTRY, AND PHARMACY, FREIE UNIVERSITÄT BERLIN, GERMANY

csander@zedat.fu-berlin.de; dkrueger@zedat.fu-berlin.de

Biology education is not limited to school or university. In every situation where people acquire basic knowledge of biological processes, biology didactics can improve teaching, learning and understanding. In medical consultations, it is important for the patients to understand basic biological processes to comprehend their disease pattern and the necessity for a certain treatment. In this study, educational concepts were constructed on the basis of patients' individual disease conceptions. Thirty-four patients with various rheumatic diseases filled out a questionnaire with open-ended questions about their conceptions of their disease cause and processes. Based on their answers, an interview guide was developed and eight interviews with systemic sclerosis patients were conducted. The conceptions of patients about disease were closely related to their individual disease experiences. Information about the disease was rejected if it did not correlate with the patient's individual disease experience. Individual conceptions of the function of the immune system were found to differ profoundly from medical conceptions, which can hinder an understanding of the efficacy of the medical treatment and related adverse effects.

1. INTRODUCTION

Educational researchers can help to improve learning situations with their expertise. If we 'think outside the box', we find that there are other places where teaching and learning take place besides schools and universities. The communication between patient and physician is one such situation where experts present their knowledge to laymen, who depend on this knowledge transfer to understand their disease effectively. It is important for patients, particularly those with chronic diseases such as rheumatic ones, to develop a medical concept of their disease. Normally, there is no available cure for such diseases. Currently, only alleviation of symptoms or a slowdown of the disease progress is medically possible. Patients are tied to therapy, taking medication and medical care for their entire lives. Properly informed patients can and do participate in many complex medical decisions (Brody 1980; Kravitz 2001). The aim of the research presented in this paper was twofold: firstly, to help patients develop an understanding of the physiological processes taking place in their body and the efficacy of their medical regime, and secondly, to develop educational concepts for medical practitioners to enable them to support their patients' understanding.

2. WHAT ARE RHEUMATIC DISEASES?

The term 'rheumatic diseases' covers approximately 200 different diseases. Rheumatic diseases are autoimmune diseases. The immune system reacts to the cells of its own body and attacks them.

Some rheumatic diseases primarily affect the joints and the spine, for example ankylosing spondylitis. Here, the inflammation caused by the immune reaction leads to the ligaments in the spine gradually turning to bone, leaving the patient with an inflexible spine. There is strong evidence that this disease is hereditary (Loddenkemper *et al.* 2002).

Systemic sclerosis belongs to a subgroup of diseases called collagenoses, which include rheumatic diseases that show a primary effect on the soft tissues of the body rather than the joints. A prominent symptom of systemic sclerosis is the overproduction of extracellular matrix by cells of the connective tissue, which are stimulated by the immune system. The additional extracellular matrix is deposited in the skin and organs, leading to dysfunction of the involved body parts. In addition to autoimmunity and the overproduction of extracellular matrix, the third prominent feature of this disease is an extreme reaction of blood vessels to stress or cold temperatures. Autoimmune-based processes are also assumed to be the cause for these abnormal vessel contractions (Zuber *et al.* 2006). Knowledge about the causes of systemic sclerosis is still vague, but a combination of genetic predisposition and other agents has been discussed as the cause of the disease. Therefore, treatment concentrates on the alleviation of symptoms and a slowdown of the disease progress. A common therapy is an immune-suppressing treatment through medication (Loddenkemper *et al.* 2002).

3. CURRENT STATE OF RESEARCH

In both medical and educational research, the interest in individual conceptions is growing (Amann and Wipplinger 1998; Duit *et al.* 2005), because, according to the constructivist theory (Duit *et al.* 2005), it is necessary to link new information to previously existing individual conceptions in order to achieve understanding.

The overview of research concerned with biological processes of rheumatic diseases is therefore split into two different fields. Educational research normally focuses on students' conceptions. Here, conceptions of the immune system are found mostly in relation to conceptions of germs and infection (René and Guilbert 1994; Simonneaux and Bourdon 1998; Hoersch and Kattmann 2005; Precht 2006). These studies revealed a homogeneous picture of the immune system as a body system that fights intruders. The metaphors that the interviewees in various studies used to describe the immune system were related to the concept of war, e.g. battle, attack, fight, weak, strong, lose, win. This construct always involved two parties, the one that protected the human body (the immune system) and the one that attacked the human body (germs, viruses, bacteria, dirt). The relationship that Precht (2006) found can be described as a stimulus–response concept: the intruders are needed to trigger a reaction of the immune system: 'The brain sends the body's defences to the afflicted parts of the body, which are then eaten up by the body's defences.' The overall concept of two antagonists is manifested by the commonly shared concept of germs generally being bad for the human body (René and Guilbert 1994; Bayrhuber and Stolte 1997).

Medical research, on the other hand, focuses on patients' conceptions of particular illnesses. Studies that looked at rheumatic patients (e.g. Langer and Bormann 1992, Lee 2004) focused on conceptions of rheumatic disease causes. Whilst the patient groups investigated in these studies had different rheumatic diseases, the pool of causes that the interviewees drew their conceptions from was basically a limited one: hard work, coldness and dampness, psychological conditions, heredity, malnutrition, an unhealthy way of living (alcohol, little exercise) and environmental pollution. Whilst patients' conceptions of the cause of their disease were found to be quite explicit, conceptions of the disease processes were rather vague. Langer and Boremann (1992) found 'inflammation' as the most commonly named reason for their patients' disease (ankylosing spondylitis). Overall, the conceptions of the disease processes were only vaguely described, if at all.

4. THEORETICAL BACKGROUND

4.1 Individual conceptions

Individual conceptions are the beliefs, ideas and theories that someone develops of the world. They are formed based on assumptions about objects, facts and events, and are verified by everyday experiences. Individual conceptions help to govern actions and to define situations, i.e. they help to classify and evaluate situations (Dann 1983). Closely related to this is the explanation function and the prediction function of individual conceptions, which help to estimate which conditions trigger certain incidents.

To define the function of individual conceptions further, Dann (1983) compared individual theories with scientific theories. The wide range of terms, e.g. individual conceptions, lay theories, misconceptions, and the problem of finding a consistent terminology referring to this construct, became evident here. The classification of Gropengiesser (2001) was used (see Table 4.1) to set a framework for using these terms in this article.

Dann (1983) compared scientific theories with individual theories to distinguish further the characteristics of individual conceptions. Similar to scientific theories, individual theories were evaluated so that they could fulfil the functions mentioned above. However, individual theories differ from scientific theories because they do not have obligations of certain evaluation proceedings (Dann 1983), nor does an individual theory have to be consistent with itself. According to Langer and Bormann (1992), individual theories are similar to collages. When the metaphor of the collage is applied to Gropengiesser's system, it could be said that the information bits of the collage can range from concepts to complex subtheories, which form the overall picture of the collage. As objective evaluation measurements are not required to prove consistency in individual theories, there may not be an awareness of inconsistencies. When it comes to individual conceptions of a patient's own disease, emotional involvement also has to be taken into account. Verres *et al.* (1985) argued that the verbalisation of their disease conceptions therefore often has an emotional connotation. These emotional and motivational connotations can cover the cognitive–rational core of the individual disease conceptions.

4.2 The theory of experiential realism

The theory of experiential realism is used to interpret conceptions. Following this theory (Lakoff 1990), our basic – embodied – conceptions grow out of bodily experience. Moreover, the core of our conceptual system is directly grounded in perception, body movement and experiences of a physical and social character. In contrast, imaginative conceptions are not directly grounded in experience. They are developed by transferring conceptions from a domain that is experienced directly to a domain

Table 4.1 Corresponding terminology for complexity levels of the mental domain and the verbal domain (Gropengiesser 2001; translated by Gropengiesser, personal correspondence)

Mental domain: conception	*Verbal domain/sign*
Theory	Treatise, delineation
Principle	Maxim, motif, declaration, argument
Notion	Proposition, statement
Concept	Technical term, word

that is not experienced directly. For this transfer, metaphors or analogies are used. In this sense, metaphors do not serve as poetic decoration but rather as a basis for conceptual structuring. This metaphorical concept is inextricably linked to our normal talking and thinking (Gropengiesser 2003). Therefore, we create a systematic similarity between the directly experienced area and the non-directly experienced area during the process of understanding and talking.

4.3 The model of educational reconstruction

The model of educational reconstruction serves as a framework to prepare, carry out and evaluate research in science education (Kattmann 2007). The three components of the framework – clarification of scientific conceptions, investigations of laymen's perspectives and design of learning environments – are related to each other to create more effective communication (Figure 4.1).

The individual conceptions are not judged or categorised as right or wrong. They are important to understand in order to offer alternative medical conceptions that seem plausible to the patient.

5. RESEARCH QUESTIONS

This study addressed three research questions:

1. What kind of cognitive conceptions do patients have regarding their disease processes and treatment regime?
2. How do patients' conceptions and medical conceptions differ?
3. What sources do patients use to generate their conceptions?

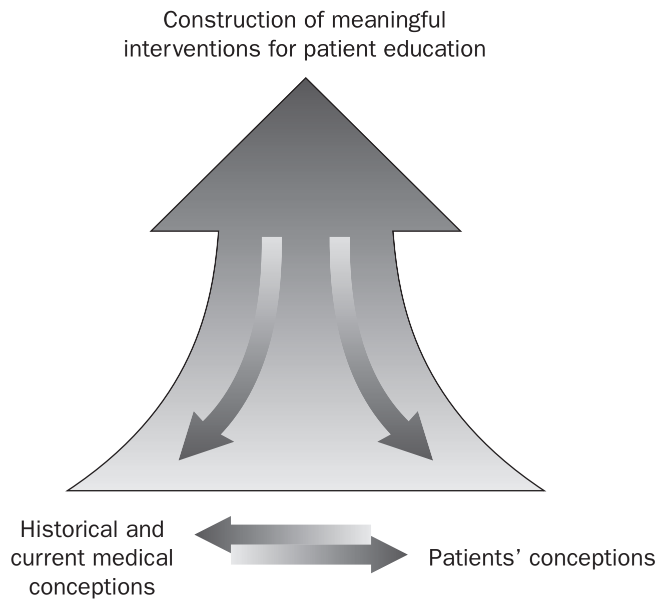

Figure 4.1 Relationships between the single components in the model of educational reconstruction for patient–physician communication (modified from Kattmann 2007)

6. DESIGN OF THE STUDY

6.1 Pilot study

A questionnaire was constructed based on the preliminary findings of seven explorative interviews with patients with various kinds of rheumatism. The questionnaire included three requests to elicit further cognitive conceptions of the disease processes and the effects of therapy from the patients:

- Please describe the conceptions you have of the cause of your rheumatic disease.
- Imagine you have to explain to a child what happens in the body of a rheumatic patient. Please try to describe, in simple words, *how* the rheumatic condition evolves.
- Please try to describe to the child *how* the medication alleviates the rheumatic condition.

The patients who took part in the pilot study were all visitors to the Information Day on Connective Tissue Disease in Berlin in September 2004. The open-ended questions of the questionnaire were analysed by qualitative content analysis (Mayring 2003; Gropengiesser 2005) using the qualitative data analysis software MAXQDA version 2. The data were analysed qualitatively by looking at the content of the answers.

6.2 Main study

The interview guide from the pilot study was revised based on the data from the questionnaire. To gather qualitative data about patients' conceptions of their disease, the questions were reduced and restructured. The huge variety of symptoms and processes involved in rheumatic diseases in general led to a study design with only one type of rheumatism. For the interviews, only patients with systemic sclerosis were interviewed to narrow down possible disease conceptions. Eight individual interviews were conducted. Interviewees were patients of the Department of Rheumatology at the Charité Hospital, Berlin. The average length of interviews was 38 minutes. Data was analysed by qualitative content analysis using MAXQDA version 2.

7. RESULTS

7.1 Pilot study

From a total of 160 questionnaires, 39 were returned. Thirty-four had adequate answers to the three open-ended questions. The question about disease causes was most often answered with 'heredity' and 'stress'. 'Preceding diseases', 'viruses and bacteria' and 'hormones' were also frequently named causes. Other possible causes mentioned were 'psyche', 'immune system', 'nutrition', 'age', 'physical factors' and 'dysfunction of the brain'. Some participants named more than one cause for their disease. It was also mentioned that physicians also do not know the cause of rheumatic diseases.

The conceptions of the effect of the medication given most frequently were 'pain relief' and 'alleviation of symptoms'. Participants also stated a 'decrease in immune activity', 'halting of cell destruction' and 'stimulation of cell regeneration'. Some participants named more than one target for the medication effects.

The answers revealed that patients had different levels of disease conceptions. In some questionnaires, the participants only mentioned that 'the body' was fighting against itself, whilst others described in detail how immune cells attack other cells in organs and therefore cause rheumatic conditions (see Figure 4.2).

The request to explain the disease processes in simple words to a child was mastered in different ways. The processes were explained using anthropomorphic descriptions, by analogy to other

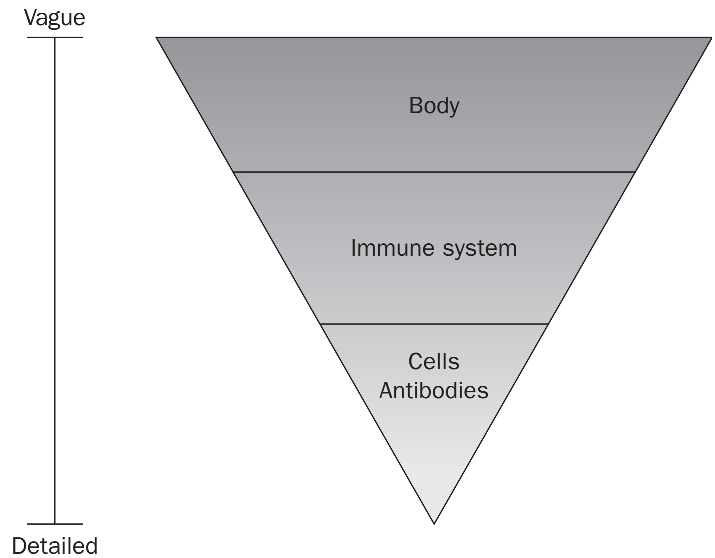

Figure 4.2 Levels of disease conceptualisation

commonly known diseases or using metaphors. In anthropomorphic descriptions, the words 'medication', 'cells' or 'body' were used, but they were given their own will power to do something. For example, 'Some parts of the body (cells) think that other cells are bad and that they have to defend themselves against those "bad cells".' The most prominent metaphor for the immune system was police that guard the body (Sander and Krueger 2006). However, we also found descriptions that compared the body to mechanical items. One participant compared her disease to the engine of a car that is not running properly because of contaminated gasoline: the medication reduces the contamination and the engine runs better (Figure 4.3).

Another patient with a degree in engineering drew on his conceptions of technical processes to construct a conception of his disease processes: 'Now sometimes the defence system itself is defective. It produces misprogrammed antibodies.'

The following description of a sketch was also provided by a patient answering the request to explain the disease to a child (Figure 4.4):

> Imagine in your body there are little men who look after your health. They send all the illnesses away. But all of a sudden they are not friends anymore and they start to fight each other. This is the reason why illnesses are able to enter the body all of a sudden and they make you ill, because nobody knows who is a friend and who is an enemy. When you have this illness called rheumatism, parts of your body can really hurt and that does not disappear. Sometimes it hurts more, sometimes less. But there is help for you when you have rheumatism. There are pills that see to it that the little men do not hurt you so much. And there are also pills or injections that chase the bad little men away and only the friends stay.

Even though the text is short, we can draw some conclusions about the patient's individual conceptions from it. The 'little men' that protect the body against illnesses started to fight each other when the patient developed rheumatism and 'illnesses' were able to enter the body. Thus, the patient describes rheumatism as a disease where the immune cells fight each other and therefore they are

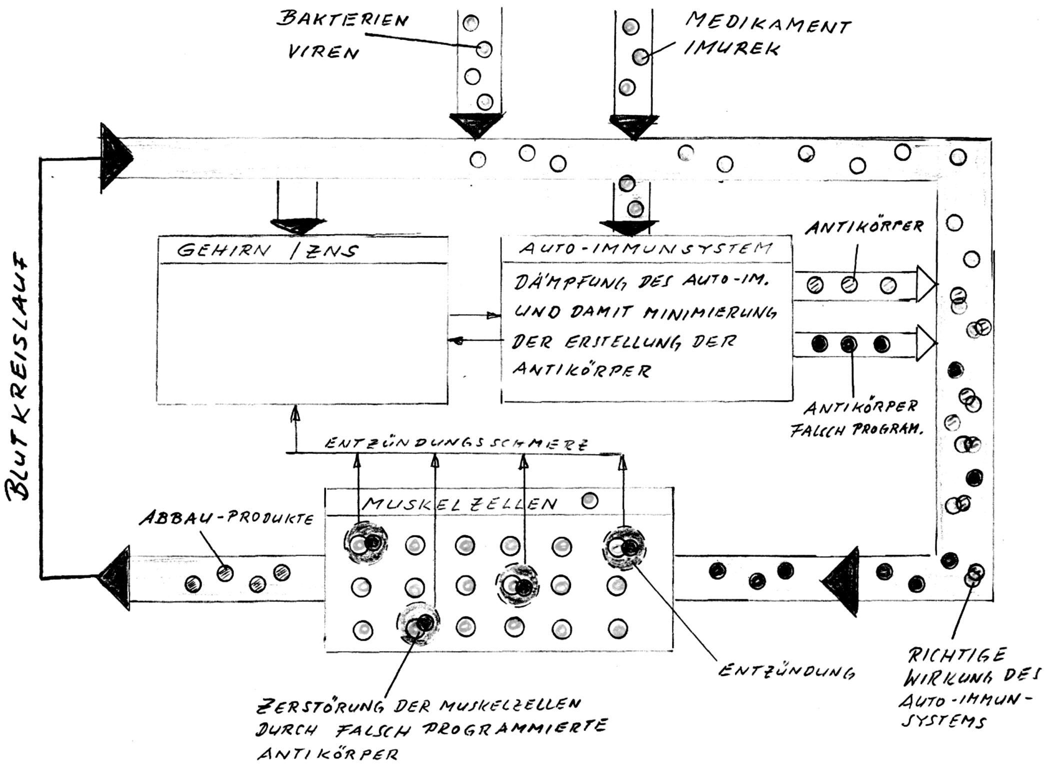

Figure 4.3 Sketch of rheumatic disease processes and medication effects (drawn by a patient)

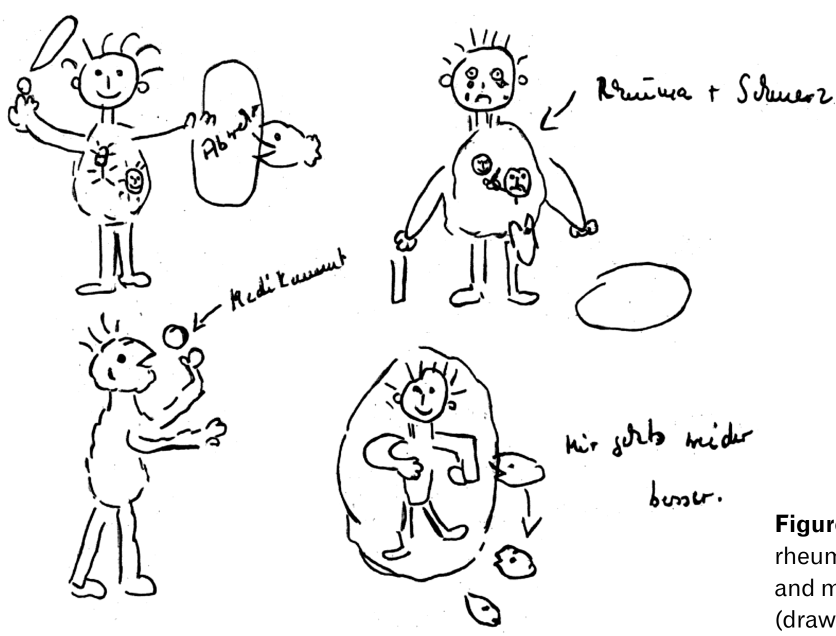

Figure 4.4 Sketch of rheumatic disease processes and medication effects (drawn by a patient)

not able to protect the body against illnesses. These illnesses can enter the body and make the person sick. Medical theory describes a different disease process: the immune system stimulates or attacks the cells of its own body and therefore probably triggers the disease process. The patient explains her symptoms and pains by the illnesses that enter her body because of the dysfunction of the immune system. The medicine has an effect on the 'bad little men', so that they disappear and only the 'good ones' stay, which are able to protect the body again.

7.2 Initial results of the main study

Because rheumatic diseases are so heterogeneous, the study has focused on one defined disease (systemic sclerosis), so that it was possible to compare the conceptions of all of the interviewees.

Even though all eight interviewees were diagnosed with the same chronic disease, their conceptions and descriptions offered a manifold picture. Asked about the cause and the disease features, each interviewee offered their own symptoms to describe the disease and their own conceptions of the disease causes (Table 4.2). Their own experience with their disease was an important source of information about the disease. Two interviewees could not name an individual cause for their disease, but they had evaluated possible causes and excluded them based on personal experience, e.g. 'I cannot have inherited this disease because neither my brother nor my parents, nobody has this kind of disease' (PI 12). Other information sources seemed to be mainly their physician, but relatives, friends and other patients were also relevant in learning about their disease. In addition, the patients used the Internet to get further information. Disease experiences, together with information from the environment, seemed to form the patient's disease conceptions (Sander and Krueger 2006). Because rheumatic diseases are auto-immune diseases, the interviewees were asked about their conceptions of the immune system (Table 4.3).

In addition, some of the interviewees' conceptions of systemic sclerosis included a weakening of the immune system and therefore the immune system needed to be strengthened in order to fight

Table 4.2 Systemic sclerosis patients' conceptions of disease causes

Patient interview (PI)	*Conception(s) of disease cause*	*Selected quotes on related symptoms/personal observation*
PI 02	Heredity/primary chronic disease	'My mother has chronic leukaemia; maybe I have a predisposition. I had a rupture of the stomach . . . that became a chronic condition. Maybe it is both.'
PI 04	Stress	'In my case stress controls the body heat. I am a person who always needs to be on time and this pressure is not healthy.'
PI 07	Heredity	
PI 08	Weakness of the immune system	
PI 09	Heredity/defective genes	
PI 10	Environmental pollution	'I don't think I drank too much alcohol or smoked too much. In my opinion our environment is becoming more and more polluted.'

Table 4.3 Conceptions of the functions of the immune system

Patient's conception of the immune system	*Patient answer*	*Medical conception*
Protection The immune system protects the body against germs	'Without an immune system we could not live anymore, because we would contract so many diseases and the body cannot fight them anymore' (PI 04)	The immune system protects the body against germs
Supply The immune system supplies the body with nutrients	'If you do not have an immune system, the organs are not sufficiently supplied' (PI 02)	Blood is responsible for nutrient supply
Regulation The immune system regulates body functions	'If the immune system does not work anymore, all the organs will do whatever they want. All the muscles, sinews, ligaments will get out of control' (PI 09)	Body functions are regulated by the nervous system and hormones
Protection and supply The immune system protects and supplies the body	'The immune system supplies all the organs and protects them' (PI 08)	The immune system does not have a supply function

their disease. One interviewee said that the immune system needed to be strengthened to fight 'rheumatism'.

8. DISCUSSION

In our pilot study, we asked the patients about their conceptions of the causes of their disease. The causes our interviewees named were drawn from the same pool of causes that was found in earlier studies: heredity, infections (viruses, preceding diseases), involvement of the immune system, psychological factors, stress and environmental pollution. The cause conceptions of individuals were closely linked to personal observations (see Table 4.2). If a patient did not have family members with a similar disease, they eliminate the possibility of having inherited rheumatic disease. Individual conceptions help to classify and evaluate situations. Personal experience is compared with information about the disease. For constructing conceptions about the cause of a disease, the only relevant information about the disease is that which holds true from personal experience. None of the patients with systemic sclerosis argued that the cause of their disease was based on abrasion. However, patients with rheumatic diseases of the joints and bones, e.g. ankylosing spondylitis, frequently named this cause (Langer and Bormann 1992), even though it does not apply to inflammation of the joints or vertebra. The theory of experiential realism postulates that our conceptions arise from bodily experiences, and this seems to be a major source of disease conceptions. Together with information and knowledge, they are the basis on which disease conceptions develop (Lewis and Daltroy 1990).

Pain relief and alleviation of the symptoms were the most frequently named effects of medication. What patients directly experience is what they describe as the salient effects of their medication. They also named a decrease in immune activity as a target of the medicine; however, because we chose to use a questionnaire to collect the data, asking for a more detailed description was unfortunately not possible.

Some patients described what is fighting against their body as 'the body', some named the 'immune system' and others named 'cells' or 'antibodies' (Figure 4.2). Again, the study design did not allow us to ask for more detailed explanations, but this shows that conceptions about which part of the body is responsible for the disease differ in their complexity. In turn, this is important for a physician to know when they explain the effects of medical treatment. A patient who does not have a concept of the immune system or immune cells will probably not be able to follow a more detailed explanation.

The metaphors used by the patients to describe how they would explain the disease to a child gave valuable insight into how patients understand the processes of the disease. From this, it is possible to derive advice for physicians on how to describe the processes in an understandable way. The theory of experiential realism postulates that we use metaphors to develop conceptions of domains where we cannot have our own experiences. Rheumatic disease processes at a cellular level are one such domain. For our sample of patients, the most prominent metaphor for the immune system appeared to be the police. Police and the immune system both share the same function: they protect us from bad things and intruders who want to harm us. Physicians could use this metaphor to clarify the complex disease processes of rheumatic disease and the effect of the treatment regime.

The disease conceptions of the patient who described her disease as a fight of the immune cells against each other (Figure 4.2) differs somewhat from medical conceptions. A physician can tie in with this explanation and tell her that 'the little men' do not fight each other, but fight other parts of her body. They are still strong enough to fight other diseases, but they no longer recognise which are the 'good' cells of the body and which are 'bad intruders'. Other metaphors such as technical ones (Figure 4.3) were also found. If the physician can adapt his explanation to the patient's conception, the patient has a better chance of understanding the complex processes of the disease (Gerstenmaier and Mandl 1995).

In the main study, different conceptions of the function of the immune system were found. Whilst some interviewees described a protective function, we also found the conception of supply function, and one interviewee described the immune system as a kind of regulation system that controls, for example, the movement of the limbs. We also found the conception that systemic sclerosis is a disease that includes a weakening of the immune system and that the immune system needs to be strengthened in order to reduce the disease activity. This conception that the immune system has to be strengthened to fight against a disease was a prominent one that agrees with the observation of Jacob *et al.* (1999) that infectious diseases are easier to comprehend than chronic diseases, such as rheumatism, because they normally have a defined cause (e.g. a virus or bacteria). Therefore it is easier to find a treatment for an infectious disease and, compared with chronic diseases, the course of the disease is relatively short. According to medical conceptions of autoimmune diseases in general, the immune system is not too weak to fight viruses or bacteria, although the medication that the patients get to reduce their symptoms is an immune suppressant that weakens the immune system deliberately to reduce the impact that the immune system has on the patients' bodies (Loddenkemper *et al.* 2002). These are individual conceptions that physicians are generally not aware of, but which they should take into account when talking to a patient about their disease.

A divergence in conceptions between the patient and the physician could cause a misunderstanding that could affect the effectiveness of the therapy. A misunderstanding can only be averted if the physician is aware of the different conceptions when they talk about the effects of immune suppressants with the patient. If the therapy does not meet the patient's expectations, they may not follow it as prescribed (Hayes-Bautista 1976) and may even drop out of the therapy. Therefore, it is important that patients understand their disease processes and the effects of therapy, because they are more likely to adopt the therapy proposed by their physician if it seems plausible to them (Basler 1985). This is where educational research can tie in with its theories of learning and understanding to help the patients develop a medical conception of their disease. On this basis, patients and physicians will be able to find the best therapy for the patient.

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5 One year after teaching, how consistent are students in using the scientific theory of biological evolution by natural selection?

Anita Wallin

DEPARTMENT OF EDUCATION, GÖTEBORG UNIVERSITY, SWEDEN

anita.wallin@ped.gu.se

A teaching–learning sequence about the theory of biological evolution was developed by linking theoretical reflection, instructional design and classroom research in a cyclic process. Seventy-nine students participated in three trials of this sequence. The students, aged 17–19 years, had all chosen the science branch of upper secondary school in Sweden. Before teaching, the students were given a pre-test and, 1 year later, a post-test. The students' pre- and post-test results were categorised into one of four groups: consistently scientific; mainly scientific; mainly non-scientific; and consistently non-scientific. In the post-test, 43 per cent of the students used the scientific theory of evolution consistently throughout the test compared with 6 per cent in the pre-test. Sixty per cent of the students used non-scientific ideas consistently in the pre-test and 5 per cent in the post-test. Thirty students changed their way of reasoning between the pre- and post-tests in such a profound way that it could be considered a conceptual change. The analyses of the students' performance revealed that students who partly used scientific ideas in the pre-test did not demonstrate a more consistent use of scientific ideas in the post-test than students starting with exclusively non-scientific ideas.

1. INTRODUCTION

This study focused on how consistently students use ideas in their reasoning in written answers to pre- and post-tests. Our research interest was to establish whether or not the students had managed to learn the theory of evolution sufficiently well to be able to use it consistently in the post-test, 1 year after teaching. Could the conceptual change model (CCM) formulated by Posner *et al.* (1982) be used to understand how these students learn? This model predicts what is needed to change from one concept to another. A student who uses a scientific theory consistently after teaching, but not before, may have undergone such a conceptual change.

1.1 Context of the study

This study formed part of a larger project, the overall purpose of which is to study how upper secondary school students (grade 10–12, aged 17–19) develop an understanding of evolutionary biology as a result of teaching. The students' reasoning in written tests, interviews, small groups and whole-class discussions was analysed. In these analyses, the students' preconceptions, the conceptual structure of the theory of evolution and the aims of teaching were kept in mind. This provided insights into those learning and teaching demands that constitute challenges to students, as well as to teachers, when beginning to learn or to teach evolutionary biology. A teaching–learning sequence was developed, implemented and assessed in a cyclic process.

1.2 Learning science

The CCM (Posner *et al.* 1982) predicts what a learner must experience to change from one concept to another. He or she must be dissatisfied with their existing understanding, and any new concept must be intelligible, plausible and fruitful. Caravita and Halldén (1994) discussed the CCM in relation to different scientific contents, including the theory of evolution. By analysing students' written essays from several different studies, they found students who had acquired a large number of facts but who failed to apply the theory in a scientific way. In spite of being rather critical of the CCM, these authors described its usefulness in certain areas of science, such as the theory of evolution.

The focus of our project was on the students' learning of the theory of biological evolution by natural selection. In this respect, the CCM for learning may be interesting, despite the criticism it has been exposed to. It has, for example, been criticised for talking about exchange of concepts, which a number of studies have shown that students do not do (Solomon 1983, 1984; Pintrich *et al.* 1993; Caravita and Halldén 1994; Pintrich 1999; Duit and Treagust 2003; Helldén and Solomon 2004). In spite of this criticism, Duit and Treagust (2003: 674) do not advocate rejecting the CCM, but contribute to its development, as they argue that 'conceptual change approaches have proven superior to more traditionally-oriented approaches in a number of studies'.

1.3 Ideas about evolution

When Darwin published his pioneer work, *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, in 1859, he initiated a change in paradigms in the science of biology. This theory can be explained without using complicated terms. Briefly, one can say that evolution is a consequence of a populations' existing variation in heritable characters meeting the environment. Thus, natural selection favours individuals with advantageous characteristics in any given environment. These individuals produce more offspring, who, in turn, constitute a greater proportion in the next generation of the population.

Bishop and Anderson (1990) found in their study that most students see evolution as a process where all individuals of a species change by adapting gradually to the environment. In several studies, authors have shown that pupils and students do not change their ideas to any considerable extent after teaching (e.g. Halldén 1988; Bishop and Anderson, 1990; Demastes *et al.* 1995a). Ferrari and Chi (1998) wrote that, in spite of natural selection being a relatively simple process, most students have problems grasping it, and non-scientific ideas are very evident.

1.4 Consistency in using scientific ideas

Studies show that students have difficulties using scientific ideas consistently in the area of biological evolution (Engel Clough and Driver 1986; Halldén 1988; Demastes *et al.* 1995b). For instance, Brumby (1984) found that two-thirds of her 32 university students had difficulties recognising that different problems discussed in an interview dealt with the same topic – biological evolution or natural selection. Shtulman (2006) studied students' understanding of six evolutionary phenomena and found that approximately one-third used one idea consistently among all six.

Engel Clough and Wood-Robinson (1985) interviewed pupils about adaptation and found that, in different contexts, the pupils used different non-scientific ideas. Engel Clough and Driver (1986) found in their study that scientific responses appeared to be used more consistently than non-scientific responses. They also found that the consistency varied among different contents and contexts.

Students were also shown to have difficulties using theories and models consistently in other areas of science (Mortimer 1995; Redfors and Ryder 2001).

2. AIMS AND RESEARCH QUESTIONS

One aim of this study was to investigate how consistently the students used scientific and non-scientific ideas in their reasoning in answering items in pre- and post-tests. Another aim was to analyse the students' changes in answers between the pre- and post-tests, and to discuss this in the light of the CCM. Thus, the questions addressed in this study were:

1. Do students use scientific and non-scientific ideas consistently in their pre-test and 1 year later in the post-test?
2. Did any students change their reasoning in a profound way, as predicted by the CCM?

3. SAMPLES AND METHODS

3.1 The teaching–learning sequence

The teaching–learning sequence was designed for a compulsory course in biology in the Natural Science Programme in upper secondary schools in Sweden. This course comprised 50 hours of teaching and covered mainly ecology, ethology and evolution (National Agency for Education, 2001). Evolution was strongly emphasised in the course curriculum, and 14 out of the 50 hours were exclusively used for teaching evolution. These 14 hours were divided into nine lessons. The teaching–learning sequence has been described in detail elsewhere (Hagman *et al.* 2003; Wallin 2004).

3.2 Students, teachers and schools

Three experimental groups from a total of 79 students, aged 17–19 years, were taught according to the designed teaching–learning sequence in three successive trials. Two teachers were engaged in the study, both as teachers and as researchers. The students attended schools in and around the city of Göteborg, Sweden. In two of the groups, most students were ethnic Swedes, but in the third the majority had another ethnic background. The students themselves had all chosen the Natural Science Programme, and due to the programme's reputation of being highly demanding, the students could all be described as well-motivated.

3.3 Teaching strategy

One of the most distinguishing features of the teaching–learning sequence in this study was the many structured small-group and whole-class discussions. Another aim, inspired by the CCM, was to make the students aware of their own and their peers' existing ideas and to compare these with the scientific ones. By articulating ideas and examining them critically, some ideas will lose status, whilst others will increase in status. The teacher has a central and important role in this teaching–learning sequence, as they must not only create a classroom atmosphere that is open and friendly and invites the students to express and discuss various ideas, but must also introduce and support scientific ideas.

To promote learning with long-term understanding, we paid great attention to students' possibilities of repeatedly using the theory of evolution by natural selection in many different contexts. The students wrote logbook entries and it was obvious that they noticed, appreciated and often commented on the application of the theory in many different contexts.

3.4 Data collection

The consistency in using ideas was analysed by using the students' written answers to the pre- and post-tests. Seven questions were identical in both tests, but in the post-test, a new question was also added. The questions were of different kinds (see Table 5.1 and Appendix 5.1).

The students' responses to the open-ended problems were categorised using a system of eight qualitatively different levels. In this categorisation, the five principles from Ferrari and Chi (1998) were used: variation, survival, reproduction, heredity and accumulation. Answers categorised as levels 1–4 were labelled non-scientific and answers categorised as levels 5–8 were labelled scientific (see Table 5.2). In the multiple-choice problems, one or occasionally two alternatives were correct and labelled scientific. Both pre- and post-tests contained three different questions using a Likert-type scale (see Table 5.1). The student answers were categorised by taking into consideration the results from the Likert-type scale as well as the opened-ended motivation. These answers were categorised into eight different levels similar to the open-ended problems, and levels 1–4 were labelled non-scientific and levels 5–8 scientific. The additional problem in the post-test (the 'lice' problem; see Table 5.1 and Appendix 5.1) was categorised in the same way.

Table 5.1 Questions set in the pre- and delayed post-tests (see also Appendix 5.1)

Problem theme	*Type of question*	*Name of problem*	*Pre-test*	*Delayed post-test*
Variation	Multiple choice	The origin of variation	✓	✓
	Multiple choice	Existing variation	✓	✓
	Likert type with open motivation	The origin of variation	✓	✓
Inheritance	Likert type with open motivation	Inheritance	✓	✓
Natural selection	Multiple choice	Changes in a population	✓	✓
	Likert type with open motivation	Changes in a population	✓	✓
Theory of evolution	Open-ended	The cheetah problem	✓	✓
	Multiple choice with open motivation	The lice problem	✗	✓

Table 5.2 Labels and levels of responses to open-ended problems in pre- and post-tests

Principle/idea	*Label*	*Level*
Variation/survival/reproduction/heredity/accumulation	Scientific	8
Variation/survival + two other principles	Scientific	7
Variation/survival + one other principle	Scientific	6
Variation/survival	Scientific	5
Alternative ideas + scientific terms	Non-scientific	4
Alternative ideas	Non-scientific	3
Do not know/irrelevant	Non-scientific	2
No answer	Non-scientific	1

Some responses to the open-ended 'cheetah' problem (Table 5.1; Appendix 5.1) were chosen in order to illustrate the different levels in Table 5.2. The following six quotations were selected because these students wrote relatively short responses containing the basic characteristics for each level:

> Sara: They have developed, because they need to run faster in order to catch prey and to escape dangers. (Level 3)
>
> Lisa: Some learnt to run faster. These were favoured by natural selection and their offspring passed on. (Level 4)
>
> Adam: Natural selection. Through mutations, faster cheetahs were created. Compared to their mates, they run a bit faster and for that reason they managed to catch more prey. (Level 5)
>
> David: Offspring that could run faster had greater chance to survive and to pass on their 'fast genes'. The character was favoured by natural selection. (Level 6)
>
> Johan: The fastest cheetahs can more easily manage to get food; for the slower this is harder due to their somewhat weaker running capacity. The fastest survive and get more offspring, which can pass on their genes. (Level 7)
>
> Karl: The fastest cheetahs born got most food during their lives, and had the largest survival. As this contributed to their larger production of offspring during their life time, this 'fast' gene passed on, and a larger and larger proportion of the population became fast runners. (Level 8)

3.5 Intercoder reliability

The reliability of categorising the students' answers into scientific or non-scientific was tested. The data base contained 333 answers to the open-ended 'cheetah' problem, with 158 of them being from the students reported in this paper (two answers each from 79 students). The same answers were categorised twice (by A. Wallin, this study), approximately 1 week apart (see Table 5.3: same person). Then, another well-informed person categorised the same answers. During these categorisations, the answers were arranged randomly, according both to type of test (pre- or post-test) and group of students (experimental or others). The reliability for categorisation of answers into scientific and non-scientific answers was high (see Table 5.3).

3.6 Constructing categories of consistency

All answers to the items in the pre- and post-tests were categorised as scientific or non-scientific as described in Table 5.2 and were labelled A (alternative, or non-scientific) or S (scientific). Each

Table 5.3 Intercoder reliability in categorisation of answers to the open-ended cheetah problem (n = 333) into two different categories: answers with non-scientific and scientific ideas, respectively

Idea	*Reliability:*	
	Same person (%)	*Two different people (%)*
Non-scientific or scientific	98	99

student's (n = 79) results in the pre-and post-tests were plotted (see Figure 5.1 for three examples of plots).

The plots showed whether a student's answer was categorised as non-scientific (A) or scientific (S). If an answer was categorised as non-scientific (A), it appeared low in the plot, close to the *x*-axis, whereas if an answer was categorised as scientific (S), it appeared at the top of the plot. The entire pre-test was represented by a band and the post-test by another band directly after each other. Thus, if all answers in a test were categorised as non-scientific (AA), the band appeared as a low line in the plot, and if all answers were categorised as scientific (SS), a high band appeared at the top of the plot. Students who were not consistent were represented by bands alternating between the low non-scientific and the high scientific levels in the plots (AS and SA).

Each student's overall pre- and post-test results were categorised into one, and only one, of four categories:

- AA: The student uses non-scientific ideas consistently throughout the test. In a test, no more than two multiple-choice problems or one Likert-type problem are categorised as scientific. The open-ended problems are never answered with scientific ideas.
- AS: Mainly non-scientific ideas. At least one multiple-choice and one Likert-type problem must be answered scientifically. The open-ended problems are seldom answered with scientific ideas.
- SA: Mainly scientific ideas. At least four multiple-choice or Likert-type problems must be answered with scientific ideas. The open-ended problems are seldom answered with non-scientific ideas.
- SS: The student uses scientific ideas consistently throughout the test. In the test, no more than one multiple-choice problem is categorised as non-scientific. The open-ended problems are always answered with scientific ideas.

These plots (Figure 5.1) were used to show all answers to both pre- and post-tests for each student in one overall figure. These figures, one for each student, were printed out, grouped and regrouped repeatedly until the result was stable. I was interested in investigating how many students solved their pre- and post-tests consistently across the range of problems.

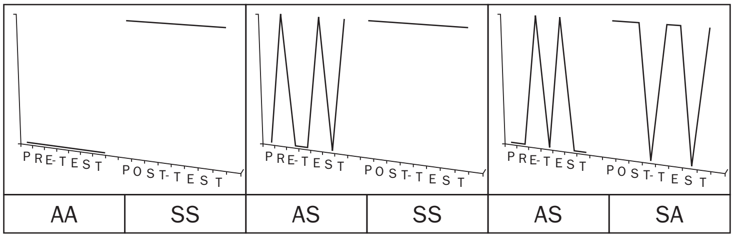


Figure 5.1 Examples of three students' plots, which show the pre- and post-test content of scientific (S) or non-scientific (A) answers. The first plot shows the results from a student who gave consistently non-scientific answers (AA) in the pre-test and consistently scientific answers (SS) in the post-test. The second and the third plots show students whose answers were categorized as AS in the pre-test (i.e. mainly non-scientific) and as SS and SA in the post-test (i.e. consistently scientific and mainly scientific, respectively). Each letter in the words pre-test and post-test on the *x*-axis represents the student's answer to one problem in the test

4. RESULTS

4.1 Different categories of consistency

Table 5.4 Number of students in the four different categories of consistency (n = 79)

Test	*AA*	*AS*	*SA*	*SS*
Pre-test	47	17	10	5
Post-test	4	17	24	34

The results from the three experimental groups of students are grouped together in Table 5.4, as they did not differ significantly (χ^2 test; 2×4 table; non-significant). However, the students' performance in pre- and post-tests was significantly differently distributed over the categories of consistency (χ^2 test; 2×4 table; $P<0.001$) (see Table 5.4).

In this study, 47 students (59 per cent) answered the pre-test consistently non-scientifically and five students (6 per cent) were consistently scientific. Altogether, 52 students (66 per cent) were consistent in the pre-test. In the post-test, the corresponding percentages were 5, 43 and 48 per cent. In other words, the students were less consistent in the post-test, with the percentage of students who were consistent decreasing from 66 to 48 per cent, but overall more students were scientifically consistent.

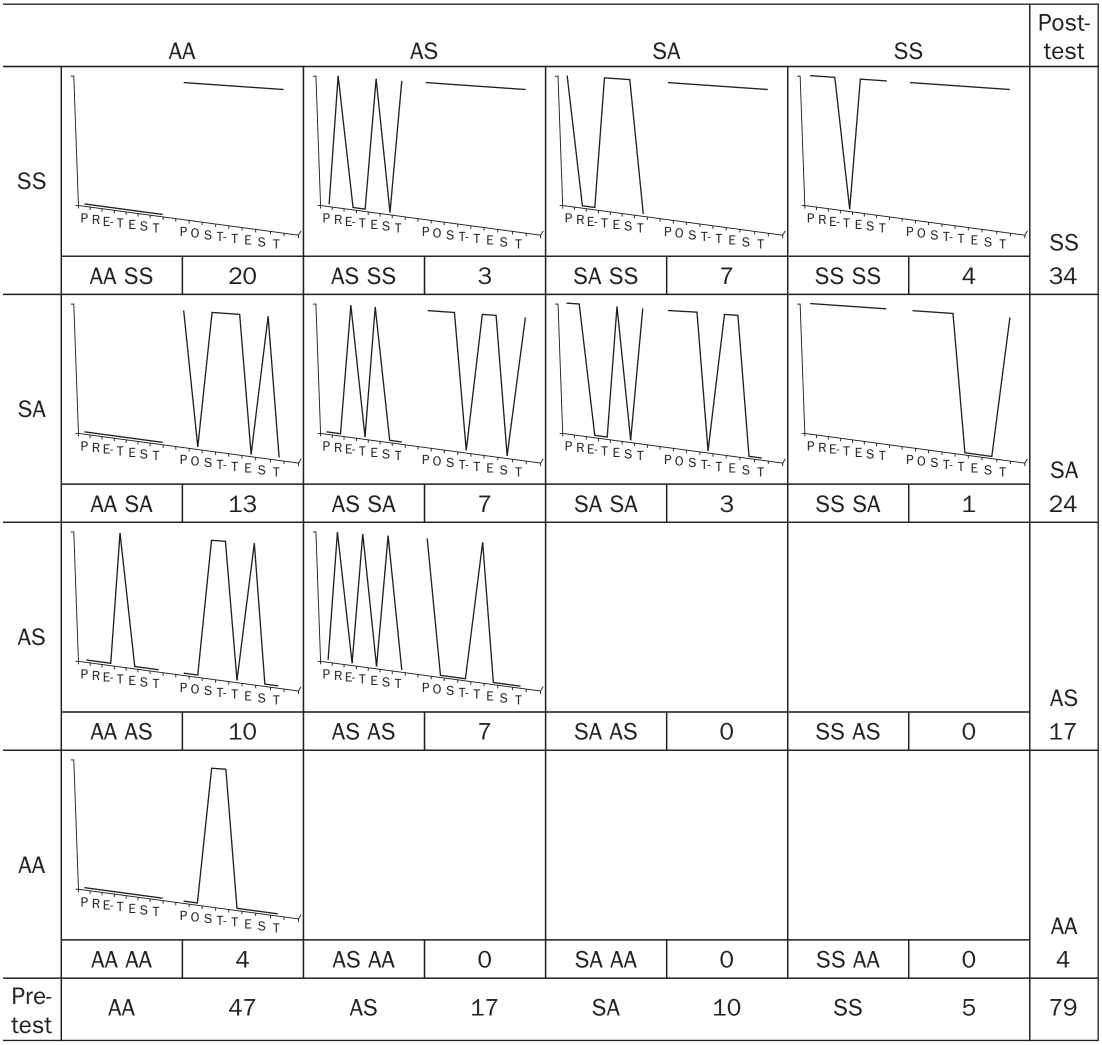
Figure 5.2 presents this distribution in more detail. The squares in the diagonal from the lower left (AA AA, followed by AS AS and SA SA) to the upper right (SS SS) represent students who were categorised in the same category of consistency both in pre- and post-tests. There were 18 students overall (23 per cent) whose post-tests had the same category of consistency as their pre-test. It is still possible that these students developed their knowledge of the theory of evolution if their answer to one or more questions entered a higher scientific level within the scientific levels (levels 5–8). The majority (14/18) did in fact increase their scientific level in the post-test compared with the pre-test. However, this change did not influence the category of consistency.

One student ended up in a lower consistency category in the post-test, from SS in the pre-test to SA in the post-test. This student appears below the diagonal in Figure 5.2, and was the only student in this study who did not perform better in the post-test compared with the pre-test. Of the total 16 combinations of possible results, 11 were represented by any students' performance in the pre- and post-test. No student in the study ended up in the five remaining squares below the diagonal (Figure 5.2). The remaining 60 students (76 per cent) reached a higher scientific consistency category in their post-tests. They were represented above the diagonal in Figure 5.2 as AA SS, AS SS, SA SS, AA SA, AS SA and AA AS.

4.2 Changes in categories of consistency between the pre- and post-tests

A profound change in ideas between the pre- and post-test is shown by any student who uses non-scientific ideas consistently in their pre-test (AA) and 1 year later consistently uses scientific ideas (SS), or vice versa. Twenty students changed from consistently non-scientific to consistently scientific (AA SS in Figure 5.2). In addition, the ten students who partly used scientific ideas in the pre-test and ended up in the consistently scientific category in the post-test (AS SS and SA SS) had changed their reasoning in a profound way. Thus, overall, 30 students changed their way of reasoning between the pre- and post-tests in such a profound way that it could be described as a conceptual change.

In the pre-test, 47 students used non-scientific ideas consistently throughout the test (AA; Table 5.4 and Figure 5.2). Of these, 43 per cent (the 20 categorised as AA SS) were among the students who used scientific ideas consistently in their post-test. Among the 32 students who at least partly used scientific ideas in the pre-test, 14 students (44 per cent; AS SS, SA SS and SS SS) used scientific ideas consistently in their post-test. Thus, for the students in this study, it does not seem that they benefited from having at least partly understood the theory of evolution before teaching in terms of being able to use scientific ideas consistently in the post-test.



Post-test \ Pre-test	AA		AS		SA		SS		Post-test
SS	AA SS	20	AS SS	3	SA SS	7	SS SS	4	SS 34
SA	AA SA	13	AS SA	7	SA SA	3	SS SA	1	SA 24
AS	AA AS	10	AS AS	7	SA AS	0	SS AS	0	AS 17
AA	AA AA	4	AS AA	0	SA AA	0	SS AA	0	AA 4
Pre-test	AA	47	AS	17	SA	10	SS	5	79

Figure 5.2 Changes in consistency between the pre- and post-tests. Below every plot is given the abbreviation for the category of pre- and post-test, and the number of students in each category (total *n*=79). SS, consistently scientific; SA, mainly scientific; AS, mainly non-scientific; AA, consistently non-scientific

5. DISCUSSION

5.1 How consistent are the students in using the scientific theory of evolution?

In this study, 34 students (43 per cent) were consistent in using scientific ideas throughout the entire post-test, whilst four students (5 per cent) used non-scientific ideas consistently. Whether this proportion of students with scientific use of ideas is a relatively high proportion or not is difficult to say, and comparisons with other studies must be made very carefully. For example, Shtulman (2006) investigated students from high schools and colleges together with three individuals with doctoral degrees in biology. Thirty-one per cent of his participants used either scientific or non-scientific ideas consistently over all six evolutionary phenomena (30 items). Redfors and Ryder (2001) analysed their university students' consistency over three different questions about interaction between electromagnetic radiation and matter, and found that 47 per cent used one model consistently, either a scientific or a non-scientific one. The scientific model was used by 19 per cent of the students consistently. Ardac and Akaygun (2005) showed that 75 per cent of the students used a particular model of molecules consistently after instruction with dynamic visuals on an individual basis compared with slightly less than 50 per cent after instruction with dynamic or static visuals on a whole-class basis. These studies indicate that the level of consistency may depend on many variables, such as content area and teaching approach.

It may be that some reasons for the students in this study reaching higher consistency levels compared with, for example, the study of Redfors and Ryder (2001) can be found in the design and performance of the teaching–learning sequence. Redfors and Ryder stated that:

> . . . teaching using exemplary phenomena is an important first step as students begin to understand the key elements of a model. However, we suggest that such teaching needs to be followed by using the model to explain an extended range of phenomena. The intention of such teaching would be to enable students to recognise the relationship between the model and different phenomena. In this way the teacher is able to draw out the distinctions between the model and the phenomena to be explained, and therefore the limitations of the model.

One of the most distinguishing features of the teaching–learning sequence described in this paper was the students' possibilities for using and communicating the theory of evolution by natural selection in a variety of contexts.

5.2 The CCM

Among the students whose pre-test results were categorised as consistently non-scientific, 20 students' post-test responses were categorised as consistently scientific. Ten students who answered with partly scientific ideas in the pre-test used scientific ideas consistently 1 year later. Among these 30 students, it was possible find students who had undergone a conceptual change according to the CCM (Posner *et al.* 1982). The post-test was performed 1 year after teaching and this supports the idea that they had successfully undergone a conceptual change. Another supporting factor is that the students experienced the theory of evolution in many different contexts, which may have allowed the possibility for them to undergo conceptual change. This factor could also provide an explanation for the finding that the advantage of knowing about the theory before teaching started became negligible in this study.

The post-test results of 40 students was categorised as AS or SA. These students used both non-scientific and scientific ideas when they answered evolutionary problems and they did not seem to have changed their reasoning radically, but they could be considered examples of what Pedersen and Halldén (1994) describe as assimilation into an established framework, or, as described by Aikenhead (1996), these students' life culture did not agree with the subculture of science. The data collection did not allow any deeper analyses of these students, relating for example to their life culture.

The eight students who answered their pre-test consistently and ended up in the same consistency category in their post-test can also be said to have assimilated an established framework, whether scientific or non-scientific. The four who assimilated their pre-existing scientific framework succeeded better in the post-test compared with the pre-test by enhancing their scientific level within levels 5–8 (see Table 5.2).

5.3 Some educational implications of these results

In spite of the fact that the students in this study were well-motivated and were taught by experienced teachers, not all of them could use the theory of evolution consistently in the post-test. Many students showed by their logbooks that they needed many lessons to be able to use the theory. Only 43 per cent of our students used the theory of evolution consistently in their post-tests. Compared with other studies, however, this is a high proportion. If we really want our students to understand and be able to use scientific theories, they need time to practise and solve more problems in different contexts than is common practice in Sweden today.

I believe that the CCM is a useful tool when thinking about students' learning in science. It is necessary to understand that it is not easy for a student to undergo conceptual change. For example, a new concept has to fit into the individual's present conceptual ecology. For many (most) of our students, science does not easily fit in, and to change one's conceptual ecology is hard work.

Acknowledgements

I would like to thank all 79 students who so willingly answered the questions, both in interviews and in written tests. I would also like to thank the two teachers who were engaged in the study, both as teachers and as researchers, Mats Hagman and Clas Olander. I also want to express my gratitude to two anonymous referees for many good comments, which enhanced the quality of this paper.

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APPENDIX 5.1 QUESTIONS IN THE PRE- AND POST-TESTS

Variation: The origin of variation
Throughout time living organisms have developed a variety of different traits. What is the origin of this enormous variation?

1. The traits arose when they where needed.
2. Random changes in the gene pool of the organisms.
3. Living organisms strive to develop.
4. Great variation is needed in order to get balance in nature.

Variation: Existing variation (Bishop and Anderson 1990; Jensen and Finley 1995)
A number of mosquito populations today are resistant to DDT (a chemical used to kill insects), so that DDT treatment now is less effective than it used to be. Biologists believe that the DDT resistance evolved because:

1. Individual mosquitoes developed resistance to DDT after being exposed to it.
3. A few mosquitoes were probably resistant to DDT before it was ever used.

2. The mosquito populations needed to be resistant to DDT in order to survive.
4. The mosquito populations became resistant by chance.

Variation: The origin of variation (Bishop and Anderson, 1990; Jensen and Finley, 1995)

(a) The trait of webbed feet in ducks appeared in their ancestors because . . .

. . . they lived in water and needed webbed feet to swim.	1	2	3	4	5	. . . of a chance mutation.

(b) Why did you choose this answer?

Inheritance (Bishop and Anderson 1990; Jensen and Finley 1995)

(a) While ducks were evolving webbed feet, with each generation most ducks . . .

. . . had about the same amount of webbing on their feet as their parents.	1	2	3	4	5	. . . had a tiny bit more webbing on their feet than their parents.

(b) Why did you choose this answer?

Natural selection: Changes in a population
Which one of the following alternatives best explains changes in a population with time?

1. Some individuals are better at reproducing than others.
2. Some individuals starve to death, whilst others survive by moving to new places.
3. Organs and structures that are needed evolve.
4. Individuals can adapt to survive.

Natural selection: Changes in a population (Bishop and Anderson 1990; Jensen and Finley 1995)

(a) The population of ducks evolved webbed feet because. . .

. . . the most successful ducks adapted to their to their aquatic environment.	1	2	3	4	5	. . . the less successful ducks died without offspring.

(b) Why did you choose this answer?

Theory of evolution: The cheetah problem (Bishop and Anderson 1990)
Cheetahs are able to run fast, around 100 km/h, when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could only run at 30 km/h?

Theory of evolution: The lice problem (after Jiménez-Aleixandre 1994)
The following question was given in a biology test: 15% of school children were infected by head lice during the winter. The exact cause of this recent epidemic is not known, given that hygiene has improved, but everything seems to point to the fact that insecticides no longer seem to have any effect on lice. How do you think a biologist would explain the fact that insecticides affected lice some years ago but not now?
The answers from two students were:

Student A: Because being an animal that gives birth so many times, only the strongest stay alive; those not affected by the insecticide and their offspring are attacking now.

Student B: Against the higher quantity of insecticides, the lice seek survival, and get used to them; this is what in biology is known as *adaptation*, until in the end it doesn't affect them; that is, they became *resistant* to the insecticide, and the new generations will inherit this and will be more resistant over time, because, following Mendel's laws, new generations evolve until they are more perfect than the former.

(a) Choose the answer that best agrees with the theory of evolution! Answer A or Answer B?
(b) Why did you choose this answer?

6 The reasoning of students aged 11–16 about biological evolution

Clas Olander

DEPARTMENT OF EDUCATION, GÖTEBORG UNIVERSITY, SWEDEN

clas.olander@ped.gu.se

The approach in this study was to design and validate topic-oriented teaching–learning sequences as a collaborative effort between teachers and researchers. In an iterative process, data about learning and teaching of biological evolution were generated through continuous cycles of design, teaching, evaluation and redesign. The participating teachers worked with students aged 11–16 (grades 5–9) in compulsory school in Sweden. This paper focuses on the students' ways of reasoning when writing about evolution. The overall aim was for the students to be able to use the theory of evolution as a tool when explaining the development of life on earth, and for the teaching to emphasise the students' active use of scientific language and ideas. Students in the experimental group were found to develop their reasoning, which was estimated using pre- and post-tests. Students in the experimental group also attained the aim of the study to a greater extent than a national sample. This result was observed even among the youngest students, indicating that evolution is a topic that can be taught at an earlier age than is currently the norm. The results of this study argue that the exemplified contributions have the possibility of strengthening the practical application of educational research, e.g. tools for scaffolding and assessment for learning.

1. BACKGROUND: FRAMEWORK AND AIMS

Whether or not there is a dividing line between research and practice is an issue that concerns governments as well as communities of educational research (Millar *et al.* 2006). Design research is one strategy to bridge the supposed gap between research in science education and current teaching practice. Several groups in Europe work in this field (for an overview, see Méheut and Psillos 2004). The approach in the study presented here was to design and validate topic-oriented teaching–learning sequences in authentic practices as a collaborative effort between teachers and researchers. In an iterative process, data about learning and teaching of biological evolution were generated through continuous cycles of design, teaching, evaluation and redesign (Andersson *et al.* 2005).

The general theoretical framework of our teaching–learning sequences is a social constructivist perspective of learning (Leach and Scott 2002; Andersson and Bach 2005) where language and communication are essential in the development of understanding. The relationship between learning and teaching is not straightforward, but Lemke (1990: 172) gives several recommendations for science teaching, e.g. the importance of talking and writing in science class and the need to 'have students translate back and forth between scientific and colloquial statements or questions'. Most science educators would agree with Ogborn (1997) that science consists of ideas created by humans. This also means that students cannot discover scientific ideas merely by observations and experimentation on their own. On the contrary, students are dependent on scaffolding from books, other media or educated persons (Mortimer and Scott 2003), especially as learning science also involves learning a specific language agreed by the scientific community. Teachers are therefore important as representatives of scientific culture and introducers of ideas and language usage.

In science classes, students are often asked to explain phenomena and are then expected to use a causal explanation. This is not a self-evident task. First of all, students have to distinguish descriptions from explanations. Ogborn *et al.* (1996: 14) concluded that describing and labelling is common in science classrooms, because it provides 'material for explanations. The entities which are to be used in explanations have to be "talked into existence" for students.' When explaining biological phenomena, students often use spontaneous and situated explanations. This could mean attributing human characteristics to non-human organisms, or reasoning in terms of events having a goal, purpose or even a design, i.e. anthropomorphic or teleological reasoning (Zohar and Ginossar 1998, Kattmann, Chapter 1, this volume). According to Kelemen (1999), reasoning in a teleological way is common in the sense that we always ask 'Why?' and 'What's that for?' when confronted with a biological event. For example, when we see the webbed foot of a duck, we immediately explain that it is for swimming. Causality in biology could be regarded as either proximate or ultimate according to Mayr (1961) or, as Ariew (2003) rephrased it, proximate or evolutionary explanations. Answers to questions that start with 'What is the cause?' tend to be short term (proximate) where responses are due to immediate previous events (these short time scales are appropriate in physiology and medicine), whilst evolutionary (ultimate) explanations involve a longer period of time, such as several generations, and selection. Students often do not distinguish proximate and evolutionary explanations or do not recognise what kind of time perspective their answer should deal with. Abrams *et al.* (2001) developed the idea that there are both proximate and ultimate answers to 'how and why' questions. Ariew (2003) suggests that answers to questions about 'how' should refer to proximate causes, whilst evolutionary explanations are more fruitful for 'why' questions.

The majority of published studies about learning and teaching of evolution deal with older students in voluntary school forms, e.g. upper secondary school or high school, whilst studies that investigate younger students' understanding in compulsory education are less common. One reason for this is that biological evolution is taught late, if at all, in compulsory schooling. Zetterqvist (1998) reported that in Sweden only 10 per cent of the teachers teach evolution continuously in grades 7, 8 and 9 (age 13–16) and 45 per cent address evolution exclusively in the last semester of grade 9. Jiménez-Aleixandre (1992) stressed the importance of using theory when teaching. She described a successful teaching intervention with 14-year-old students that focused on explicit comparisons of explanatory models referred to as 'thinking about theories or thinking with theories'.

Evaluation of interventions in school could be either internal, e.g. pre- and post-tests, or experimental versus control groups, i.e. an external evaluation where the aim is to compare with other teaching practices. Irrespective of the approach, evaluation is performed in relation to specific goals. The Swedish curriculum for compulsory schooling in grades 1–9 states that 'the school in its teaching of biology should aim to ensure. . .that pupils develop their knowledge of the conditions and development of life and are able to see themselves and other forms of life from an evolutionary perspective' (National Agency of Education 1994). In the present teaching–learning sequence, this was interpreted as meaning that the students should be able to use the theory of evolution as a tool when explaining the development of life.

Specifically, this study focused on how students reason in qualitatively different ways about biological evolution. Students' written answers were analysed before and after intervention, and also in comparison with a national sample.

2. METHODS

2.1 Design of the study

The study could be described as a cyclic knowledge-building process, in which both teachers and researchers contributed. Explanatory letters were sent to schools and as a result four teachers volunteered to participate. It was not a random sample, but these teachers represented various teaching experiences, gender and age. The students were all part of the compulsory school system and came from different environments: one school was situated in the centre of town, two were in multicultural suburbs and one was slightly outside town but still within commuting distance. All four teachers carried out the sequence twice with different groups during one school year (Table 6.1). This meant that about 180 students in eight groups, aged 11–16 years, were involved (these groups are henceforth referred to as 'the experimental group'). Data about the students were generated from a written pre-test and a delayed post-test (3 months later), logbook entries, videos and observations of classroom practises, and peer-group discussions.

During the first design phase, teachers and researchers had four meetings and discussed the nine aspects shown on the periphery of the circle in Figure 6.1. As our overall goal, we decided that students should be able to use the theory of evolution by means of natural selection as a tool when explaining the development of life on earth. This meant a restriction to adaptive evolution (natural selection), and there was a conscious decision, mainly due to time limits, not to include for example neutral evolution or drift. The teaching strategy was to build on students' use of scientific language and ideas, i.e. talking science, with many opportunities to discuss their own ideas. We agreed on a first set of areas to highlight: evolutionary time, heredity, variation and selection. We suggested some student activities around these areas. In addition to this, the teachers had the opportunity to plan their own teaching, guided by local circumstances, e.g. in relation to their students' age and previous experience.

After the first cycle, we evaluated the outcomes, shared our experiences and redesigned the sequence. The teachers proposed new activities and at the same time pointed out weaknesses in other activities that had shown a low contribution to the overall goal when tried in practice. New key aspects were incorporated, e.g. the nature of science, especially discussions about what a theory could be, and the relationship between science and religious faith. Again, the teachers were free to choose activities as long as they engaged students in 'making meaning' around key aspects. Often this meant that teaching was organised around group activities where students were supposed to justify their argument, e.g. when students had played a game where they acted as predators, they were asked to explain the results of the game. This is probably not a unique approach, but teachers in this project encouraged students to use the introduced key terms such as variation and selection in their reasoning; students were offered explanatory tools and were given the opportunity to practise talking science. These group discussions were followed by whole-class discussions and summaries by the teacher.

Table 6.1 The working process over two cycles

Month(s)	*Process*
May/August/September/October	Design meetings
November/December	Teaching 1
January	Evaluation 1/new design
February/March	Teaching 2
May/June	Evaluation 2

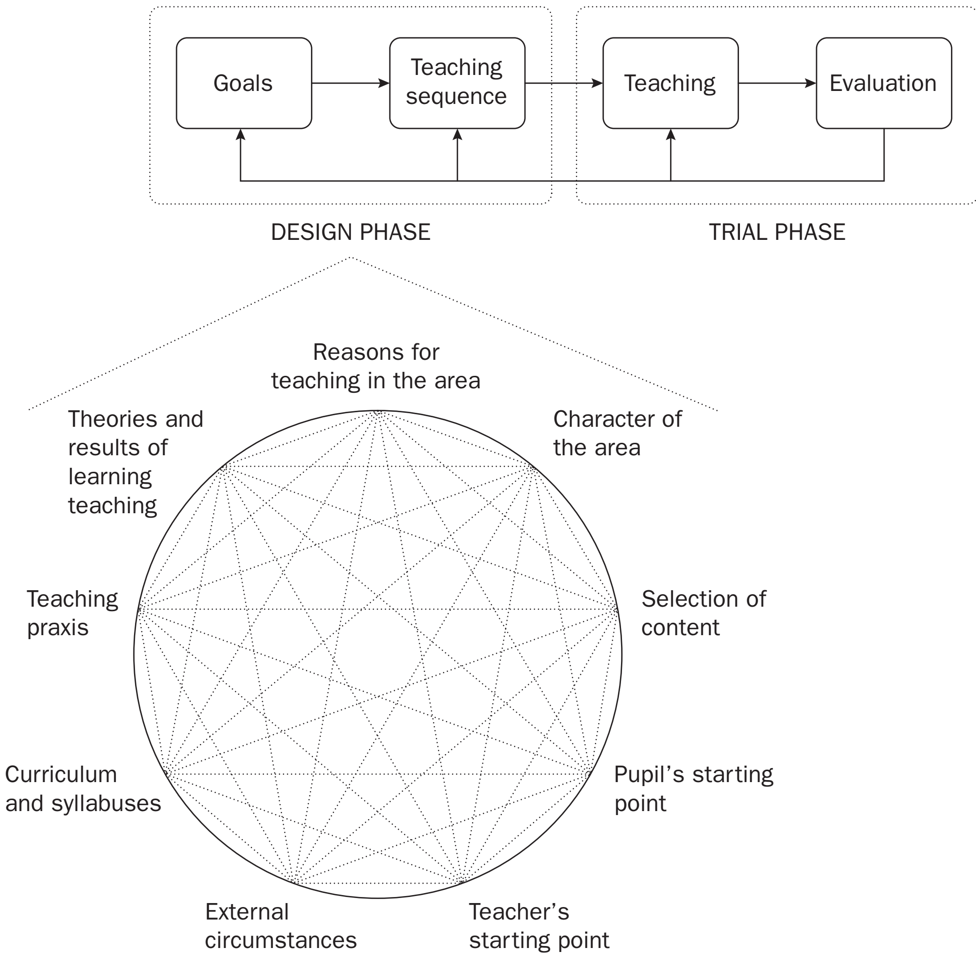

Figure 6.1 The cyclic working process (top) and aspects of the design phase (around the circle)

2.2 Analysing answers about the evolution of a new trait

The overall goal of the sequence was to enable students to use the theory of evolution as a tool when explaining the development of life on Earth. In order to assess this objective, we gave students, among other things, a delayed post-test 3 months after the teaching had ended. One question in the post-test was adopted from Bishop and Anderson (1990):

> Cheetahs are able to run fast, around 100 km/h when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could only run at 30 km/h?

Students' written answers were grouped in order to reflect qualitatively different ways of reasoning where categories originated from reading answers repeatedly. The researcher was aware of previous educational research about students' ideas and ways of arguing, as well as scientific views of the specific area, but the students' actual wording was considered to be the most important factor. The students' answers to the 'cheetah' problem were categorised as follows:

(a) Student describes but does not explain: 'They developed and got longer legs and they became more vigorous.'
(b) Student explains in a teleological way, mainly with words like 'need', 'had to', 'strive', etc.: 'Cheetahs have to run fast in order to catch their prey.'
(c) Student explains with some scientific terms: 'A biologist would explain like this; it got mutations in the genes of the cheetah, which made it run faster.'
(d) Student explains in terms of natural selection: 'When one cheetah was born it had e.g. longer legs, which made it run faster and therefore get more food, survive longer and then spread its genes.'
(e) Student gives no answer, repeats the question or gives an irrelevant answer: 'Don't know', etc.

The categories reflected qualitatively different levels of reasoning. The answers in the first category described change, either changes in the environment or in the anatomical changes an animal might have gone through when evolving the actual trait. Here, it is also a matter of knowing what the acceptable school scientific vocabulary is, especially the distinction between a description and an explanation. Teleological or anthropomorphic answers were put together in the second category, and here the students tried to explain with a purpose in mind. Explanations in category (c) were influenced by some scientific terms, mostly 'genetic words' and mainly dealt with proximate causes. This involved a mix where students' growing understanding and mimicking of the scientific language was used. Natural selection was the basis of the fourth category, but the depth of the explanation varied from simply mentioning differential survival to differential reproduction and accumulation of a trait/gene.

2.3 Analysing answers about the origin of a new trait

> In the future, it is most likely that entirely new hereditary traits will develop among living organisms – traits that never existed before. What is the origin of an entirely new hereditary trait?
>
> Choose the statement that you consider is the best. Justify your choice.
>
> - The individual's need for the trait.
> - Random changes in the genes.
> - The species strives to develop.
> - Nature strives for equilibrium.

The second question, shown above, dealt with the origin of a new hereditary trait. The answer most in line with the scientific explanation is 'Random changes in the genes.' The question was given as a multiple choice, used previously by Wallin *et al.* (2001), and the students were requested to give a reason for the chosen alternative.

A system of categories was generated in the same manner as above in relation to the open- ended justification task. Two main categories emerged. One type dealt with descriptions or explanations of development in general, whilst the other was based on ultimate causes of new traits. The latter type of answer referred more thoroughly to the heredity part of the task. The first type of answer used words like 'need', 'strive' and/or 'adaptation', often referring to individual organisms.

2.4 Selection of questions and mode of comparisons

The Swedish National Agency for Education initiated a national assessment in 2003, which was given to a random national sample of students in grade 9. In biology, students were given 12 tasks to solve, two of which dealt with evolution. These questions were also given to the experimental group, but only in the delayed post-test, so that they were unfamiliar to the students and could serve as a point of comparison with the national sample. However, the students' level of ambition was probably lower in the national sample, i.e. there are around 50 per cent who did not answer the open-ended tasks compared with less than 10 per cent in the experimental group. It should be noted that this was not a case of missing values; the students had the opportunity to answer, but preferred not to write anything, or wrote something irrelevant. With these differences in answering rates in mind, a conversion of the national assessment results was made in order to get a fairer comparison and not to overrate the results of the experimental group. The percentages presented in the findings were recalculated as proportions of students answering the actual question. The same recalculation was applied to the experimental group.

The intercoder reliability was checked by giving the answers and category headings to two educational scientists who were familiar with the issue. They independently categorised the answers to two questions. Initially, there was agreement between their results and mine in 77 per cent of the cases, and after a discussion about the interpretation of headings, 90 per cent agreement was reached.

3. FINDINGS

3.1. Experimental group versus national sample

3.1.1 Evolution of a trait

One of the questions was about the evolution of cheetahs' ability to run fast (see section 2.2). In the experimental group of 15–16-year olds (grade 9), half of the students answered in terms of natural selection. In the Swedish national assessment, 14 per cent of the students answered in a similar way. Of the experimental group in grades 5–7, an average of 15 per cent gave answers in the category 'natural selection' (see Table 6.2). As mentioned before, a recalculation of all groups was made so as not to overestimate the results of the experimental group. Following this recalculation, the number of students that were compared then decreased in the experimental group grades 5–7 from 80 to 73, i.e. seven students did not answer the question. In the same way, the number of answers from the experimental group for grade 9 declined from 83 to 82, and the national sample from 620 to 335.

Table 6.2 Students' explanations of how the cheetah's ability to run fast has evolved

Category of student response	*Experimental group (%)*		*National sample (%)*
	Grades 5–7 (n = 73)	*Grade 9 (n = 82)*	*Grade 9 (n = 335)*
(a) Describes but does not explain	14	9	38
(b) Explains in a teleological way	49	25	38
(c) Explains with some scientific terms	21	16	10
(d) Explains in terms of natural selection	15	50	14

In the national sample, 76 per cent of the students who gave answers used a type of reasoning that was not in line with the scientific view. In the experimental group of the same age, the proportion of non-scientific answers was 34 per cent. Even the younger students, in grades 5–7, answered in a more scientific way in the experimental group than grade 9 students in the national sample.

It should be noted that, unless otherwise stated, the differences between the groups listed were significant, with a χ^2 value of $P<0.001$.

3.1.2 Origin of a new trait

The question about the origin of a new trait was discussed in section 2.3. Here the proportion of results with 'no answer' in the multiple-choice question was the same in all groups so no recalculation was necessary.

The choice of answer that is most in line with the scientific view is 'Random changes in the genes.' This was also the answer that was chosen most often by all groups, but both experimental groups chose the correct answer significantly more often than the students in the national sample (Table 6.3).

Table 6.4 shows examples of the students' written statements when asked to justify their choice of alternatives. The percentage of students in the experimental group in grades 5–7 who explained the origin of the new trait was lower than the percentage of students who correctly answered the multiple-choice question (Table 6.3), mainly because many of the students did not write any explanation as justification. On the other hand, the percentage rates for the groups in grade 9 was higher. This increase was due to the fact that students wrote a justification in line with a scientific view, despite of their choice of an incorrect answer in the multiple-choice question. As an example, two explanations from students who chose the alternative 'need' in the multiple-choice question are given in Table 6.4.

It is noteworthy that there was no difference between the answers from the national sample and the experimental group in grades 5–7; they gave similar answers in spite of the age difference. The experimental group in grade 9 wrote answers more in line with current views in science with a greater frequency (an increase of 27 per cent compared with the national sample).

3.2 Experimental group before and after teaching

In the pre-test, the students were asked to explain how a trait had evolved in seals.

> Seals can remain underwater without breathing for nearly 45 minutes as they hunt for fish. How would a biologist explain how the ability to not breathe for long periods of time has evolved, assuming their ancestors could stay underwater for just a couple of minutes?
> (Settlage 1994)

Table 6.3 Students' choice of answer for the origin of a new trait

Multiple choice alternative	*Experimental group (%)*		*National sample (%)*
	Grades 5–7	*Grade 9*	*Grade 9*
(1) The individual's need for the trait	29	27	24
(2) Random changes in the genes	45	57	31
(3) The species strives to develop	13	11	30
(4) Nature strives for equilibrium	8	0	8
No answer	6	6	6

Table 6.4 Students' justifications of the origin of a new trait

Category of student response	*Example of response*	*Experimental group (%)*		*National sample (%)*
		Grade 5–7 (n = 59)	*Grade 9 (n = 82)*	*Grade 9 (n = 335)*
(a) Explains the development, but not the origin of a new trait		65	38	59
(a1) Describes development	'At first humans were apes and then over the years we have developed to become humans.'	24	11	10
(a2) Uses 'need' as a rationale	'You develop things that you have a great need of in order to survive.'	22	18	15
(a3) Uses 'will/strive' as a rationale	'Everybody wants to develop and become better. Then maybe you develop if you try.'	14	5	21
(a4) Uses adaptation	'Animals adapt to the environment you/they live in. Something like the birds on Galapagos.'	5	4	13
(b) Explains the origin of a new trait		35	63	41
(b1) Explains how 'changes in the gene pool' originate	'It could have been like when a baby is malformed but something good happens instead and you get that trait.'	27	31	31
(b2) Also specifies the mechanism of natural selection	'If an animal happens to get a random change which gives that individual an advantage, it makes it live longer and it is able to spread its genes. . .'	8	32	5
(c) Other	'E.g. a mole that lives on worms has to dig in soil; it was therefore made with feet that are easy to dig with.	0	0	5

Results are given as percentages after recalculation of *n*.

These answers were compared with the answers given in the post-test about the evolution of a trait in cheetahs. There may be a problem of comparison when you change the question. Students may have different experiences or knowledge about the subject of each question, in this case, seals and cheetahs. From pilot studies, we concluded that the difference in context had little effect. The advantage was that presenting a totally new question would make the comparison with the national sample fairer, as it would be a novel question for both groups. The students did improve their explanation with respect to the use of more scientific language (see Table 6.5): this occurred more

Table 6.5 Students' explanations of how a trait evolves

Category of student response	*Grade 5–7 (%)*		*Grade 9 (%)*	
	Pre-test (n = 81)	*Post-test (n = 80)*	*Pre-test (n = 87)*	*Post-test (n = 83)*
(a) Describes but does not explain	43	12	36	8
(b) Explains in a teleological way	38	45	46	25
(c) Explains with some scientific terms	4	19	5	16
(d) Explains in terms of natural selection	1	14	2	49
(e) Not answered	6	9	10	1
(f) Other	7	1	1	0

with the grade 9 students than with the younger students. There were few differences between grades 5–7 and grade 9 with regard to the pre-test results and the percentages were nearly the same for categories (c) and (d), which were the categories with at least some scientific terms.

4. DISCUSSION AND IMPLICATIONS

The prevalence of teleological expressions when explaining evolution is well documented in the literature and this study showed the same pattern when students answered questions before the teaching intervention. However, the findings indicated that students in the experimental group did develop their reasoning, according to the goal, based on the results of the pre-test and the delayed post-test. Students in the experimental groups also attained the goal to a larger extent than the national sample. This was the case even with the younger students, indicating that evolution is a topic that could feasibly be dealt with at an earlier age than is currently the norm.

The national assessment is one point of reference with regard to the actual teaching practice of evolution of life in Swedish compulsory schooling. Two striking features were the low attainment of national goals and the large proportion of students who chose not to answer. The researchers who wrote the report (National Agency of Education 2004) speculated that, although the curriculum since 1994 has emphasised evolution, apparently teaching practice does not. This conclusion is supported by the present study, as students, irrespective of their age, gave similar answers in the pre-test. If this is a reflection of teaching practice, it shows few signs of the impact of previous teaching of evolution. Another similarity between the outcome of the national assessment and pre-test results from this study was the high proportion of descriptions. Students tended only to describe changes, anatomical and/or environmental; they did not give explanations. This proportion of descriptions was reduced when students answered the questions 3 months after teaching. A tentative explanation of this reduction is that, during the teaching sequence, the descriptions have been 'talked into existence' as Ogborn *et al.* (1996) suggests.

An interesting issue is whether this 'good outcome' is due to some specific part of the intervention. Two main points in the approach were 'using theory as a tool' and 'talking science'. Teleological reasoning is so intertwined in our way of reasoning that there is no way of escaping it. We have to get the words out into the air as Zohar and Ginossar (1998) and Ulrich Kattmann (Chapter 1, this volume) suggest, always letting the students investigate what colloquial words stand for in a scientific environment. One example is the frequent use of the word 'need' when explaining evolution, which in this study was used most often when students reasoned with a purpose in mind, i.e. teleologically.

However, there were examples when students elaborated on this word and made sound scientific sense of it. This also calls for caution about context when interpreting statements as teleological (Wallin *et al.* 2001). The teaching intervention focused on 'theory as a tool', which might be an important critical detail, as Jiménez-Aleixandre (1992) has proposed. Further analysis of students' discussions in group activities could shed light on how the students perceive this and other critical aspects.

The purpose of the introduced system of categories was to reflect different qualitative levels of reasoning. It works as an analytical tool and could facilitate assessment of learning (Black and Wiliam 1998), i.e. it could give the teacher clues about what to distinguish in the scaffolding process. The range of different answers could be seen as a reflection of Vygotsky's notion of the 'zone of proximal development', in the sense that the system of categories points to a possible range of explanations. It is connected to teaching at school because, according to Vygotsky (1978: 84), school learning 'is concerned with the assimilation of the fundamentals of scientific knowledge'. Another tangible application of the system of categories is to distinguish between different types of causation. As causality in biology can be understood and applied as both short-term and long-term causation, it is important that those who pose questions and those who answer them both interpret them in similar ways. In category (c) ('Student explains with some scientific terms'), many answers contained explanations on a short-term, proximate level. They often referred to recent events as mutations or changes in DNA without connections to time, several generations or other evolutionary reasoning.

The approach and contributions from this study have the possibility of strengthening the practical application of educational research. Contributions are repeatedly validated in authentic practice, e.g. tools for scaffolding and assessment for learning. In this respect, this study promotes a bridge between educational research and practice.

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2 Student interest and motivation

7 Choosing biotechnology: a narrative exploration of significant educational episodes influencing career choices in biotechnology

Bev France[1] and Catherine Buntting[2]

[1]FACULTY OF EDUCATION, UNIVERSITY OF AUCKLAND, NEW ZEALAND; [2]CENTRE FOR SCIENCE AND TECHNOLOGY EDUCATION RESEARCH, UNIVERSITY OF WAIKATO, NEW ZEALAND

b.france@auckland.ac.nz; buntting@waikato.ac.nz

Biotechnologists have the potential to be role models for students of science and technology. In this study, a series of conversations with biotechnologists explored the pedagogical potential for capturing students' interest. This research, where biotechnologists told their educational stories, provides a vehicle for both biotechnologists and the reader to identify and make sense of the educational situations (formal and informal) that open doors to a career in biotechnology. The research design provided space for four biotechnologists to recount their educational journeys to their present positions, as well as the educational influences that impacted on their career pathways. A narrative inquiry methodology was used to develop their stories so that their experiences were made meaningful by the co-construction of a narrative between the participant and the researchers. The analysis was in terms of how the participants (biotechnologists and researchers) made sense of what happened. As well as providing an insight into the qualities they believe are important in practising their profession, the narratives made sense of educational experiences that influenced career choices. Such conversations provide an opportunity to examine those educational interactions that may facilitate border crossing between biotechnologists and the educational community.

1. INTRODUCTION

An interview with Professor John Tagg on New Zealand's National Radio provided the inspiration for this research. In the interview, we heard the story of a 12-year-old boy who had caught rheumatic fever from a throat infection and was required to take penicillin every day for 10 years. Professor Tagg was this boy, and he remembered being told that he smelt like a mushroom. This experience had a significant impact on his career choices. His interview was reported in a teaching publication:

> '. . . and I thought, there's got to be a better way.' The result was that he went on to university and trained as a microbiologist 'to try and find a better way to prevent *Strep* sore throats. . .a better way than letting forth an atomic bomb blast of penicillin . . . why not stop the infection at the start?' He went on a 15-year search 'for a friendly bacterium that would target the bad guys'.
>
> TENZ (2002: 11)

Professor Tagg trained as a microbiologist and, later in his career, developed an application for BLIS (bacteriocin-like inhibitory substances), a pharmaceutical product that introduces probiotic organisms into the body to increase immunity to sore throats (O'Hare 2002).

Even though this and other stories about scientists exist in the literature, there are few narratives that teachers can examine for information about how to bridge the gap between the world of the scientists and classroom-science education experiences. The stories of Bianca, Charlotte, Janine and Noriko (Chinn 2002) provide one example, and demonstrate the power of narrative inquiry to reveal the complexity of influences interacting in scientists' career choices.

The current research used narrative inquiry to explore and analyse the formative educational experiences of four biotechnologists. The intention was that these narratives would provide an opportunity for educators to see the world from other viewpoints, and to layer these events into a 'communal practice of lived experience' (Wenger 1998) that enables borders between the two communities of biotechnology and education to be broached (Aikenhead 1996).

This narrative research provided opportunities for biotechnologists to tell the story of their educational journey and to identify specific episodes they considered to be significant. The key research question was: What are the significant educational (formal and informal) episodes that may have influenced you in your career choice?

2. RESEARCH DESIGN AND RATIONALE FOR A NARRATIVE INQUIRY

Narrative inquiry provides space to understand the complex influences upon human decision-making (Gudmundsdottir 1991) and is based on the premise that people's actions and the choices they make are deeply personal matters inexorably linked to one's identity and life story (Carter and Doyle 1996). As Polkinghorne (1988: 14) observed: 'At the individual level, people have a narrative of their own lives which enables them to construe what they are and where they are headed.'

With this methodology, personal meaning can be given to particular incidents. The episodes become artefacts that are constructed in such a way that both the narrator and the reader can gain a new understanding of the larger issue(s) behind the incidents (Gudmundsdottir 1991). The power of narrative is in its ability to be recognised by others as resonating with their own experiences (Xu and Stevens 2005). For this reason, a narrative research design should provide a dialogue of comparison and recognition that can make one's own experience a lens of empathy (Carter and Doyle 1996). In order to develop verisimilitude, authenticity, plausibility and transferability, it is recommended that a collaborative development of a narrative occurs within a process of mutual storytelling and re-storytelling (Connelly and Clandinin 1990; Clandinin and Connelly 2000).

This study involved the co-construction of narratives with four biotechnologists who were interviewed by telephone and then provided with opportunities to contribute to the ongoing co-construction of their story. They were chosen opportunistically because the researchers had met them informally before formally requesting their participation. This negotiation of entry was given particular attention in order to give a sense of equality among participants (Clandinin and Connelly 2000).

To facilitate the co-construction of a story, the researchers provided an underlying direction by providing questions prior to the telephone conversation. However, these were not intended to prescribe the direction or pace of the conversation (Casey 1995–1996).

The questions were:

- Tell me about your job. Tell me about your journey to this position.
- Tell me about your experience of science at school. What were your impressions?
- Can you remember anyone who fostered your interest in science?

- What were the most important influences that opened the door to your participation in the scientific world?

Transcripts of the interviews were sent to the participants as the first stage of co-construction and they were asked to record additions, elaborations and contradictions. Because narrative analysis presumes that personal narratives are organised into implicitly evaluative schemas that help the speakers (i.e. the biotechnologists) to construct and understand their own lives, notes about the analysis process accompanied each transcript and the initial narrative. These notes provided them with evidence that 'lack of grammar' in oral conversations is not 'ungrammatical', but is a perfectly normal way of negotiating a verbal story with their audience in order to develop coherence (Linde 1993). For example, marker words such as 'because' and 'so' indicate that the speaker is demonstrating coherence, and 'you know' indicates an attempt at negotiating a shared understanding between the speaker and the listener (Devault 1990). The addition of phrases to these marker words further emphasised that such explanations and evaluations were occurring, for example, 'so that', 'so of course' and 'so I decided'.

Evaluative schemas were identified through a process of open coding, and narrative sketches were developed that included a broad description of the plot (educational journey) and scene (community in which they worked). Secondary analysis used open coding to identify themes underpinning educational episodes. The levels of the narrative were thus the educational episodes (first level), combined into a narrative (second level) that illustrated a particular theme and gave meaning to the episode (third level) (Gudmundsdottir 1991).

In order to show the complexity of the stories, the following writing devices were used: where possible, the biotechnologist's voice was left unedited, indicator words were identified, explanatory comments were included within square brackets and the researcher's voice was kept to a minimum with only the occasional question or linking statement contributing to the story.

3. FINDINGS

Each person was placed within their institutional setting, and the narrative provided a statement about their beliefs about science that was intended to provide the reader with a glimpse of their attitudes. In each case, only one educational episode is reported.

The biotechnologists were:

- Mary, an industrial biotechnologist;
- Jan, a research scientist;
- Malcolm, a senior science technician;
- Regina, a research biotechnologist.

3.1 Mary, an industrial biotechnologist

Mary is an industrial scientist working for a company that produces value-added products from animal sources. She leads a team that tests new products, for example bioactive compounds used in food products. As a senior development scientist, she designs and evaluates experimental programmes.

Her enthusiasm for science was very evident:

> Seeing the results. That still gets me up in the morning. When I go to work, have I got results to go and look at? Because it is really exciting to see what's happened. You have set up an experiment for a reason . . . you are endeavouring to find out something. You are trying to work out a puzzle or to solve a problem. What's the answer going to be? Can you

> interpret an answer? Is it completely different from what you expected? That sort of thing really gets me going.

Mary reflected on the qualities that she considered important when working in science:

> The fact that I take care about my observations. I write everything down even though it may not seem relevant at the time. Because you can always go back and have a look at it when you get another result that may shed light on the situation. Possibly the people that I manage don't appreciate this, but I always insist that everything is written up and that you don't just do an experiment and then discard it. Write it up properly so that you can go back to it and refer to it.

The following extract from an educational episode provides a link between Mary the observing scientist and Mary the observant schoolgirl.

3.1.1 Educational episode: watching the teacher teach

Mary was aware of the teacher's interactions with the class. Mary tells of her experiences in the chemistry class:

> I don't know what it was about chemistry that fascinated me. . .Maybe mixing the chemicals, doing stuff in test tubes, because there were reactions, there was something happening, there was either a gas coming off or there was changing colour or something was going on. And it was all about the observation of it. It was crucial that you looked at what was going on.
>
> Trying to understand it. Why did it change colour? Because that's quite a mystery. A mysterious thing that you could add two colourless solutions and suddenly you would have a really brightly coloured result . . .
>
> Well, it was really funny at the time, I remember one of my science teachers always had this pre-programmed thing in her mind about what the colour should be, or what the reaction should be. And sometimes it wasn't that at all and it used to drive her nuts. And it was hilarious for the class when she would say, 'Look at this bright pink.' And it wasn't pink at all, it was red or whatever colour it was.
>
> And I think she said, 'Well, okay, it's not bright red but it's almost red.' Well, you know, it was interesting because instead of waiting to see what would happen, she would always anticipate it in terms of what was supposed to happen. And I suspect probably the chemicals weren't pure so you weren't to see necessarily the true reaction.
>
> But I think one of the things, too, I always enjoyed about [the practical work] was the observation. Writing down what you see. Not making a predetermined guess about what you should see, but actually what you observe.
>
> To be honest, to this day that is something that I remember doing. And even when I am talking with other people now: 'What did you see, don't tell me about what you expect to see. What did you actually see?'

3.2 Jan, a research scientist

Jan is a team leader of a research group of government-funded scientists investigating gene expression patterns in crops. The team uses microarrays to look at the changes in gene expression involved in fruit development from pollination to fruit harvesting:

> And [the research is] almost pure discovery science, in a sense; we are collecting a huge number of observations. We are going to look at those observations and see what shows up, and then follow where that leads us. Let's look at everything that is happening and then see if that raises other questions for us. . .and of course it will.

Jan is acutely aware of the need to do 'good' science as the following comment reflects:

> No science is bad. All observations are important, but sometimes you can be doing things that are relatively mundane, where you can very much predict what you are going to get from an experiment.
>
> And other times you can be doing experiments where you are really not sure what you are going to get as the answer and [these questions] are inherently more interesting. Or . . . you can be using techniques that are less well developed so you might have to spend more time on the technical part of the work to get things working. And that can be very hard sometimes, but very rewarding because a new technique or new technology allows you to capture new observations.

His reflections of his schooling have a strong metacognitive focus as the following educational episode demonstrates.

3.2.1 Educational episode: valuing the process of learning

Jan's parents are European immigrants who settled in New Zealand after World War II. Neither parent had a scientific education, but both valued learning. He remembers:

> They were always not so much interested in science, but interested in learning. They didn't really care what we learned. I mean, one of the messages I got from my father was it doesn't really matter what you learn, just learn. He really meant it and you know it could be anything from languages to politics through theology to science. Learning was the key activity that was important.

An incident that supported this philosophy occurred when he was at intermediate school.

> In Form 2, I was very lucky. I had one teacher there, Mrs G., who was my home room teacher. And I distinctly remember one thing she did. We spent a couple of weeks studying learning and so, you know, we all had assignments to go and look at how people learn, and different kinds of learning, and how people remembered things and so on.
>
> She allowed us to come to the conclusion that what we learned at school was pretty much irrelevant. It almost certainly would not have much relevance in our careers. It almost certainly would not be what we used day to day and therefore really the only point of what we were learning in school was the process of learning. It's a measure of how good a teacher she was that she allowed the class to realise that.
>
> And that one piece changed the way I looked at what I did at school from then on because it didn't really matter. Again, coming back to what my father had already said, it didn't matter what I was studying, it was how I was studying that was important. And learning how I learned things. And then when I needed to learn anything new I would have those skills, and the idea that learning is a skill which you can improve with practice.

3.3 Malcolm, a senior science technician

Malcolm works in a government-funded research centre and is responsible for 160 possums in two free-range facilities. His job has both curatorial and scientific components. Some of the research activities carried out under his guardianship include the immunisation of possums with biological agents that could compromise fertility, monitoring the reproduction of females and biochemical assays to measure hormone levels in blood, as well as dissecting adults and joeys.

Malcolm described a sophisticated and complex relationship with the possums:

> I really like the animals. The animals are probably one of the best things about the job, mainly because some of them I've worked with for so long. Some of our animals are on a sort of a breeding trial and we've got breeding records for those animals going back 5 years in some cases. So in a way they're a bit like pets, those ones.
>
> We've had a number of possums we use for demonstrating to school students and visitors as they were particularly well-behaved animals. One possum in particular, George, was particularly famous. George and I were on the front page of the *Evening Post* one year, George sitting on my shoulder eating a jam sandwich (his favourite).

However, he is very aware that these animals are experimental animals:

> But we've got another unit where we just bring in animals where we put them down almost immediately just to collect tissues from them for the experiments and . . . yeah, you just have to accept that happens and just try not to get too attached to some of them . . . or any of them sometimes.

With this realisation, Malcolm also recognises his responsibilities not only to the scientific enterprise but also to the animals.

> Certainly in my job, where I've got animal responsibilities, I find myself in there in weekends, after hours, and not necessarily because I need to be there. Sometimes I just go in there because I want to be there. I just want to . . . I want to make sure the animals are okay . . . yeah, make sure nothing has gone wrong.

3.3.1 Educational episode: doing science with scientists

Malcolm was introduced to a scientific community when he was invited to represent his school at a day's filming at the research institute in which he is now working.

> I was asked whether I'd be interested in going to [the research institute] for a day to represent the school. So I went along there and [a film producer] was there doing some filming . . . and they got me to do some gel electrophoresis and looking at the DNA . . . and I really enjoyed it, and we talked about science a bit . . . it was the first time I'd been in a real lab I think. And I knew that I was pretty privileged to be there, because no one else from my school or my year were there.

As a result of this experience, Malcolm was invited to participate in 3 days' work experience in the laboratory where the filming had taken place. He explains that this gave him a first-hand experience of working with scientists:

> Well, I was running a lot of assays and measuring antibody levels in blood samples that they had collected, and I guess a lot of it was just watching them do their work, but that was fun. I mean . . . I was at school and I'd never been in a lab and just watching them mixing up all their different reagents and things, it was quite exciting.
>
> And I remember going down to see the animals one day . . . they had to take a blood sample from a rabbit, and I remember walking through the small-animal unit and seeing possums in cages and rabbits and guinea pigs and . . . sort of not knowing quite what to make of it. Sort of aware that there were people who didn't like that sort of work going on, but also understanding the need for it to happen.

When Malcolm returned to school, there was no opportunity for him to talk about his experience and he had the sense that no one was really interested.

> I didn't [have to report on it], and nobody really asked me about it. I didn't really want to say a lot about . . . you know if people asked me, I would say what I did, but not a lot of people seemed to be that interested in it, yeah.

3.4 Regina, a research biotechnologist

Regina works in a government-funded research institute investigating the potential of marine bioactives and natural products. Even though she has a broad understanding of diverse biological issues, with a first degree in general biology, she is fascinated by the invisible world and her PhD research was in plant virology. She reflects:

> I liked the manipulation of small things. It didn't worry me that I couldn't see what I was doing. And the whole molecule thing. Altering this base and that particular part of the compound fascinated me, and how small changes in DNA have such huge and far-reaching changes to the whole organism.

The following description provides a vivid description of how molecular biologists work:

> It was really that small stuff . . . I remember once starting off with something in a tube that I couldn't see and I worked away for a whole week at this, whatever was in the tube. And at the end of the week I'd got to the stage where I could really visualise it again, and when I tried to see it on a gel, well, it wasn't there. And I don't know to this day whether I lost it 1 hour after I started my 1 week's work or whether I lost it 1 minute before I put it on the gel, but I could have been working with an empty tube for a whole week and I didn't know. It didn't matter to me. So working with those unseen small things and making these tiny changes as I said that lead to these big changes is something that really fascinates me.

Even though she was fascinated by the invisible world, Regina's initial interest in science was kindled by her fascination with the nature and the natural world.

> . . . because for some reason, all of my life, I've always had an empathy to the natural world. I really like things like that. I've always had a curiosity about looking . . . and I'd just spend all my time outside. My mother used to have a whistle and at tea time she would blow the whistle and you'd hear it a long, long way away and I'd know I'd have to come back then, but I was never around at home; I was always gone and doing stuff.

3.4.1 Educational episode: the nature table

Regina attended a small country primary school where the classroom extended into the countryside. The nature table was a vivid memory:

> I'd always contribute to the nature table, and certainly by the time I was in Standard 5 and 6 we'd do sort of ecology-type things. Where do you find animals? Why are they like this? What are they eating? How are the plants involved in this?
>
> You'd have to bring the stuff along and, you know, you might bring along a caterpillar chrysalis and you'd have to bring it along and then at morning talk time you would stand up and you would show your thing off and say, 'I found this in so and so and such and such,' and you'd say where you found it, and if you knew what it was you could say what it was.
>
> So you had to give a little talk about it, so it wasn't just dumping it on the table and leaving the teacher to attend to it. You actually had to give a wee talk about it and from memory people were primarily responsible for looking after their own thing. If they had a live thing on the table, then they had to look after it. The boys would sometimes bring mice or cockroaches and eventually they had to take them home. It was very interactive, if you see what I mean.

4. DISCUSSION

Because of the narrative research focus, it is not appropriate to make generalisations about these stories. Instead, we have chosen to identify some noteworthy characteristics that the each narrator contributed to the conversation:

- The level of passion and commitment that they brought to the scientific enterprise.
- The capacity to tell vivid stories about their educational experiences.
- The multiplicity of influences on their route to a career in biotechnology.

All four biotechnologists demonstrated a willingness to reflect on what was important in their work. These reflections enable the reader to make empathetic links with the passion and commitment exhibited in the stories. For example, in an attempt to explain her world, Regina reflected on the commitment required to do science:

> I enjoy science and you need to know there is depth [in the work]. You need to have the courage to do the science. You need to have the courage to be different and you need to understand that you have to do really good background work to make sure you can back up your own claims. And I think you have to be honest and ethical.

In the telling of self-selected significant educational episodes, the biotechnologists created a story of their educational experiences. Even though it could be said that these educational episodes depict an 'illusion of causality' (Neuman 2000), the coherency and vivid detail of the narratives provide a sense of authenticity. At the same time, the participants told a parallel story where they made sense of the incidents being described (Linde 1993). The following quote, from Jan, demonstrates this parallel internal conversation:

> I can remember a physics teacher . . . he was always struggling. And he had the worst time getting some of his experiments to work. And in a sense it was kind of fun because you

> always learned more figuring out why the demonstration didn't work than maybe you would have learned if it had all gone according to plan.
>
> And in retrospect, thinking about it . . . I guess the class was more involved in the failures than we would have been involved in the successes. And because of that, we were probably more involved in physics than we would have been otherwise.

The four narratives also demonstrated the complexities and multiplicity of educational influences on these biotechnologists' journeys that ranged from parental influences, experiencing good teaching, interacting with scientists and an early experience of the nature table in primary school.

5. FUTURE AVENUES OF RESEARCH

Because narratives deal with the particular rather than the general, there is no need to apologise for our opportunist choice of biologists or our lack of conclusions. Instead, the narratives provide examples of experiences with which the reader can empathise. What gives life to the narratives is that each of the biotechnologists can make sense of their educational experiences as they progressed along their diverse career pathways. However, we acknowledge that further characterisations could be developed and elaborated if this research was repeated with a more homogenous group.

What seems to us to be more important than generalisations is that these narratives provide an opportunity for border crossing between biotechnologists and teachers (Aikenhead 1996). This research has demonstrated the potential for critical examination of lived experiences in that these biotechnologists have critiqued their educational experiences. The telling of their stories may provide a link to a commonality of experiences. This will be explored in the next stage of the research, in which teachers will be asked to interpret the educational episodes for pedagogical relevance.

Preliminary analysis of the ongoing work suggests that the narratives presented here do indeed invoke parallel stories from teachers where they have remembered similar incidents in their own lives, or observed them in the lives of others. It seems that a parallel construction of a biotechnologist's and teacher's narrative could make the pedagogy visible (Arellano *et al.*, 2001).

As Halai and Hodson (2004: 205) noted, it is often 'not the facts and events of a life story that are important for teachers but the interpretation given to them that is meaningful'. It is hoped that the educational experiences highlighted in the narratives will provide an opportunity for educationalists to see the world from other viewpoints and to be able to layer these events into a communal practice of lived experience that enables borders between the two communities of biotechnology and education to be broached.

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8 Biotechnology education: topics of interest to students and teachers

Gillian Kidman

QUEENSLAND UNIVERSITY OF TECHNOLOGY, BRISBANE, AUSTRALIA

g.kidman@qut.edu.au

This paper presents the findings of a survey that investigated the biotechnology topics of interest according to students and teachers for inclusion in biology lessons and reports on the similarities and differences in biotechnology topics of interest to teachers and students. The study is of significance as biotechnology has been identified as a key area of technological and economic importance worldwide, yet there is scant literature relating to the interests of teachers and students concerning biotechnology education topics. The survey was completed by 500 students and their 15 teachers. Interviews were conducted with three teachers and 60 students. The responses indicated that there is a mismatch in the interests of students and teachers and what they perceive as possible topics for inclusion in biology and biotechnology lessons. Where teachers are provided with the freedom to design and assess their own units of work, this mismatch of interests causes problems. The study found students withdrawing from biology courses in post-compulsory settings due to lack of interest and a perceived lack of relevance of the course. It is possible that this lack of agreement on topics of interest is a factor in the worldwide decline in enrolment in the sciences.

1. INTRODUCTION

1.1 Aims of biotechnology education

'A recurring evidence-based criticism of traditional school science has been its lack of relevance for the everyday world' (Aikenhead 2006: 31). Many students do not see the relevance of the school science curriculum, a factor that contributes to the low number of students pursuing science courses in high school and university (Baram-Tsabari *et al.* 2006). There is a need for the science curriculum to be relevant, modern and reflective of the needs and values of the community. It is argued that by upholding these curricular guidelines, there is an important place in a modern science curriculum for biotechnology education to contribute to these needs and values. Biotechnology is increasingly playing a role in the daily lives of citizens and so of foremost importance is public understanding of this new technology. This understanding cannot occur without a sound and comprehensive biotechnology education. If people are not educated in this field of science and technology, they cannot have a meaningful participation in the public debates concerning these issues. A biotechnology education is required if students, and thus future citizens, are to be sufficiently informed to be able to engage effectively in public debate. In a contemporary science education, foundation knowledge of biotechnology principles and the related ethical issues are essential for effective engagement in public debate concerning biotechnology. The teaching of biotechnology therefore must provide a sound understanding of its scientific basis. In addition, there need to be opportunities for students to develop critical thinking and decision-making skills regarding the ethical use of biotechnology.

Biotechnology topics that could be taught in a general biology curriculum include: bioethics in biotechnology; biotechnology in agriculture, medicine, environmental science and industry; defining biotechnology; molecular biology of cancer; organismal biochemistry; microbiology; genetic engineering; human genetics and genomic libraries; molecular biology as a discipline; and DNA fingerprinting. However, teaching all of these topics is not practical. A mandate already exists in the case of the biological science curriculum in Queensland, Australia, to allow teachers in this state to use their professional judgement in making decisions on what materials are taught in view of their specific student circumstances (Queensland Studies Authority 2004). To date, no formal planning has occurred in relation to determining the particular attitudes and interests of the key stakeholders, i.e. the students and teachers. This study aimed to determine the biotechnology interests of Queensland secondary school students and their teachers.

Dawson and Taylor (2000: 184) support biotechnology education, stating that 'if our students are to become well-informed decision makers then they need to be aware of the practical applications of current developments in biotechnology, and appreciate the social and bioethical implications of this relatively new and controversial science'. It has been suggested (Schibeci 2000) that, as biotechnology is a rapidly developing technology with many health, economic and environmental benefits to Australia, the teaching of biotechnology and its impact on the community is of importance. Schibeci advocated that, rather than devote a special unit on ethics or the social implications of science and technology, these topics can be taught with the use of a variety of techniques such as laboratory exercises and case studies. Regardless of the methods employed in their teaching, Schibeci further recognised that the teaching of biotechnology is important both in terms of its science and to provide a vehicle to examine ethical issues associated with its use.

Crucial to the development of biotechnology education in secondary classrooms are the teachers themselves. Whilst Australia has syllabus mandates and commonwealth-funded web sites (e.g. *Biotechnology Online*: http://www.biotechnologyonline.gov.au/) to develop biotechnology skills and understanding in the classroom, there seems to be a reluctance from the teachers to present biotechnology lessons. Steele and Aubusson (2004) interviewed a number of teachers to determine why they were not presenting biotechnology in their biology classrooms. Although the teachers appeared to have a sound understanding of the content, they considered biotechnology to be too difficult for the students and that this would disadvantage the students in the university entrance examinations. Another problem according to the teachers was the lack of opportunity for practical work in the classroom.

1.2 Biotechnology attitudes and interests

Researchers have shown that becoming a scientifically literate person is not a high priority for many students (Atwater *et al.* 1995; Zacharia 2003). A particular need identified by Zacharia is to investigate the extent to which the learning experience enhances the students' attitude towards science learning. Zacharia found that a teacher's attitude towards the subject matter and its effective presentation was as significant as the students' perspectives in determining the success of the teaching–learning experience. Fishbein and Ajzen (1975) indicated that the connection between attitude and intention is important when considering the impact a teacher has on the curriculum and learning environment.

The attitudes of students and teachers have been investigated in various separate studies in recent decades. Haladyna and Shaughnessy (1982) posited that students' attitudes are determined by interaction of the teacher, the student and the learning environment. Simpson and Oliver (1990) later found that the preparation of the teacher, the nature of the hands-on activities and the student involvement in the learning are important variables related to student attitude. Hewson *et al.* (1995)

argued that teachers' conceptions and attitudes have a strong influence on science teaching and learning.

Dawson and Schibeci (2003) and Gunter *et al.* (1998) both conducted surveys of secondary school students' attitudes about what are acceptable biotechnology processes. Students supported the use of micro-organisms for specific purposes such as beer manufacture. Students did not support the genetic modification of plants for food, and even less support was reported for the genetic modification of animals and humans. Dawson and Schibeci (2003) also found that, after 10 years of compulsory schooling in science, the majority of students did not understand the processes of biotechnology.

Recent research (e.g. Pintrich and Schunk 2002) has indicated a wide range of factors impacting on learning of which student interest played a significant role. Students are rarely taught topics of interest, and they generally lose interest during learning (Prenzel 1998). There is some support for the notion that scientific interest affects science achievement (Benbow and Minor 1986; Kahle and Meece 1994; Simpson *et al.* 1994), but the findings have not been consistent. One reason postulated by Chambers and Andre (1997) for inconsistent results in interest research is that the interest instruments used may not be valid instruments. Ajzen and Fishbein's (1980) reasoned that it is possible that inconsistent results arise from the use of a domain-general instrument rather than a topic-specific instrument. Domain-general attitude and interest measures should not be expected to produce quality results in topic-specific studies. Topic-specific attitude and interest instruments are necessary to explore attitude and interest relationships. Consistent with this notion, the present study examined biotechnology interests through a purposely constructed topic-specific instrument.

1.3 Importance of the study

There is a scarcity of research into biotechnology education. A second reason for this is that teachers' attitudes have an effect on science classroom practice in general, but the extent is not known in relation to biotechnology. A third possibility is the link between the biotechnology interests of both students and teachers – an as-yet uninvestigated area.

This paper can be regarded as a contribution both to the currently scarce literature of biotechnology education and to the recent growth area of 'student voice' (Jenkins and Pell 2006). Jenkins and Pell (2006) postulated that an increase in knowledge about students' interests will make it more feasible to develop a curriculum that is engaging and that empowers otherwise silent voices in debates surrounding biotechnological issues. The underlying issue is the curriculum relevance seen from the point of view of the students, rather than that of the teacher or curriculum developer.

The aim of this study was to provide data on student and teacher interests relating to biotechnological topics and processes. The present paper is a component of a larger study that explored student and teacher biotechnology knowledge, as well as teacher skills and professional development needs across the areas of environmental biotechnology, agricultural biotechnology, genetically modified foods and human uses of biotechnology in science lessons.

2. SURVEY METHODOLOGY AND STATISTICAL ANALYSIS

A series of surveys (Biotechnology Education Learning/Biotechnology Education Teaching Survey or BELBETS) were used with 508 15–16-year-old students of senior biological science and their 15 teachers from eight secondary schools scattered throughout Queensland, Australia. Eight student surveys were discarded. Of these, six students did not complete the survey in any meaningful fashion (they answered 'Strongly agree' or 'Strongly disagree' to all statements or made no attempt to respond to any statement at all), whilst the remaining two students left major sections blank. A small pilot study involving 12 Year 11 students was conducted to seek information on the wording and readability of the statements.

This paper reports the initial findings of the 500 students and their 15 teachers. The survey (see Appendix 8.1) used a five-point Likert scale (strongly agree, agree, neutral, disagree and strongly disagree) with statements adapted from the literature (e.g. Curriculum Corporation 2001; Dawson and Schibeci 2003). The student and teacher surveys varied slightly in that the student's version was written as: 'I would be interested in learning about cloning' whereas the teacher's version read: 'I would be interested in teaching about cloning.' Interviews were held with 60 students and three teachers (from three geographically different schools). Statistical data (Cronbach's α coefficient, factor loadings, interscale correlations and Pearson's χ^2 test) are available from the author upon request.

3. RESULTS AND DISCUSSION

To facilitate comparisons between the student and teacher responses, a mean score was calculated for each statement. Student and teacher data were treated separately to allow comparison between the student and teacher. Using responses of the whole group (either student or teacher) and by scoring 'strongly agree' responses as 1.0, 'agree' as 0.5, 'neutral' as 0, 'disagree' as –0.5 and 'strongly disagree' as –1.0, the mean was calculated for each statement. As the mean approached a value of 1, it indicated affirmation of the statement, and as the whole group mean approached –1, it indicated rejection of the statement (Skamp *et al.* 2004). By plotting the 'whole group mean' in a horizontal bar graph, a visual impression of the relationships between student and teacher responses was possible (for example, see Figure 8.1).

3.1 General biotechnology interests

The general biotechnology factor presented students and teachers with statements relating to natural antibiotics, ethics, DNA and cloning. It was considered important to discover educational interests relating to these issues, as technological and scientific advances currently outpace the capacity of society to keep abreast of their current applications.

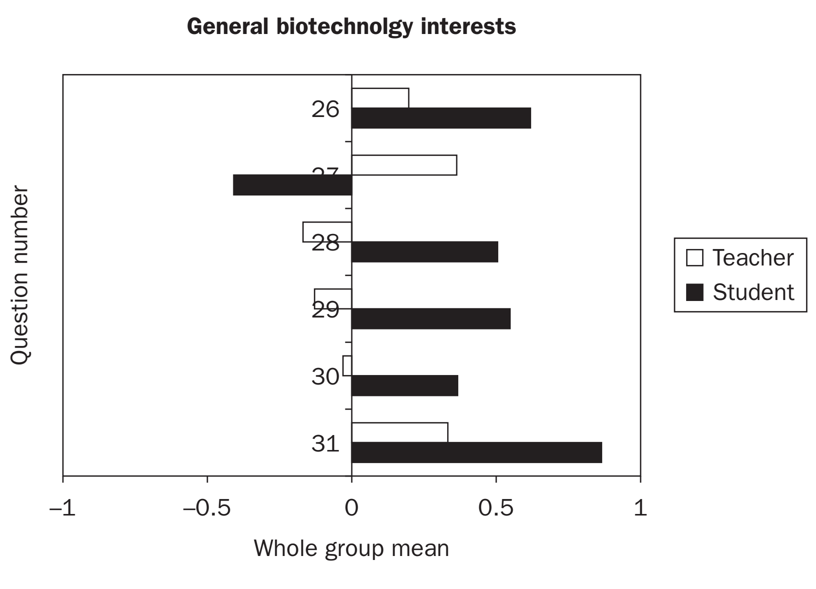

Figure 8.1 Whole group mean scores for interests relating to general biotechnology issues. Note that as the mean approaches a value of 1, it indicates affirmation of the statement, and as the mean approaches –1, it indicates rejection of the statement

To facilitate comparison between student and teacher responses, it was convenient to compare the whole group mean for the students with that of the teacher. Figure 8.1 clearly shows this difference graphically. For example, student statement 26 (see Appendix 8.1) shows a student whole group mean of 0.62, which indicates good agreement with the statement. Compare this with the teacher whole group mean of 0.20. The students indicated that they were quite interested in testing natural antibiotics, yet teachers were not so interested. This difference in interests was more apparent with the remaining statement (27–31, see Appendix 8.1). From Figure 8.1, it is obvious that students and teachers have very different interests in terms of DNA (statement 28) and genetic codes and sequencing (statements 29 and 30). Statement 31 indicates that both teachers and students were interested in producing a plant clone; however, students were clearly more interested in this activity than teachers.

Clarification of responses was sought from students and their teachers. Michelle, a student at School 6, was quite emphatic about not being interested in investigating media articles relating to ethics (statement 27):

> Michelle: No, I am not interested in that idea ’cause it’s boring. Um, the boring bit is reading the paper articles or long print-outs from the web. I am not into reading things like that. The ethic thing might be interesting, but I probably won’t give it a go to find that out.

One of Michelle’s classmates was very keen to see DNA and the notion of being able to extract DNA outside a forensic laboratory was exciting for her:

> Sally: Me extract DNA? Yes, that would be great, but I doubt I will ever even see it for real. You need fancy scientific equipment in a sterile lab, you know like on CSI.
>
> Interviewer: Actually that is not quite true. You do see it like that on TV, but there are simple procedures you can do in your kitchen at home, or in the school lab to extract DNA from fruit.
>
> Sally: You’re kidding! Wow, that’s cool. How do I do it? Is it hard? I bet my class won’t ever do it – we talk too much so we have to copy notes instead of doing pracs.

Sally’s teacher was asked for information on the same two statements:

> Mr H: It is easier to deal with ethical concepts through pen-and-paper worksheets because the kids sit quiet and learn the stuff quietly. If you try to discuss things, there is usually a group who change the topic. So I get them to do worksheets. They seem to like taking notes and reading.
>
> Interviewer: Have you considered extracting DNA with your students?
>
> Mr H: Yes, extracting DNA would be OK, I guess. But I don’t know how to do it because I don’t have time to go to the seminars. They need them during school time not after school when I have other stuff on. I don’t know if the kids would be too into it though. The concepts would be tricky I expect, so they may not understand it.

It seems pedagogy, in this case, has a role to play in interests relating to biotechnology. If the task itself is not engaging, then the student is unlikely to engage in the scientific topic. The teachers may not have the discipline knowledge or skills to teach the topic, but may be reluctant to undertake professional development outside school hours, as in the case of Mr H. Also, teachers may perceive some topics to be unnecessarily complex.

3.2 Interests in human uses of biotechnology

Figure 8.2 indicates that both the students and the teachers were ambivalent about their interests in studying and teaching the different purposes of genetic testing and gene therapy (statement 55). However, student statement 56 indicates that a phenomenal 94 per cent of students were interested learning about gene profiling for paternity testing. This was compared with 21 per cent of teachers wanting to teach this topic. Paternity issues are of major interest to students. When asked why, one student explained:

> Simon: Well, I am kind of curious why it takes so long to do the tests. On the news you hear about a lot of forensic stuff and drug tests taking weeks to get a result back, so paternity would be the same. But like, off the TV shows from America, their tests only take overnight. Also I am interested in what happens after a kid finds out dad is not really dad. I know a guy who has a step-dad, but that is different I think.

This curiosity was not shared by the teachers. Very few wanted to teach paternity issues. Three teachers were interviewed and they all indicated that they were uncomfortable discussing paternity because a child might find out something they shouldn't:

> Mrs P: It's the same as genetics in a way – volatile ground potentially. I once had a class go home to investigate eye colour in parents and siblings – extended family as well. Anyway, one boy had brown eyes, and went home to find mum and dad had blue and green eyes. Now in class we had gone through dominant and recessive genes. This boy took his knowledge home to do the homework task. Well, to cut a long story short, there were all sorts of troubles and a divorce. Never again!

> Mr H: No, too messy. I just stick to what's in the text book. You need to be careful or you could be in trouble.

> Miss A: It is a very private area. I don't have the skills to sort out class discussion as I am not all that much older than the kids. Students might want to drift on to discussion on

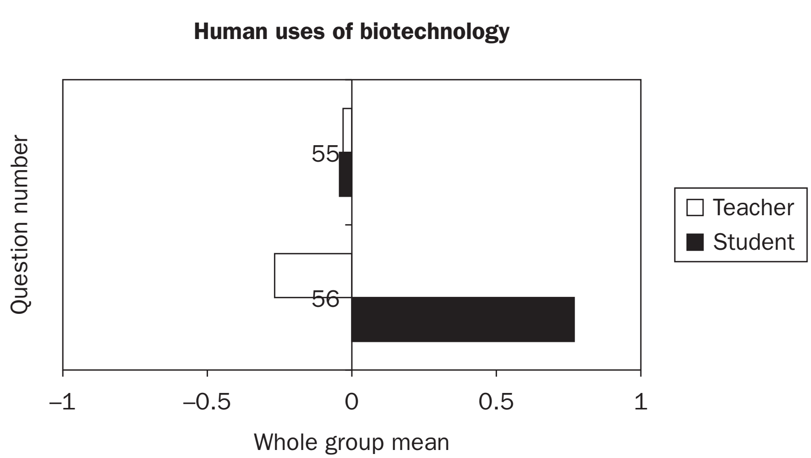

Figure 8.2 Whole group mean scores for interests relating to human uses of biotechnology

> multiple partners, then how I answer might tell them my values or preferences. I blush too easily.

These teachers did not want to be the catalyst in a paternity case, so they shy away from the topic. Teachers may also see paternity as equivalent to genetics, and as a personal issue.

Simon, the student curious about forensic time delays, is interested in paternity. However, it does not appear he is interested in paternity issues to find out whether his family has secrets. His interest is borne from what he hears or sees on the television, and so he is grappling to understand procedures as well as implications.

3.3 Science lesson topics

Figure 8.3 shows the results of the student and teacher responses as to which biotechnology topics should be taught in our classrooms. The wording of each statement in this factor differed from all other statements in that specific reference was made to science lessons, thus anchoring each topic to the curriculum. In other factors, the teacher statements were only suggestive in this respect – alluding to the teacher's interest in teaching the topic. In this factor, the students and teachers were required to consider whether or not a topic should be included in their lessons, irrespective of their personal interest in the topic.

Once again the students and teachers were opposed. Students felt that bioethics, prenatal testing and human cloning should all be included in their science lessons. It is worth noting that all students thought birth control should be included in science lessons. Teachers generally opposed the inclusion of all four topics, especially statement 59 relating to birth control and its associated issues.

Seventy per cent of Year 11 students declared an interest in having bioethical topics presented in the classroom:

> Simon: Bioethics, yeah, they are everywhere, like on the news, TV shows and in the papers. I saw a cool episode once on *House* where the team had to decide to do an emergency op not in the theatre 'cause another person also needed the operating theatre. Doctors have to make decisions like that all the time so we should be able to do debates and stuff like that too. . .Lessons would be more interesting if they were gory and real.

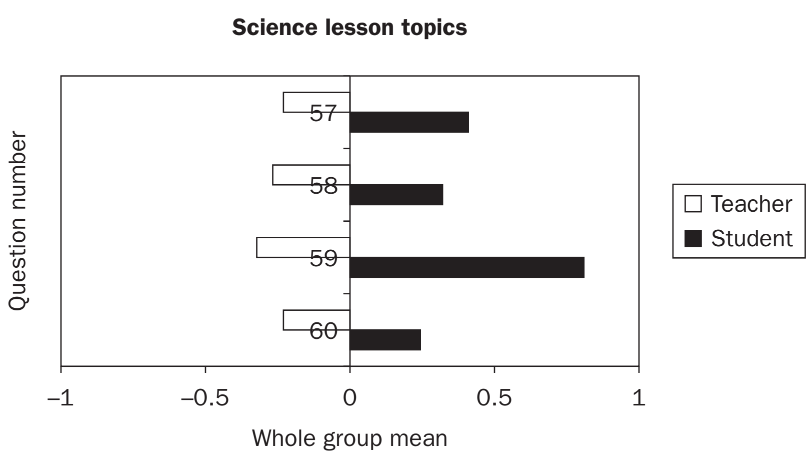

Figure 8.3 Whole group mean scores for science lesson topics concerning biotechnology

As Simon's teacher indicated:

> Mr H: I don't want to cover such things. There is a possibility that someone may be offended by another's views, discussions could become a debate, and it is the English teacher's job to do debates, not mine.

Similar patterns can be found in the responses to statement 58 relating to prenatal testing. The majority of teachers do not want to teach prenatal testing:

> Mrs P: I don't like the idea of a woman knowing her unborn child has a problem, and then her choosing a termination. What if the father didn't want to terminate? We then have a problem. No, ethically I don't like it. I don't think the students should have to explore such things. It isn't really relevant to them at the moment. Besides, it isn't in our text book I don't think.

An examination of Figure 8.3 indicates that the students and teachers surveyed had very different ideas of what topics were of interest for inclusion in biology lessons. This opposition of interests was responsible for at least one student reconsidering his enrolment in the subject:

> Paul: This subject is boring. If I had known we would not be doing cool stuff like CSI, I wouldn't have done biology. I am going to drop it next term and do something else.
>
> Interviewer: Why is biol so boring? Is it the topics or what?
>
> Paul: All the teacher does is text book stuff like study questions and stuff. We do an experiment once in a while if we are good, but sometimes they don't work out like they should.

4. SUMMARY

It is well known that students are not selecting the sciences in post-compulsory schooling, and this has had a follow-on effect into tertiary studies. There have been a number of explanations posited for this decline in science interests; however, very few if any have explored the link between the interests of teachers and students. It is obvious from these factors that the students and teachers have opposing interests. The teachers are not interested in providing lessons on the topics that students are interested in learning about.

An examination of the interests across the factors gives rise to two interesting observations. First, students are interested in topics that have a perception of personal relevance where the topic relates to their health and well-being, as indicated by the comments from the students above. Students are also interested in topics where there is a perception that it may involve practical hands-on activities. Students also seem to have the ability to predict how a topic will be 'taught' by their teachers, and this prediction is enough to prevent some students from engaging with their lessons. Secondly, teachers have interests in topics that are available in printed material. They appear to be interested in teaching topics that lend themselves to worksheets and note-taking. They tend not to be interested in biotechnology topics that have an element of risk or involve practical work. Teachers also have the perception that some aspects of biotechnology may be too difficult for the student, on the basis that the teacher themselves does not have the required knowledge.

In Queensland, this is problematic, because the teachers design the curriculum for their particular students. It seems that teachers do not want to get involved in controversial issues, and they do not want to present topics not found in the text book. Students, on the other hand, want to explore ethical concerns. They view television shows and consider this material to be 'real', and they have a desire to do practical 'hands-on' work. One student enrolled in biology in a post-compulsory classroom, but found his interests were not being met. He planned to withdraw from the study of biology at the first opportunity. The student (Paul) did not know what subject he would enrol in after biology, except that he knew 'it wouldn't be a science subject'. It is unknown how widespread this 'lack of interest' causing departure from a science subject is.

5. IMPLICATIONS FOR CURRICULUM DEVELOPERS

Students have well-developed ideas of what is of interest and what is not. Teachers and curriculum designers should be encouraged to determine these interests and to relate the interests to subject matter to provide a base for new knowledge. The 'student voice' needs to have greater prominence in the design of our science curriculum. At present, it is the adults who design the curriculum based on adult notions of what is of interest to students. Teachers also need to consider the appropriateness of their selected pedagogy. This system is failing our students, and they are choosing not to do further study in the sciences beyond the compulsory years. Therefore, more emphasis needs to be placed on what students are interested in and incorporating this into a curriculum that serves the student.

In a recent OECD forum (OECD 2006), students' science and technology interests were discussed. It was noted that teaching often focuses on memorising rather than on understanding, and heavy workloads leave little time for experiments. It was highlighted that students need to feel the relevance of the subject to society and to their own world, but in reality what is taught is often disconnected from cutting-edge science and from today's applications of science and technology, and tends to dampen interest. A recommendation of particular interest is that curricula should be redesigned to reflect the reality of modern science and technology, and to emphasise their contributions to society. Specific actions can focus on encounters with science and technology professionals, exposure to cutting-edge science and technology and their applications in modern life, debates on the role and social relevance of science and technology, and actions directed towards a 'humanisation' of science teaching (OECD 2006).

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APPENDIX 8.1 SAMPLE OF STUDENT QUESTIONNAIRE

SA If you *strongly agree* with the statement
A If you *agree* with the statement
N If you *neither agree nor disagree* with the statement or are not sure
D If you *disagree* with the statement
SD If you *strongly disagree* with the statement

If you change your mind about a response, cross out the old answer and circle the new choice.

26.	I would be interested in testing a range of natural products (natural antibiotics) to find out how effectively they kill bacteria.	SA	A	N	D	SD
27.	I would like to investigate different media articles on the ethics involved in biotechnology when using animals.	SA	A	N	D	SD
28.	I would like to actually extract DNA myself.	SA	A	N	D	SD
29.	Investigating the altering of human gene codes to reduce human genetic disorders would be interesting.	SA	A	N	D	SD
30.	I would be interested in studying the process of identifying sequences of DNA.	SA	A	N	D	SD
31.	I would like to produce my own clone of a plant by tissue culture.	SA	A	N	D	SD
32.	I am interested to learn more about ways to control/ eradicate pests (e.g. the fox, cane toad, or minor bird) harmful to the Australian environment.	SA	A	N	D	SD
33.	I would like to investigate the harmful effects of genetic engineering on our environment.	SA	A	N	D	SD
34.	I would like to know more about the implications of releasing a genetically altered organism into the environment.	SA	A	N	D	SD
35.	I would like to know why we are bothering to save the bilby.	SA	A	N	D	SD
36.	I would like to examine the decisions involved when saving species considered as most important to save.	SA	A	N	D	SD
37.	I would like to know how biotechnology can help metabolise oil slicks and other wastes.	SA	A	N	D	SD
38.	I would be interested in understanding why there is such an interest in cloning the thylacine (Tasmanian tiger).	SA	A	N	D	SD
39.	I would like to know what issues influence the decisions made to conserve particular plants or animals.	SA	A	N	D	SD
40.	I am interested in investigating the effect of cholesterol and saturated fats on my health.	SA	A	N	D	SD
41.	I am interested in investigating the effects individual foods like genetically modified canola have on my health.	SA	A	N	D	SD
42.	I am interested in studying the effect of weeds in Australia.	SA	A	N	D	SD
43.	Investigating the steps that scientists usually follow to produce a genetically modified organism is of interest to me.	SA	A	N	D	SD
44.	I would like to explore the concerns or opinions that people may have regarding the growing of genetically modified canola in Australia.	SA	A	N	D	SD
45.	I would like to know what the experts think about labelling of genetically modified foods.	SA	A	N	D	SD
46.	I think it is important that I understand the information that can be found on food labels.	SA	A	N	D	SD
47.	I would like to know more about biotechnology to form an understanding of whether I would feel, and be safe to eat genetically modified food.	SA	A	N	D	SD

48.	I would like to see non-genetically modified farming continued so that I can have a choice as to what I eat.	SA	A	N	D	SD
49.	I am interested in finding out the extent of insect damage to the Australian cotton crops and ways of controlling it.	SA	A	N	D	SD
50.	I am interested to find out whether the pollen from genetically modified plants is responsible for killing Monarch butterflies.	SA	A	N	D	SD
51.	I am interested in finding out how scientists have been able to develop genetically engineered cotton that produces its own insecticide.	SA	A	N	D	SD
52.	It is important that I understand issues relating to the impact genetically modified crops have on the Australian environment and on our health and well-being.	SA	A	N	D	SD
53.	I would like to know more and be responsible for formulating my own personal understanding and opinion whether genetically modified organisms are good or bad for the environment.	SA	A	N	D	SD
54.	I would like to know from who and how foods in Australian supermarkets (and other food outlets) get their approval.	SA	A	N	D	SD
55.	I would like to investigate the different purposes of genetic testing and gene therapy.	SA	A	N	D	SD
56.	I am interested in studying the issues involved in the use of gene profiling for paternity testing (identifying the biological father).	SA	A	N	D	SD
57.	Bioethics education should be discussed in science lessons.	SA	A	N	D	SD
58.	Prenatal testing and the issues associated with it should be discussed in science lessons.	SA	A	N	D	SD
59.	Birth control and the issues associated with it should be discussed in science lessons.	SA	A	N	D	SD
60.	Human cloning and the issues associated with it should be discussed in science lessons.	SA	A	N	D	SD

3

Student values, attitudes and decision-making

9 Students with a view: explaining attitudes towards modern biotechnology

Tanja Klop and Sabine E. Severiens

ROTTERDAM INSTITUTE FOR SOCIAL-POLICY RESEARCH, ERASMUS UNIVERSITY ROTTERDAM, THE NETHERLANDS

klop@risbo.eur.nl

This study investigated background factors, values and opinions associated with secondary-school students' attitudes towards modern biotechnology. A total of 504 students completed a questionnaire on attitudes and associated factors. Descriptive and multinomial logistic regression analyses were conducted to examine the relationships between different attitudes held by secondary school students, and their background and value factors. The results showed that there was a significant relationship among the educational level, ethical perceptions and awareness of benefits on the one hand, and attitude towards modern biotechnology on the other hand. Students with more developed attitudes often stemmed from higher educational levels, held more outspoken ethical views and considered the development in modern biotechnology more often to be beneficial than did students with poorly developed attitudes. Implications for science education and future research are discussed.

1. INTRODUCTION

Genomics, the general term for scientific research on heredity and genes, and its associated technologies (modern biotechnology) are set to become one of the more important scientific and technological revolutions of the 21st century (Kirkpatrick *et al.* 2002). As such, it is important that the public understands the main concepts behind modern biotechnology. One should understand how modern biotechnology and society influence one another, and be able to use this in everyday decision-making. Socio-scientific issues, such as cloning, stem cell research and genetically modified foods, will have significant effects on everyday life. For this reason, it has been recognised that science education must provide pupils with insights into some of the challenging ethical and moral decisions that have to be made about new technologies and how we should apply them (Waarlo *et al.* 2002). Students should develop the profound attitudes needed to become responsible citizens, and should be able to think for themselves and to function effectively in an increasingly complex and technology-dependent society.

Several studies have suggested that secondary-school students have a limited interest in, and understanding of, concepts and implications of modern biotechnology (Macer 1992; Gunter *et al.* 1998; Dawson and Schibeci 2003). Furthermore, in a previous study, we demonstrated that the majority of the students held rather poorly developed attitudes towards modern biotechnology (Klop and Severiens 2007). This study complements our previous work on attitudes towards biotechnology of Dutch secondary-school students. The goal was to explore in further detail the types of student who are unsure about what to think of modern biotechnology, compared with others who are more outspoken. It contributes to the state of the art regarding attitudes towards modern biotechnology by relating overall attitudes to the main background factors and underlying values and opinions. This insight will provide input for potentially successful education in biotechnology, as several authors have argued that attitudinal indicators are an essential component in determining the state of science education (Simpson *et al.* 1994; Zacharia 2003).

As the present study complements our former study, we will first summarise our previous work and then describe the main attitudinal indicators that we identified.

1.1 Attitudes towards modern biotechnology

In general, an attitude can be described as 'a summary of evaluations; representing favourable or unfavourable feelings towards a specific or psychological object' (Eagly and Chaiken 1993; Weinburgh and Engelhard 1994; Ajzen and Fishbein 2000; Zacharia 2003). In this case, the object is modern biotechnology and its associated technologies. We conceptualise attitude according to the tripartite model of attitudes (Katz and Stotland 1959; Rosenberg and Hovland 1960; Breckler 1984; Eagly and Chaiken 1993). This model encompasses three basic attitude components: an affective component (positive feelings as well as anxieties and fears), a cognitive component (beliefs, thoughts and knowledge) and a behavioural component (intention to act, buy or use).

A sample of 574 Dutch secondary-school students was asked to answer a pilot-tested questionnaire (see Table 9.1) in order to determine their attitudes (Klop and Severiens 2007). Cluster analyses on each of the attitude components resulted in four different attitudes:

- Confident supporter (22 per cent). The confident supporters were a positive, pro-biotechnology and well-informed group of students, who seemed to welcome biotechnology in their daily lives.
- Concerned sceptic (18 per cent). The concerned sceptics represented a relatively well-informed group of students, who tended to be very sceptical and concerned about biotechnology.
- 'Not for me' (17 per cent). The smallest group, the 'not for me' group of students, was rather negative about biotechnology. They had poor knowledge of the subject, and their beliefs and affective reactions were very negative.
- 'Not sure' (42 per cent). The last cluster, the so-called 'not sure' group, formed the largest group. Their views tended to be rather unclear; they were neither 'anti-biotechnology' nor 'pro-biotechnology' and their overall knowledge of the subject left something to be desired.

1.2 Background factors

In this and the next section, an overview is given of relevant variables with possible impact on attitudes. A distinction is made between background factors is this section and value factors in the next.

1.2.1 Gender

An important background factor in research of attitudes towards science or biotechnology is gender. Several researchers have examined gender differences in students' attitudes toward science and have consistently found that boys have more favourable attitudes towards science than girls (Miller *et al.* 2006), and that boys more often choose science subjects (Hykle 1993; Olszewski-Kubilius and Turner 2002; Miller *et al.* 2006).

1.2.2 Religious background

It is plausible that attitudes towards biotechnological issues differ according to religious backgrounds. Articles that frequently appear in religious journals express concerns about interfering with genes (Nelkin 2004). Experiments in gene therapy and genetic engineering have brought about objections from the Christian community, some of whom are convinced that scientists are playing God, tampering

Table 9.1 Attitude and value factors with scale name, description, exemplary item, reliability and descriptive values, based on principal component analyses

Attitude components	*Attitude factors*	*Description*	*Exemplary item*	*Cronbach's α (no. of items)*
Cognitive component	Biology and genetics[a]	Knowledge of biology and genetics	DNA contains the information for all your hereditary factors.	0.63 ($n = 9$)
	Biotechnology[a]	Knowledge of biotech applications	Normal tomatoes have, in contrast to GM-tomatoes, no genes.	0.71 ($n = 17$)
	Beliefs	Evaluative knowledge of biotech/beliefs about biotech	I think genomics can solve food problems in the third world.	0.70 ($n = 5$)
Affective component	Basic emotion	Basic emotional reactions	Genetic modification (GM) is bad.	0.78 ($n = 13$)
	Unavoidable	Feelings of biotech being unavoidable	Biotechnology is absolutely necessary.	0.76 ($n = 9$)
	Worries	Worries about biotech	How many worries do you have about genetic research?	0.79 ($n = 5$)
Behavioural component	Own intentions	Consuming intentions; own interest	I would eat GM food if it's cheaper than normal food.	0.78 ($n = 5$)
	Medical intentions	Medical intentions	Would you take a genetic test during your pregnancy?	0.74 ($n = 4$)
	Critical intentions	Consuming intentions; critical conditions	I would buy GM food if it was grown more environment-friendly than normal food.	0.74 ($n = 3$)
Antecedents	*Value factors*			
Ethical perceptions	Medical applications	Medical use of biotechnology	Do you agree with the use of modern biotechnology for improving defective genes?	0.90 ($n = 15$)
	Qualitative use	Use of biotech to improve/change quality of organisms	To what extent do you agree with changing genes of tomatoes so that they stay fresh longer?	0.90 ($n = 14$)
	'Unnecessary' application	Use of biotech to improve/change features with no 'real need'	Would you agree with changing of genetic features, such as eye colour?	0.88 ($n = 16$)
Interest	Interest	Interest in science	I find science interesting.	0.73 ($n = 5$)
Benefit	Benefit	Benefits of modern biotechnology	The benefits of science are larger than the possibly negative effects.	0.78 ($n = 13$)
Risk	Risk[b]			0.60 (n= 10)

[a] Bivariate data.

[b] Reliability was too low; scale was not included in subsequent analyses.

with God's will and touching on immortality. Other religions, including most sects of Judaism and Islam, have no objection to, for example, stem cell research. Within these religions, the early embryo is not considered to be fully human (Reichhardt *et al.* 2004). On the other hand, religious values attached to animals, in the case of transplantation (however far-fetched and scientifically impossible) may also influence attitudes towards biotechnology.

1.2.3 Ethnic background
An ethnic background was defined using the definition of the Netherlands Statistics (CBS): 'A person who is a Dutch resident and of whom at least one parent was born abroad.' The National Science Foundation (1996) observed differences in achievement within science courses when grouped by ethnicity. They found that not only women, but also minority groups, such as African-Americans and Hispanics, lagged behind. They took fewer science courses in high school, undertook fewer BA, MA and PhD degrees in science and engineering, and were less likely to be employed in science and engineering than were white males (National Science Foundation 1996).

1.2.4 Personal experience
It is known that a person will express an attitude more outspokenly when the attitude is important to themselves or to someone close to them, and when it is based on personal experience (Eagly and Chaiken 1993). Therefore, people with a genetic disease or those who are related to someone with a genetic disease possibly have a different attitude towards biotechnological issues compared with people with no familiarity with this subject.

1.2.5 Level of education
Level of education has been shown to be related to both scientific literacy and attitudes towards science and technology (Pardo *et al.* 2002; Gaskell *et al.* 2003). Compared with students with a lower education level, students within higher levels of education have a more extensive knowledge base available, which can affect their attitude towards biotechnology (Cannon and Simpson 1985). In addition, Rennie and Punch (1991) found a positive correlation between grade levels and achievement, and attitudes towards science.

1.3 Value factors

In addition to the (more or less) independent background factors, there are several 'moral value' factors. These factors should not be confused with the attitude components in the tripartite model. Conceptually, we consider these factors to be antecedents of attitude.

1.3.1 Ethical perceptions
Issues such as cloning, stem-cell research, genetic modification of food require thinking about moral and ethical limits. Ethical perceptions may be a key factor associated with attitudes towards biotechnology, among others (Gaskell *et al.* 2003; Macer 1994). This is the case as:

> No technology is 'value-free': needs arise from a variety of causes and perceptions and the ways they are addressed depend upon a complex set of relationships in society, the resources that are available; the priorities that society holds and the culture, beliefs and values that influence the decision making in that society.'
>
> (Ministry of Education 1995: 41)

Dimopoulos and Koulaidis (2003) argued that biotechnological issues with possible impact on society are often ground-breaking and therefore go together with uncertainties, making this issue sensitive to related social pressures and thereby value-laden. How one evaluates the ethical aspects in this field of research can therefore have an important impact on attitudes towards biotechnology (Gaskell *et al.* 2003; Macer 1994).

1.3.2 Benefit and risk

The perception of benefits and risks has a direct influence on the eventual attitude towards biotechnology according to several studies (Pifer 1996; Pardo *et al.* 2002). Generally, if the risks are perceived to be high, the attitude will be more negative. For many people, the idea of genetically tampering with food is perceived as highly threatening for health and safety (Gunter *et al.* 1998). In contrast to this finding, the Human Genetics Commission (2000) found, in a public attitudes survey in the UK, that young people (<25 years) possessed a more risk-taking attitude and better knowledge of biotechnology than older people.

1.3.3 Scientific interest

Students who are interested in technology and science in general are more likely to have intentions to engage in future learning behaviours (Norwich and Duncan 1990). This can be an important indicator of students' attitudes towards biotechnology.

2. METHOD

The present study investigated to what extent the background and value factors explain attitude towards biotechnology.

2.1 Participants

A sample of 634 pupils from 13 different schools completed a questionnaire on attitudes towards biotechnology, background variables and value factors. In The Netherlands, the secondary education system for pupils aged between 12 and 18 years is divided into three main levels: at the lowest educational level, secondary vocational education (VMBO, 12–16 years); at the medium educational level, general secondary education (HAVO, 12–17 years); and at the highest level, pre-university secondary education (VWO, 12–18 years). Students were excluded from subsequent analysis if they completed less than 33.3% of the questionnaire or showed a 'suspicious' answer-pattern, e.g. all questions were answered in an identical fashion, or the answers included contradictions. This resulted in a dataset of 574 respondents. The participating students were taken from these three different levels: low educational level (25.6 per cent), medium level (25.6 per cent) and high level (48.8 per cent). The sample consisted of 262 males (45.6 per cent) and 312 females (54.4 per cent), and the average age was 15.8 years (SD = 0.66).

2.2 Measures

The development of the questionnaire has been reported previously, as well as the construction of items and scales on attitude components, and background and value factors (for details, see Klop and Severiens 2007). All scales and their reliabilities are described in Table 9.1.

2.3 Analyses

The first step in the analysis was to determine the relationship between the background factors and the four attitude groups. In the second step, the significant background factors as well as all value factors were also included in the analysis. Because our dependent variable was discrete, we performed multinomial logistic regression (Hosmer and Lemeshow 1989). In logistic regression, parameters are typically interpreted using odds ratios [exp.(B)]. An odds ratio describes 'the odds of a categorical outcome at one level of a categorical predictor relative to the odds of the outcome at a comparison level (i.e., the reference category)' (Kilpatrick *et al.* 2000: 22). Odds ratios above 1.0 indicate an increased likelihood whereas ratios between 0 and 1 indicate a decreased likelihood. The 'not sure' cluster (majority of students) was set as the reference category, as this was the least outspoken and largest group.

3. RESULTS

3.1 Background factors

The first regression analysis with background factors showed three significant relationships:

1. Male students were well over three times more likely to be confident supporters than a student from the 'not sure' group (see the odds ratio of 3.18 in Table 9.2).
2. Students with a higher educational level were 1.5 times more likely to be confident supporters and 0.20 times more likely to reject biotechnology compared with the 'not for me' group (the odds ratio of <1 implies a decreased likelihood).
3. The same was true for 'Bio as exam subject', i.e. students who chose biology as an examination subject. These students were 2.04 times more likely to be a confident supporter and 0.24 times more likely to be in the 'not for me' cluster compared with the reference group.

In the second step, the value factors as well as the significant background factors of step 1 (i.e. gender and school factors) were included in the logistic regression analysis (Table 9.3). The results showed that, of all background factors, educational level and taking biology as an exam subject remained significantly associated with attitude. Furthermore, all value factors except for interest were significantly related to attitudes towards biotechnology.

The effect of gender disappeared in this second step. A possible cause is that gender differences can be explained by the value factors. In post-hoc analyses, this explanation was confirmed for ethical perceptions, but not for differences in interest. Boys and girls differed considerably in their ethical perceptions, and this seemed to overrule the main effect of gender. Girls were more critical in their ethical considerations compared with boys (medical applications: $t = 2.54$, $P = 0.10$; qualitative use: $t = 5.87$, $P = 0.00$; unnecessary application: $t = 8.16$, $P = 0.00$).

3.2 Value factors

Students with positive ethical values regarding medical applications were less likely to be concerned sceptics (0.36) and less likely to reject biotechnology (0.30). Students with a positive ethical perception of the qualitative utilisation of biotechnology were more than eight times more likely to be confident supporters and, respectively, 0.40 and 0.18 times more likely to be concerned sceptics or in the 'not for me' group. Remarkably, students with no ethical objections to the somewhat 'unnecessary use of biotechnology' were 2.63 times more likely to be in the 'not for me' group. In other words, whereas the 'not for me' group negatively evaluated all other value factors, they seemed to have fewer problems

Table 9.2 Logistic regression analysis for background factors by cluster (step 1)

Factor	*Likelihood ratio tests*				*P value*			*Odds ratio*		
	χ^2	*d.f.*	*P value*		*Cluster 1: Confident*	*Cluster 3: Sceptic*	*Cluster 4: Not for me*	*Cluster 1*	*Cluster 3*	*Cluster 4*
Gender	34.358	3	**0.000**[a]	Male	**0.000**[a]	0.141	0.766	**3.18**	0.68	0.92
				Female	.	.	.	.	.	.
Personal experience	3.486	3	0.323	Exp	0.463	0.296	0.371	0.84	1.30	0.75
				No exp	.	.	.	.	.	.
Religion	12.876	9	0.168	Christianity	0.149	0.031	0.956	0.68	1.81	1.02
				Islam	0.734	0.057	0.130	1.21	2.92	2.32
				Other	0.834	0.172	0.899	0.92	1.73	1.06
				No religion	.	.	.	.	.	.
Ethnic background	2.409	3	0.492	Native	0.416	0.320	0.862	0.80	1.36	0.94
				Non-native	.	.	.	.	.	.
Socioeconomic staus (SES)	1.653	3	0.647	SES	0.890	0.838	0.232	1.05	0.94	0.69
Educational level	91.315	3	**0.000**[a]	Educational level	**0.017**[a]	0.176	0.000[a]	**1.53**	0.80	**0.20**
Grade	2.566	3	0.464	Grade	0.373	0.648	0.307	1.34	0.85	0.64
Biology as exam subject	40.857	3	**0.000**[a]	Yes	**0.004**[a]	0.119	0.000[a]	**2.04**	0.67	**0.24**
				No	.	.	.	.	.	.

[a] $P < 0.001$; a '.' indicates that one or both of the parameters is redundant.

The reference category is cluster 2: 'Not sure.' Model fit criteria: –2 log likelihood = 1116.00, $\chi^2 = 209.84$, d.f. = 30, $P<0.001$; Nagelkerke $R^2 = 0.330$

Table 9.3 Logistic regression analysis for significant background factors and explanatory variables by cluster (step 2)

Factor	*Likelihood ratio tests*				*Scales*	*P value*			*Odds ratio*		
		χ^2	*d.f.*	*P value*		*Cluster1*	*Cluster3*	*Cluster4*	*Cluster1*	*Cluster3*	*Cluster4*
Background factors	Gender	2.168	3	0.538	Male	0.15	0.879	0.969	1.58	0.95	1.01
					Female	.	.	.	.	.	.
	Educational level[a]	59.705	3	0.000[a]	Educational level	0.008[a]	0.292	0.000[a]	**1.75**	0.83	**0.25**
	Biology as exam[a]	15.169	3	0.002[a]	Yes	0.082	0.513	0.002[a]	1.79	0.82	**0.30**
					No	.	.	.	.	.	.
Ethical perceptions	Medical[a]	15.805	3	0.001[a]	Medical	0.316	0.003[a]	0.001[a]	1.52	**0.36**	**0.30**
	Qualitative use[a]	47.121	3	0.000[a]	Qualitative use	0.000[a]	0.013[a]	0.000[a]	**8.26**	**0.40**	**0.18**
	Unnecessary[a]	27.875	3	0.000[a]	Unnecessary	0.100	0.023[a]	0.003[a]	1.60	**0.52**	**2.63**
Interest	Interest	5.420	3	0.144	Interest	0.049	0.566	0.315	1.46	0.90	0.81
Perception of benefit	Benefit[a]	23.836	3	0.000[a]	Benefit	0.021[a]	0.001[a]	0.002[a]	**3.18**	**0.22**	**0.24**

[a] $P < 0.001$; a '.' indicates that one or both of the parameters is redundant.
The reference category is cluster 2: 'Not sure.' Model fit criteria: −2 log likelihood = 878.21, $\chi^2 = 565.52$, d.f. = 24, $P<0.001$; Nagelkerke $R^2 = 0.693$

with some of the probable commercial applications of modern biotechnology than the other groups. Some of the attractive possibilities of biotechnology like 'glow in the dark fishes' may be of 'gadget value' to these students and may overrule their concerns regarding the more 'serious' applications.

Students expecting high benefits from biotechnology were 3.18 times more likely to be confident supporters, 0.22 times more likely to be sceptics and 0.24 times more likely to be in the 'not for me' group compared with the 'not sure' reference group of students.

In summary, compared with the baseline 'not sure' group, confident supporters more often stemmed from high educational levels, held positive ethical views and expected benefits from the development in modern biotechnology. The concerned sceptics were from similar educational levels and also chose biology as an examination subject. However, they did hold different ethical views compared with the 'not sure' group. They were more negative about medical applications and more negative about biotechnology in a qualitative sense. Lastly, the concerned sceptics saw the least benefits of modern biotechnology of all clusters. Of all the attitude clusters under consideration, the students that were negative about biotechnology, the 'not for me' group, differed the most in comparison with the 'not sure' group. The negative group stemmed from lower educational levels and did not often include biology as an examination subject. Furthermore, they were more negative on ethical views and did not see many benefits of biotechnology.

4. CONCLUSIONS

A previous study by us found that almost half of Dutch secondary students (taken from all of the different educational levels) were not sure what to think of biotechnology (Klop and Severiens 2007). The present study explored students' attitudes in further detail to determine what type of student was not sure about their opinion? Moreover, given the ultimate goal of stimulating scientific literacy, how could we describe the remaining students who did hold an explicit opinion (whether negative or positive)? In this final section, the main results are summarised and discussed, and implications for education and further research are presented.

One of the main findings of this study was that ethical perceptions are strongly related to attitudes towards modern biotechnology. It seems that when students are more critical in their ethical perceptions, they also have a more critical point of view concerning modern biotechnology, especially when it comes to the medical and qualitative fields of biotechnology. The more critical groups also seemed to expect fewer benefits of modern biotechnology compared with students within the neutral or positive groups.

From the school factors, the level of education and choosing biology as an examination subject showed a strong and significant relationship with the different attitudes. This result is in accordance with recent research, where levels of school grades have been shown to be related to both civic scientific literacy and to attitudes towards science and technology in general (Pardo *et al.* 2002; Gaskell *et al.* 2003; Zacharia and Barton 2004). It can be concluded that the higher the level of education and the more often a student chooses biology as examination subject, the more positive or critical the student is likely to be towards modern biotechnology, resulting in more profound attitudes. Conversely, students in the lower educational levels were more negative about biotechnology. This 'not for me' group can be identified as an 'at-risk' group. Girls, minority groups and students in the lower educational tracks were over-represented in the 'not for me' and 'not sure' – groups (see Appendix 9.1 and 9.2). One can conclude that it is possible that these students therefore also lagged behind in terms of scientific literacy. This may become a serious (social) problem in the future, and should be taken into account with in all fields of science education.

4.1 Implications for science teaching and communication

The findings of this study highlight issues that may have to be considered by curriculum planners and science teachers who wish to incorporate scientific literacy into science curricula. When educating students about modern biotechnology and its implications, one has to keep in mind that background factors play an important role in several attitude factors, cognitive as well as affective elements. If the goal is to help students to develop their attitudes, this finding shows the importance of also incorporating values into educational programmes.

In other words, science education should not only focus on what is taught and how this subject is taught, but also to whom. Paying attention to ethical views, and inviting students to think about benefits and risks more closely, might help different groups of students to create a more balanced attitude towards biotechnology. This is especially true for the groups that are at higher risk of lagging behind in the development of scientific literacy.

4.2 Future research

Our study indicates which background factors and underlying views seem important determinants of attitude. It would be interesting to examine educational programmes that actually attempt to incorporate these so-called attitudinal indicators. Such a programme would pay attention to each component of attitude (cognition and affection) and to variables such as ethical points of view and the perception of benefits and risks. A second question for a future research study would be to what extent such educational programmes are more effective compared with more traditional science education. In other words, would such an educational programme increase the number of students with 'a view'?

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APPENDIX 9.1 NOMINAL BACKGROUND FACTORS FOR CLUSTERS (%)

Factor		*Cluster 1 (n = 130)*	*Cluster 2 (n = 239)*	*Cluster 3 (n = 105)*	*Cluster 4 (n = 100)*	*Total (%)*
Gender[a]	Male	31.2	37.0	13.7	17.2	45.6
	Female	14.7	45.5	22.1	17.6	54.4
Personal experience[b]	Experience	23.5	44.4	21.4	10.7	34.1
	No experience	22.2	40.2	16.7	20.9	65.9
Religion[c]	Christian	18.3	41.9	22.5	17.3	33.3
	Islamic	16.3	22.4	22.5	33.8	8.5
	Other religion	20.5	38.4	20.5	20.5	12.7
	No religion	27.6	46.0	14.6	11.9	45.5
Ethnic background[d]	Native	23.0	44.0	19.0	14.0	69.7
	Non-native	21.8	36.2	16.7	25.3	30.3
Biology as exam subject[e]	Yes	26.50	43.00	17.80	12.60	53.8
	No	18.10	40.00	18.90	23.00	46.2

[a] $\chi^2 = 26.80$, d.f. = 3, $P = 0.000$.
[b] $\chi^2 = 9.915$, d.f. = 3, $P = 0.019$.
[c] $\chi^2 = 38.36$. d.f. = 9, $P = 0.000$.
[d] $\chi^2 = 11.07$, d.f. = 3, $P = 0.011$.
[e] $\chi^2 = 13.73$, d.f. = 3. $P = 0.003$.

APPENDIX 9.2 ORDINAL VARIABLES; COMPARISON OF MEAN (±SD), F value, d.f. and P value among the four clusters

Factor		*Cluster 1*	*Cluster 2*	*Cluster 3*	*Cluster 4*	*F*	*d.f.*	*P*
School factors	Educational level	2.58 (0.65)	2.38 (0.76)	2.21 (0.86)	1.46 (0.70)	48.16	3	0.000
	Grade	2.19 (0.37)	2.13 (0.35)	2.09 (0.32)	2.04 (0.31)	3.55	3	0.014
Socio-economic status		1.85 (0.36)	1.80 (0.40)	1.77 (0.42)	1.60 (0.49)	7.64	3	0.000
Ethical perceptions	Medical	4.30 (0.46)	3.82 (0.46)	3.26 (0.46)	3.06 (0.63)	139.84	3	0.000
	Qualitative	4.03 (0.47)	3.37 (0.43)	2.86 (0.53)	2.78 (0.65)	152.10	3	0.000
	Unnecessary	3.09 (0.67)	2.49 (0.59)	2.14 (0.70)	2.59 (0.67)	47.5	3	0.000
Interest		3.33 (0.81)	2.86 (0.82)	2.88 (0.87)	2.57 (0.86)	19.57	3	0.000
Benefit		4.01 (0.38)	3.57 (0.39)	3.12 (0.45)	2.98 (0.53)	138.83	3	0.000

10 Opinion building in a socio-scientific issue: the case of genetically modified plants

Margareta Ekborg

UMEÅ UNIVERSITY, SWEDEN

margareta.ekborg@educ.umu.se

This paper presents results from a study with the following research questions: (1) Are pupils' opinions on genetically modified organisms (GMOs) influenced by biology teaching? (2) What is important for the opinion that pupils hold and how does knowledge work together with other parameters such as values? Sixty-four pupils in an upper secondary school answered questionnaires in which they expressed opinions and gave arguments on applications of GMOs, before and after biology courses. The pupils' knowledge of genetics and GMOs was also investigated. Eleven pupils were then interviewed in order to go into argumentation in more depth. More pupils were positive about genetically modified tomatoes after the courses. Males were more positive than females. No correlation was found between knowledge of basic genetics and opinion. Most of the pupils could express arguments for and against the applications, but they built their personal opinion on different arguments. An important concern was potential risks. Depending on risk judgement and/or how they trusted scientists, the pupils came to different opinions. Few had any idea of how the different applications are risk-assessed or how scientists work. Other important factors for decision-making were the purpose of the application, the time perspective and feelings.

1. INTRODUCTION

In this paper, results from a study that aimed to investigate how pupils in upper secondary school (science programme) formed opinions on a socio-scientific issue are presented. The issue of genetically modified plants was used as an example, as it is a socio-scientific issue according to criteria set up by Ratcliffe and Grace (2003), e.g. it has a basis in science, involves forming opinions, is frequently reported by the media, involves values and ethical reasoning, may involve consideration of sustainable development and may require some understanding of probability and risks. The interest in this study was to illuminate what knowledge pupils need to feel confident about decision-making.

2. THEORETICAL BACKGROUND

Some studies show that people with a sound knowledge base find it easier to express a decided view, irrespective of whether they are positive or negative, about issues related to gene technology (Gaskell 1997; Jallinoja and Aro 2000). In a comparative study between pupils in upper secondary school in Great Britain and Taiwan, it was found that the British pupils who had had more teaching on genetic engineering and more opportunities to discuss it generally were more positive about genetic engineering (Chen and Raffan 1999). In these investigations, the participants expressed their opinions about some examples of genetic engineering. However, there has been no specific investigation into how these opinions are formed. It was stated that the pupils were not very knowledgeable about the facts, but the possible connections between knowledge, the ability of individuals to make use of that knowledge, and their ability to argue and form an opinion has not been researched. Discussion about what aspects of knowledge are important is rare. There are a number of studies showing that pupils' understanding of genetics, heredity and genetic engineering is weak (e.g. Wood-Robinson 1994; Lewis and Wood-Robinson 2000). However, Lewis and Leach (2006) reported that pupils can engage in issues about gene technology with relatively modest scientific knowledge if the teaching is well designed and contextualised.

One Swedish study investigated how upper secondary pupils worked on problem solving in questions about genetic engineering. It was found that pupils often formed opinions based on emotional reasons and that they were not critical of the sources of information (Kärrqvist 1996). The results from a longitudinal study of how student teachers specialising in science for primary school developed skills to discuss socio-scientific issues show that the students had difficulty applying their scientific knowledge (Ekborg 2005). The students often used emotional arguments when taking up a position on the issue, and it was common for them to feel a contradiction between science and ethics.

3. RESEARCH QUESTIONS

There is a need to know more about how pupils form opinions and what kind of knowledge and what aspects they need to work with to enable them to feel confident in decision-making with regard to socio-scientific issues. Therefore the following research questions were asked:

1. Are pupils' opinions on genetically modified organisms influenced by biology teaching?
2. What is important for the opinion that pupils hold and how does knowledge work together with other parameters such as values?

4. METHOD

4.1 Sample

Pupils in the science programme in upper secondary school at three different schools in Sweden participated in the study. In the 3-year programme, pupils take two biology courses. The first one (BiA) deals with ecology and genetics including biotechnology. The second one (BiB) deals with human physiology. Some genetics is also taught in chemistry. Some schools have an optional course in biotechnology after the two biology courses. The Swedish syllabuses are goal-driven and are not very detailed. There is much to be included in the courses and the time set aside for gene modifications in plants is generally short.

School number 1 was situated in a small town (Kristianstad). The pupils were in their second year and took BiA during the study. There were 24 pupils in the class and 23 answered both questionnaires. School number 2 was situated in an old university city (Lund). The pupils were in their third year and had finished both BiA and BiB and took biotechnology during the study. There were 30 pupils in the class and 20 answered both questionnaires. School number 3 was an inner-city school in a one of the largest cities in Sweden (Malmö). More than 50 per cent of pupils did not have Swedish as their mother tongue. The pupils were in their second year and took BiA during the study. There were 23 pupils in the class and 21 answered both questionnaires. Altogether, 64 pupils (39 females and 25 males) answered both questionnaires and these were the subjects of this study.

Data were collected by questionnaires and interviews. All the pupils were asked to answer one questionnaire at the beginning of the course and one after it. The questionnaires were similar and the purpose was twofold. Firstly, I wanted to get a rough overview of what the pupils found important enough to express in their arguments, what level of knowledge they possessed and if this changed after they had been taught. Secondly, I wanted to find pupils with different opinions for the interviews. The interviews were conducted after the respective courses and made it possible to go deeper into their reasoning with the pupils and to test how solid their arguments were.

This study is ideographic in the sense that the interest lies in understanding the ways in which the pupils interpret information they meet in school and elsewhere, rather than determining the frequency of different levels of understanding or different types of opinion.

4.2 Questionnaires

For the construction of the questionnaires, a model developed by Hydén and Wickenberg (Wickenberg 2004) was used. This describes that all actions that are undertaken, by individuals or groups, are developed by an interplay between knowledge, driving forces (will and values) and systemic conditions. An opinion can be considered to be an action and therefore to be an interplay between values, knowledge, and conceivable obstacles and possibilities.

Both questionnaires contained a rather scientific description of genetically modified tomatoes. The second questionnaire also included a description of genetically modified soy. The pupils gave their view on these by ticking boxes with different alternatives. They were asked whether it was acceptable to develop the modification, whether it should be sold on the market, what kind of tomatoes/soy they would buy and whether the tomatoes/soy would be dangerous to your health. They also got three open-ended questions in which they were asked to give arguments for and against the described cases, and also to state what arguments were most important for their personal decision. The reason for including the second case was to reveal whether the students could distinguish between these two genetic engineering applications as the background was different. Two questions contained statements from a researcher and from the internet homepage of Greenpeace's (www.greenpeace.se). The researcher said that the technology in itself was not dangerous but that each application should be risk-assessed. Greenpeace said that genetically modified organisms (GMOs) are released without scientific understanding about the consequences for nature and human health. This genetic contamination is an important threat to humanity as it cannot be called back after being released into the wild. The pupils could tick boxes indicating agreement, disagreement or 'I do not know'. Finally, this part contained a question that the pupils ticked to say whether they found the issues important/unimportant, interesting/not interesting and difficult/easy.

The second part of the questionnaires included open-ended questions to test the pupils' understanding of two genetic concepts – DNA and genes – and a question about the information there is in DNA. Finally, there were some questions in which the pupils judged their own knowledge about some concepts in gene technology and some applications by ticking one of the following alternatives: 'I have never heard of it', 'I have heard of it, but I cannot explain it' or 'I have heard of it and I can explain what it is'. For some reason, school 3 did not get a complete set of examples. In the second questionnaire, there was an open-ended question about the difference between conventional breeding and gene technology.

In schools 1 and 2, I gave out the questionnaires myself on both occasions. In school 3, the questionnaires were given out by two student teachers who used some of the data for their dissertation in the teacher education programme (Erlansson and Stålhandske 2005).

4.3 Interviews

Eleven pupils, from schools 1 ($n = 6$) and 2 ($n = 5$), were then chosen for further discussions. Four were against GMOs in both questionnaires, two were in favour in both questionnaires and five pupils were more positive in the second questionnaire. In the interviews, the pupils were asked to go into more depth in their arguments concerning GMOs. The interview started from a newspaper article (published at the time of the interviews) discussing whether genetically modified soy (cow fodder) should be imported. By discussing soy and other applications – Golden Rice and potatoes modified to produce only one kind of starch – the pupils expressed opinions and arguments about these. They were asked to explain, develop ideas, ask questions and react to different kinds of counterarguments. There were also questions about the pupils' view on genetically modified animals and bacteria. Finally, the pupils were asked about the quotations of the researcher and Greenpeace. The interviews were performed with one pupil at a time and lasted for about 30 minutes. All interviews were tape-recorded and transcribed verbatim.

4.4 Data analysis

4.4.1 Questionnaires

The data from the questionnaires were coded and put into a data editor in the computer programme SPSS. Simple statistics was used – frequencies, means and cross-tabs. Opinions before and after teaching were compared, as well as those held by males and by females, and by pupils at different schools. The arguments in the open-ended questions were analysed according to the model described above. As most of the responses were not very elaborate, they were simply categorised as factual statements, values and potential risks corresponding to knowledge, driving forces and conceivable obstacles and possibilities in the model (Wickenberg 2004). There were no responses indicating long-term benefits, e.g. to the environment.

- *Factual statements.* In this category, all statements referring to a fact were gathered, irrespective of whether they were correct or not. Some statements were correct, some incorrect and in some cases the factual statements were impossible to categorise as correct or not; for example, 'There is a need to use less chemicals' and 'Vitamins disappear.'
- *Values.* In this category were responses in which a belief or emotion was expressed. The statements included both values that supported the applications and those that opposed them; for example, 'You play God. It is against the tomato's nature and it can hit back' and 'Let science develop!'
- *Risks.* Risks expressed by the pupils concerned the environment, human health and unknown risks; for example, 'You don't know how it affects the tomato and the person who eats it' and 'You don't know what happens if the new characteristics are transferred to wild plants.'
- *Knowledge.* In the open-ended questions about knowledge, each response was marked as 0, 1 or 2 points. Each person could thus get a total of 6 points. The questions in which the pupils judged their own knowledge were given 0–2 points for each application or concept, which resulted in a maximum of 18 points.

4.4.2 Interviews

The interviews were read through several times. Initially, there was an attempt to analyse the argumentation using Toulmin's (1958) categories of data, warrants and claims, but this became too technical and did not answer the research question about what is important for the pupils. I also tried to identify the pupils' arguments as facts, values or conceivable obstacles and possibilities, as in the questionnaires, but it was often difficult to tell the difference between a fact and a value. Some facts included values and some values contained facts, and this method also became technical and did not include what the pupils talked about. Instead, a number of themes were identified. These were coded and the themes reported in the Results were chosen so that at least three students belonged to each one. The themes were (1) risks; (2) assessment of risks; (3) trust in research; (4) knowledge about the procedure; (5) the purpose; (6) ambiguity; (7) time perspective; and (8) feelings.

5. RESULTS

5.1 Research question 1: Are pupils' opinions on GMOs influenced by biology teaching?

According to the questionnaires, most pupils did not change their opinion. Forty-three out of 64 pupils held the same opinion on tomatoes; whilst 21 pupils changed their opinion – 14 towards a more positive and seven towards a more negative attitude. Most pupils who changed their opinion were uncertain in the first questionnaire, which meant that this number went down. Half of the pupils were positive about genetically modified tomatoes after the teaching. Males were more positive than females for both applications, and pupils at school 3 were the most positive. The number of subjects was too small to draw any general conclusions. Several pupils who approved of both genetically modified tomatoes and soy did not think they should be sold and said they would generally choose the regular ones if they had a choice. In both questionnaires, almost everyone ticked the questions as important, interesting and difficult.

About 50 per cent ticked 'I agree' to both the researcher's and Greenpeace's statement and almost as many ticked 'I do not know' to both, which indicated that the pupils did not see the difference between the quotations.

5.2 Research question 2: What is important for the opinion that pupils hold and how does knowledge work together with other parameters such as values?

5.2.1 Questionnaires

Arguments

Irrespective of whether the pupils were in favour of, against or hesitant about genetically modified tomatoes or soy beans, they presented similar arguments for and against the modifications. They also used similar arguments in both questionnaires. In general, factual statements were used to support GMOs, and values and risks were arguments put forward against these applications. The majority of pupils wrote that risks are important arguments against GMOs. Several pupils gave conditions for a positive attitude in the second questionnaire; for example, 'It is OK if there are no risks.'

Pupils who did not find it acceptable to develop genetically modified tomatoes used values and risks to support their personal opinion. A few of them also used factual arguments. These facts were often incorrect. For example, a few of students stated that GMOs are not good for the environment because you then need to introduce herbicides. Those who found it acceptable drew upon facts and values, but they did not use the same values. Sometimes they combined facts with values. The pupils who were hesitant gave arguments to a lesser extent. One group of pupils did not write any arguments at all. A majority of these pupils came from school number 3. To some questions, almost half of the pupils did not give any arguments. All of these students had Swedish as their second language.

Knowledge

The pupils at school number 2 demonstrated the best understanding of the genetic concepts according to the open-ended questions. They had taken BiA and BiB at the time of the first questionnaire and also biotechnology when responding to the second questionnaire. Pupils at school number 3 demonstrated less knowledge than pupils at the other two schools. At all schools, the knowledge score was lower in the second questionnaire. This was due to fewer elaborated responses; there were not more incorrect explanations. Out of maximum 6 points, the mean was 3.6 for school 1, 4.7 for school 2 and 2.8 for school 3 in the first questionnaire. At schools 1 and 2, the pupils' own judgement of their knowledge of concepts in gene technology and of applications of GMOs improved. The mean value went up from 7 to 13. There were no comparable data for school 3. A majority of the pupils ticked the boxes indicating that genetically modified tomatoes or soy are not more harmful to your health than conventional ones. Out of 64 pupils, 42 did not answer or gave an incorrect response to the question about the difference between conventional breeding and gene technology. There was no correlation between opinion and knowledge. In cross-tabs between scores of knowledge and opinion, all opinions were represented at all points of knowledge. There was no correlation between the pupils' judgement of their knowledge and opinion.

5.2.2 Interviews

The following themes were identified in the interviews. Some examples of interview questions and pupils' answers are given for each.

Risks

Irrespective of being positive, negative or hesitant, all of the pupils discussed the risks. The main risks were that plants or genes would spread to nature, that you can lose control, and unknown risks.

> Pupil: They have been in there, fiddling with something and changed something which has been organized by nature. Fiddling. We do not know. If we remove something and then something happens. Something might happen without us noticing it.
>
> (Female, pupil no. 17, School 1)

> Pupil: Soy. . .You change it so that it is resistant to Roundup, which kills all other plants, and then it becomes a complete monoculture. Just soy and that is not good.
>
> (Female, pupil no. 40, School 2)

As described earlier, many pupils agreed both with the researcher and with Greenpeace. Their explanations support the finding that the pupils were concerned about the risks. They agreed that each case has to be assessed and they agreed that we do not know enough about the risks.

> Pupil: Yes, Greenpeace says that it can spread and that is true and the researcher says that we have to assess each case. I think so.
>
> (Male, pupil no. 39, School 2)

Assessment of risks

If risks are important, then it might be comforting to know something about how risks are assessed, but generally pupils did not possess this kind of knowledge.

> Interviewer: Do you know how these applications are risk assessed?
>
> Pupil: Assessed?

> Interviewer: Yes, the process from a gene modification to a crop?
>
> Pupil: Well, I hope that they control it, that they do some tests.
>
> Interviewer: Do you know how?
>
> Pupil: No, no I do not.
>
> (Male, pupil no. 39, School 2)

TRUST IN RESEARCH

As it is difficult for pupils to assess risks, they instead judged the reliability of researchers. If they trusted them, the use of GMOs was acceptable, and if they did not, then it was not. Several pupils were quite sceptical about researchers.

> Pupil: If I had known something about the controls, then I might have thought differently. We do not get to know anything about that. . .The researchers sit in their labs releasing anything.
>
> Interviewer: Is that your image of a researcher?
>
> Pupil: Of course it is a kind of cliché, but still it is the kind of picture of horror you have. Someone like Frankenstein.
>
> (Male, pupil no. 15, School 1)

> Pupil: Well I do not know if you can trust them. But I do not think that they are making things up. But I do not think you can trust them when it comes to ethical reasoning. They do research in their subject and they want to proceed as far as possible.
>
> (Female, pupil no. 37, School 2)

KNOWLEDGE ABOUT THE PROCEDURE

To some pupils, knowledge about the scientific work gave them more confidence. Pupils at school 2 described how they had performed experiments in the biotechnology course and had learnt about the techniques. Some of these pupils therefore changed towards a more positive attitude.

> Pupil: I have learnt more. I know that these things are done under control. We have performed experiments – we have done some labs. It has been very controlled. It is not like doing things wrongly and having things spreading. It has been very important to do things properly. I think that these genetically modified tomatoes are good. They are not dangerous. Now knowing more, you put it in another perspective.
>
> (Female, pupil no. 46, School 2)

Another pupil who was very much opposed to all kinds of GMOs explained that it felt less scary if you knew more about how it works:

> Pupil: Of course, everything you do to understand these methods is useful. Naturally. To get an insight into how it is done. That makes it seem much less scary. . . as a matter of fact. But I still find it scary. But it is even scarier if you do not understand anything at all.
>
> (Female, pupil no. 40, School 2)

The purpose

It was important to the pupils that there was a good purpose for the genetic modification. All interviewed pupils found it quite acceptable to use genetically modified bacteria if, for example, insulin could be produced. However, several pupils did not see any reason to modify tomatoes or soy. The first example below demonstrates this. It also demonstrates that it is difficult for many pupils to see the benefits of applications that have to do with fungicides and herbicides. A number of them believed that genetically modified soy meant the introduction of herbicides to agriculture. It was even more difficult for them to understand the point of developing modified potatoes so that only one type of starch is produced. No one saw the benefit of using degradable material, e.g. for disposable plates. The statement below could also be interpreted as distrust in researchers, with the pupils believing they are ‘playing around’ and ‘doing things just for fun’.

> Pupil: I do not see that the tomatoes are of any use. They are good as they are. It is one thing if you can help people, but we do not need the tomatoes. They are good as they are.
>
> (Female, pupil no. 19, School 1)

> Pupil: ‘I think that the most important is to see to it that people do not starve and that they get the nutrition they need. Eventually, that will be economically beneficial. If there are only economical reasons. . .There must be more food as well. If you do this only because you know how, because you find it a super thing to do, that is wrong, if you do not have a real purpose.
>
> (Male, pupil no. 39, School 2)

Ambiguity

Several pupils were ambiguous in their answers, especially when discussing Golden Rice. All the pupils saw the benefits. As most of them really wanted something good for the future, it was difficult to argue against the rice.

> Pupil: Now you bring up a question when it becomes very difficult. Yes, because it is . . . Well I am very uncertain. . .It is about diseases. And about deficiencies. But at the same time, it is genetically modified.
>
> (Female, pupil no. 17, School 1)

Some pupils argued that it would be good to grow Golden Rice as it is beneficial to health, even if they did not see the benefits of soy or tomatoes. In this way, they judged each application and not just the technology. Some pupils were prepared to change their mind because of the Golden Rice. The following excerpt is from an interview with a male who was against GMOs:

> Pupil: I think it is good [about the Golden Rice].
>
> Interviewer: But it is genetically modified.
>
> Pupil: It depends on what is changed in the rice.
>
> [Interviewer explains about (β-carotene.]
>
> Pupil: I think it is good.
>
> Interviewer: But you are against modifying organisms?
>
> Pupil: That is difficult. But if you save lives. . .
>
> (Male, pupil no. 39, School 2)

Some pupils solved the dilemma by bringing up new arguments. The following excerpt from a very engaged and convinced female demonstrates this:

> Pupil: Yes, it is very bad if anyone dies or goes blind due to vitamin A deficiency. It is. I think the solution is not to grow the Golden Rice but to reorganize agriculture. Instead of growing rice, they should grow vegetables with lots of vitamins and nutrition, because the polished rice gives you very insufficient nutrition. It is better to reorganize the agriculture to be more varied. . .It is not very good to grow rice at all. It is bad for the environment as it produces huge amounts of methane gas. So you should change from growing rice to growing vegetables in any case. . .Besides, I read that the Golden Rice does not give much vitamin A at all. There is no way that people in Asia can eat rice so that they get enough vitamin A. . .But Golden Rice is the only thing done for poor people. All the rest is done for profit.
>
> (Female, pupil no. 40, School 2)

It was difficult for most pupils to understand the whole picture and to judge whether the benefits outweighed the disadvantages. A number of them showed ambiguity and it was hard for them to have a strong opinion if they had ticked both 'OK' and 'not OK' in the questionnaires. The first excerpt below is from a pupil who was opposed to GMOs in the first questionnaire and hesitant in the second one. Besides showing ambiguity, she demonstrates the importance of trust, and that familiarity with techniques increases trust:

> Interviewer: You were more negative in the first questionnaire?
>
> Pupil: Yes, I believe that is the case. I do not know why. I just feel that way. When you have learnt about biotechnology, you realise that there are so many techniques to modify genes and there are industries. If all this is there, it cannot all be wrong. And I feel that there is much to do. Something good must come out of it. I do not think that it is just bad. I guess I was a bit conservative. I do not know. Afraid of the future. I do not know. I suppose I simply have become more open-minded.
>
> (Female, pupil no. 37 School 2)

The second example is from a male who was negative in both questionnaires:

> Pupil: The tomatoes. . .It is good if you use fewer fungicides. Then I think it might work. If the environment can be helped. That is good. I am not very positive but not very negative either. But it feels like. . .And that vitamin A . . . Then it is not rice any more. I do not know . . . It is another product. Maybe that is not negative. It feels like . . .
>
> (Male, pupil no. 15, School 1)

This excerpt also is typical in that it refers to his feelings and that he does not know enough to support his arguments in any other way. The following excerpt demonstrates misunderstanding of the use of herbicides. Like most pupils, this pupil is very open to different arguments:

> Interviewer: Do you see any difference between the tomatoes and the soy?
>
> Pupil: Yes, I think there is difference when you spray all that Roundup. I do not think it is good to spread that much poison in nature. Well, I know it is not good. It becomes resistant to, or . . .?

> Interviewer: Yes, the soy is resistant to the Roundup.
>
> Pupil: Mm.
>
> Interviewer: Does that mean that you use more herbicides?
>
> Pupil: Yes and it is much stronger and more dangerous, isn't it?
>
> Interviewer: It is the opposite.
>
> Pupil: The opposite?
>
> Interviewer: The idea is that Roundup degrades quicker than most herbicides. And you do not have to spray the fields as many times.
>
> Pupil: But why have they used it before?
>
> [Interviewer explains about monocotyledonous and dicotyledonous plants.]
>
> Pupil: But if you use fewer herbicides . . .? But if it means that you can spray less then I think . . . I thought it was the opposite way – that Roundup is much stronger. Then I am for it. To decrease the use of herbicides. But to move genes, that is a little . . . I am not that much against it. But I feel that I do not have enough knowledge to know what can happen. I want to know about the consequences.
>
> Interviewer: What do you want to know?
>
> Pupil: I want to know what happens in nature. It is very difficult to know.
>
> (Female, pupil no. 17, School 1)

Time perspective

Several pupils thought that tomatoes were fine as they are, so why change? One farmer's son argued that, on his farm, his grandfather had grown the same crops and it had worked since then. Then I asked if there had been any changes in the plants over this time. He answered that of course there had been changes but they occurred gradually. Similar ideas came up with other pupils. They did not see the effect of conventional plant breeding, as the differences are small from year to year. Several pupils felt that changes happened rather quickly with gene technology.

> Pupil: Yes, the wheat grown today is different from the wheat my great-grandfather grew, but you do not see the difference. With the gene technology it is just there. Look at the rice: here is white rice and then suddenly yellow rice. It is hard to grasp. I do not know what my ancestors would think about our wheat and how we grow it. But it has changed gradually.
>
> (Male, pupil no. 15, School 1)

Feelings

As has been seen in some of the excerpts above, pupils referred to feelings when they could not find arguments. The following two examples demonstrate pupils referring to feelings more explicitly:

> Pupil: I go with my gut feelings. This feels right, and this does not feel that right.
>
> Interviewer: Do you believe that this feeling is influenced by knowledge?
>
> Pupil: Absolutely. You get more certain or more uncertain, the more you know.
>
> (Female, pupil no. 17, School 1)

> Pupil: GMOs give me bad vibes.
>
> (Female, pupil no. 40, School 2)

6. DISCUSSION

Although more pupils were more positive after teaching, most pupils held the same opinion and used the same arguments, so it is not possible to claim that teaching in general affected their opinions or arguments. The numbers in Table 10.1 indicate that it was rather difficult to come to a decision. According to their own judgement, the most important factors for decision-making were knowledge and risk assessment. Knowledge worked in two ways: some pupils stated that they had learnt about techniques, which made them feel more secure; whilst others said that they had learnt more about the ecological risks and therefore felt more hesitant. There were also pupils who referred to knowledge about herbicides and spraying; however, this information was often misunderstood.

The interviewed pupils all used genetic concepts in a way that demonstrated basic understanding. No one used the types of the argument that have been found in surveys of the general public, such as that it might be dangerous to eat genes. However, several of the pupils lacked knowledge about agriculture, for instance that most fields are regularly sprayed with herbicides and pesticides. Most pupils did not know the difference between conventional breeding and gene technology. The concept of a species was not clear to all pupils and it was difficult for them to discuss what makes a species competitive in an ecosystem. The pupils did not know much about risk assessment or about how scientists/researchers work. They found it difficult to scrutinise arguments and information. Important values to them were to do good things for humanity and for the environment, i.e. the applications had to be useful. Risks that they perceived were unknown risks, the spread of new genes in the ecosystem and losing control of what we are doing.

The pupils tried to gather a picture of an area that they found rather difficult, and they often declared that they needed to know more. Most of the pupils reasoned a lot, trying to include doing good things without taking risks and using their knowledge to come to an opinion about genetically modified plants. They were prepared to change their opinion if they could be given guarantees for safety or if they could get information about the risks.

It is obvious that knowledge, values and risk assessment interact, and it is not always possible to separate them. Knowledge about Golden Rice could support the values of the importance of doing good things. If your knowledge about how soy resistance to Roundup works is clarified, it might affect your opinion and might also affect how you assess risk. To argue that risk assessment is important is also to express values. Therefore, it was not fruitful to analyse the structure of the arguments, but rather the content of the arguments.

The issue of GMO is a true socio-scientific issue and has been discussed in the media. There is

Table 10.1 Percentage of pupils in respective groups holding different opinions in the three schools

	OK			*Not OK*			*Do not know*		
	T1	*T2*	*S*	*T1*	*T2*	*S*	*T1*	*T2*	*S*
Total	35	50	37	29	28	30	36	20	33
Females	24	41	31	34	36	33	42	21	36
Males	52	64	48	20	16	24	28	20	28
School 1	26	30	43	39	44	35	35	22	22
School 2	35	55	40	35	30	26	30	15	35
School 3	45	67	29	10	9	29	45	24	42

T1, tomato questionnaire 1; T2, tomato questionnaire 2; S, soy questionnaire 2.

also great interest from non-governmental organisations such as Greenpeace, which has performed some spectacular demonstrations, for example in the UK. The issue is difficult to understand, and it is appropriate to ask how you can prepare young people to participate in such a debate in a qualified way.

Implications for teaching

The pupils participating in this study are among the best educated in science in their age group in Sweden. However, they still found it difficult to understand and discuss issues about genetically modified plants. How then can you work with all pupils in a school? And how can you prepare them for all of the issues that we discuss in society, many of which are as complicated as this one? The pupils at school number 3 gave arguments to a lesser extent and they were generally more positive about the applications. It would be interesting to investigate the effect of not being a native speaker in your country in terms of how you engage in socio-scientific issues. There is a rather large population in Sweden who were not born in the country. It is a matter of democracy to ensure that these pupils get the tools to enable them to be involved in debates in society. All pupils need to discuss socio-scientific issues. In order to do that in a qualified way, they not only need basic conceptual knowledge in science but also specific knowledge about actual cases. They also need to know more about the nature of science and scientific work.

Pupils need guidance in analysing arguments. The pupils in this study could, in general, not distinguish between two quite different statements and they did not have the tools to analyse the statements. Instead, they trusted their emotions. These results are in line with those found by Kärrqvist (1996) and Ekborg (2005).

One suggestion is to let pupils choose different areas of gene technology and go into detail in these areas, rather than learning something about a number of different areas. As Lewis and Leach (2006) have shown, pupils do not need huge amounts of knowledge, but it has to be well designed and contextualised. It is then up to the teacher to guide the pupils in critical thinking, analysing arguments and motivating their own points of view. The pupils are then more likely to be both more critical and more secure. If they learn what questions to ask and how to interpret the information, their opinions will be formed on more specific arguments, rather than on general fear or trust.

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11 Development of decision-making skills and environmental concern through a structured, interactive curriculum

Christiana Th. Nicolaou, Konstantinos Korfiatis, Maria Evagorou and Constantinos P. Constantinou

LEARNING IN SCIENCE GROUP, DEPARTMENT OF EDUCATIONAL SCIENCES, UNIVERSITY OF CYPRUS, REPUBLIC OF CYPRUS

korfiati@ucy.ac.cy

This article focuses on the development of decision-making skills in upper elementary students (aged 11–12 years) through a structured, interactive curriculum. Additionally, it examines possible correlations between decision-making skills and environmental concern. We argue that a common deficiency of educational innovations aimed at developing decision-making skills is the lack of any kind of scaffolding for developing criteria, identifying alternatives and selecting between them. The present curriculum described here was designed to provide scaffolding in every step of the decision-making process. Moreover, it provided the necessary scientific information and allowed the consideration of multiple aspects of the problem, the study of the effects of every possible solution, and the formulation and balancing of criteria. The optimisation strategy for decision-making was adopted, because it allows the development of compensatory thinking, which is more relevant to actual situations of decision-making. The data collection relied on students' reports on and pre- and post-tests evaluating decision-making skills and a closed questionnaire measuring students' environmental concerns. The teaching intervention proved quite successful in significantly enhancing the decision-making skills of the participating students. Moreover, students' performance on the environmental questionnaire correlated well with the improvement in decision-making skills.

1. INTRODUCTION

Preparation of citizens capable of making sound environmental and social decisions is at the forefront of education (Colucci-Gray *et al.* 2006). For environmental education, decision-making skills are considered fundamental, as dilemmas concerning environmental issues are commonplace for consumers, voters or indeed any active citizen (NAAEE 2000). The effective confrontation of such issues demands not just conceptual understanding of the relevant topic, but also skills of identifying and processing the necessary information, which will render possible the selection of the preferable choice through reliable procedures (Seethaler and Linn 2004). Thus, decision-making skills are a valuable tool, giving people the ability to evaluate choices, to develop viewpoints and to participate in formulating solutions (Bell and Lederman 2003).

Nevertheless, enabling people to become efficient environmental problem-solvers appears to be a difficult task. Environmental issues are complex, often ill-structured and controversial, and may be subject to multiple perspectives and solutions. In order to deal with such problems, students should be able to reason about causes and consequences, advantages and disadvantages, and alternative outcomes in the decision-making process (Sadler and Zeidler 2005). A number of studies on students' decision-making abilities have reported a failure to understand what is required to deal with complex trade-offs (Howse *et al.* 2003). Hogan (2002) reported that a common problem was the narrow focus of students and a cursory treatment of the many dimensions of the underlying issues. Hong and Chang (2004) found that high-school students' decision-making processes were not systematic, but were based on trial and error.

Whilst the existing literature contributes significantly to pinpointing educational needs regarding the desirable improvement in decision-making skills, the actual development of appropriate curricula has not yet proved to be successful. Earlier attempts to develop instructional procedures for decision-making skills emphasised either the information and scientific aspects of a decision-making process or the traditional methods of teaching, which rendered students aware of the multiple aspects of an issue without promoting their skills to construct a conclusion and support it with evidence and a rigorous line of reasoning (McConney *et al.* 1994). Most recent attempts often provide students with the problem and some relevant information, asking them to reach and support a solution, whilst the researcher(s) record the processes of developing arguments, implementing selection criteria and taking decisions. Seethaler and Linn (2004) stated that students need scaffolding with regard to asking key questions and weighing up trade-offs.

1.1 Decision-making and environmental concern

Environmental concern is defined as the degree to which people are aware of problems regarding the environment and support efforts to solve them, and indicate a willingness to contribute personally to their solution (Dunlap and Jones 2002). The linear model for improving environmental concern, proposing that people who are more knowledgeable are more likely to become environmentally aware and therefore more motivated to act responsibly, failed to gather significant support from research findings and received widespread criticism (Marcinkowski 2004). Out of this discourse has emerged the idea that instructional processes should provide opportunities for students to develop a sense of ownership and empowerment so that they are prompted to become responsible, active citizens (Meinhold and Malkus 2005). Consequently, it is believed that a learning environment aimed at promoting decision-making, which will allow students to develop the criteria and skills to face complex situations and independently formulate well-documented decisions, can satisfy the conditions for empowerment and ultimately development of pro-environmental concern and willingness for action (Jimenez-Aleixandre and Pereiro-Munoz 2002). Thus, according to current trends in the environmental education literature, decision-making skills can contribute to the development of environmentally sensitive citizens (Arvai *et al.* 2004). However, the hypothesis for a possible connection between decision-making skills and environmental concern has not been tested in practice (Seethaler and Linn 2004).

This paper focuses on the development of decision-making skills and environmental concern by upper elementary students (11–12 years old) through a structured, interactive curriculum. We took the view that a structured curriculum that provides appropriate scaffolding for students in every step of the decision-making sequence will prove to be successful in its educational aim. Additionally, we wanted to examine the possible correlations between decision-making skills and environmental concern.

2. METHODOLOGY

2.1 Curriculum design and implementation

A structured learning environment within the Web-Based Inquiry Science Environment (WISE) was created, providing scaffolding at every step of the decision-making process and engaging student participants in the study of a real-life problem. Students had to take the following steps in order to complete their task within the framework of the proposed curriculum.

2.1.1 Introduction to the problem

The learning environment presented the challenge of solving a local problem, namely the extensive annoyance to a community caused by mosquitoes reproducing in a nearby marsh.

2.1.2 Understanding the content and the context

As it has been found that students are often unwilling to search for further information, even when it is desirable or necessary for thoughtful decision-making, it has been suggested that learning frameworks for decision-making should include ways in which students can get easy access to an appropriate range of information and viewpoints (Bell and Lederman 2003).

Five possible solutions were presented to students within the framework of our curriculum, namely: (1) the introduction of eucalyptus to the marsh; (2) the use of micro-organisms to fight the mosquitoes biologically; (3) the introduction of the mosquito fish (*Gambusia affinis*) to the marsh; (4) mild chemical spraying; and (5) strong chemical spraying. The learning environment presented these solutions and their effects on the system through both written information and simulations. Information on the possible pros and cons of each solution was incorporated in the curriculum in the form of scientific reports, taking care in every case to avoid guiding the students' opinions.

Simulations were developed using the software STAGECAST CREATOR™, representing the structure and function of a marsh ecosystem and the way it would be affected by each of the five proposed solutions. Through in-depth interaction with these simulations, students gained an understanding of the complexity and the systemic structure of a marsh and its possible transformation due to human intervention.

2.1.3 Learning and applying decision-making procedures

Learners should be able to distinguish and implement all of the criteria that pertain to a given issue. In educational practice, this very often means that students should become aware of aspects not thought of before, and thus enlarge the range of aspects included in their decision base (Bell and Lederman 2003). Moreover, potential decision-makers should be equipped with a method of examining relationships between important variables, addressing trade-offs, weighing environmental and social concerns along with technical assessments, and combining different judgements (Blackmore and Morris 2001).

We applied the optimisation strategy for decision-making as the most appropriate approach for developing environmental decision-making skills. The optimisation strategy involves a complex process of adjusting relative weights of relevant criteria, and balancing the strengths and weaknesses of the various alternative solutions, and thus it can be considered as a reasoning strategy that could be usefully applied in multi-attribute decision-making situations. Thus, it is considered relevant for treating environmental issues, where there are no clear right or wrong choices, and one has to compensate for the various pros and cons to select the best compromise (Anderson *et al.* 2005).

Within the learning procedure outlined in our curriculum, the students had to implement the following steps, which correspond to the stages of an optimisation decision-making strategy (Papadouris *et al.* 2005):

- Formulate and analyse criteria by which the alternative solutions will be evaluated.
- Rank alternative solutions with respect to each criterion.
- Account for the relative importance of each criterion and assign different weights.
- Obtaining an overall evaluation for each solution by estimating the total sum of all criteria.

These steps correspond to the basic stages of a professional optimisation strategy for environmental management decision-making, with the main difference being more sophisticated calculations involved in the latter for studying consequences, weighting criteria and evaluating alternative solutions (Anderson *et al.* 2005).

Training in the optimisation strategy for decision-making was implemented through a specific example, according to which a person was trying to decide 'Which is the best car to buy?' following the stages of the optimisation strategy. This specific content was selected because it was close to their interests. Afterwards, students were asked to implement the optimisation strategy to the mosquito problem and to select the optimal solution for the community.

2.1.4 Communication and social interaction

At the end of the study, the students had to prepare a presentation describing the process they had followed in order to reach their decision and discuss their results in class. Researchers such as Hogan (2002) and Arvai *et al.* (2004) have stressed the importance of communicative approaches as a tool for improving a student's ability to participate in social debate, environmental groups or communal decision-making.

2.2 Sample and data collection

The learning intervention was implemented in an after-school computer/science club in a suburban area of Nicosia, Cyprus, over a period of 3 weeks. Participants were 12 students (eight boys and four girls) in the fifth or sixth grade, aged 11–12, who volunteered to take part. Participants were of mixed ability and socioeconomic status. All participants were described by their teachers as being academically able, but not as being high achievers. The curriculum was implemented by two of the authors of this study. Students met with the researchers twice a week for 1 hour over a period of five meetings. Students were asked to work in pairs; however, two students decided to work independently. Group meetings with the other co-authors took place prior to and after each session.

2.3 Means of data collection

2.3.1 Decision-making skills

Students' performance in decision-making skills was measured using a diagnostic test, as well as from their reports. The combination of two independent measurements allowed us to avoid context-dependent and instructional-imposed biases and provided cross-referenced data. Specifically:

- *Students' reports.* Students were asked to prepare a PowerPoint presentation, in which they were asked to indicate which of the five solutions they considered the optimal one for the inhabitants of the community and to explain their reasoning. Specifically, they were asked to demonstrate how they arrived at their recommendation and to provide all the evidence they had used in the process.

- *Diagnostic test.* A diagnostic test was used before and after the instructional intervention to measure possible improvements in decision-making skills. The test required application of the optimisation strategy to a situation unfamiliar to the students, i.e. the need to select the best place to build a power plant. This test had already been tested for validity and reliability with children of the same age (Papadouris *et al.* 2005). According to the information provided by the test, students had to select between two potential places, taking into account the different costs of the construction at each location and the different number of inhabitants that would benefit from the operation of the power plant, depending on its location. Students had to evaluate how well each location satisfied both criteria (financial cost and social benefit), as well as to weigh up the importance of each criteria, before arriving at their decision.

Both the reports and students' answers to the diagnostic tests were evaluated according to their success in implementing the different elements of an optimisation decision-making strategy, namely: (1) use of all criteria to reach an answer; (2) conversion of data on a common scale of measurement; (3) consideration of the relative weight of each criterion; (4) addition of the scores for each solution; (5) understanding the content and the context of the issue and the criteria; and (6) providing a thorough explanation for the steps followed and the solution chosen. The first four elements represent essential decision-making skills and thus implementation of each one of these was ranked with 2 points. The last two elements concern general skills of comprehension and reasoning rather than specific decision-making skills. For this reason, students could achieve one point for implementing each of them. Thus, in total, each student was graded with a score between 0 and 10 depending on the number of aspects implemented successfully for each task.

2.3.2 Environmental concern

It has been shown that environmental concern is not one-dimensional (Stern 2000). For this reason, in the present study we developed a Likert-type questionnaire consisting of 16 items measuring different aspects of environmental concern (see Appendix 11.1). The items used were considered typical for the construction of a questionnaire of this specific content (Hernandez *et al.* 2000; Korfiatis *et al.* 2004).

3. RESULTS

3.1 Reports

The results from the assessment of student reports are presented in the third column of Table 11.1. These ranged from 7/10 for two of the pairs to 10/10 for one pair and the two students who worked individually. One pair achieved a score of 8 and one pair a score of 9.

The pair in group 5 implemented the optimisation strategy in a correct way. They first enumerated the possible solutions to the problem and then presented the criteria used to score each solution and assigned a weight to them. They created a table in which they filled in the score for each solution and provided explanations for the maximum scores they assigned to each of the criteria. They also multiplied the score for the most important criterion by two and estimated the sum for each solution.

In contrast, the pair in group 3 tried to implement the optimisation strategy but used it in an inappropriate way. These two students converted the data on a unique scale of measurement and implemented the relative importance of the criteria used. However, they failed to understand each criterion. They stated that spraying with a strong insecticide was an inexpensive solution, scoring this solution with the lowest mark (1). Nor did they provide any explanation for their decision. Overall, they received a low score (7/10).

3.2 Pre- and post-tests

Students considerably improved their skills in the optimisation strategy for decision-making after instruction. Seven out of 13 students converted the data provided into a unique scale of measurement. Five students were able to weight the importance of each criterion after instruction. Seven students were able to sum a total score for each alternative solution. No student was able to perform any of these operations before instruction.

Student 12, who obtained the highest score (10/10) in the post-test, received a low score in the pre-test (2/10) stating the following:

> It is better to build the factory in Area 2 where there are fewer people. The factory shouldn't be near a built-up area. Area 2 is also cheaper.

This student deliberately changed the sense of the first criterion: 'Number of people who will benefit from the presence of the station' by stating that 'The factory shouldn't be near a built-up area.' The answer of the same student in the post-test was:

> The government should build the power plant in Area 2. Here is why: First I scored the two areas according to the two criteria. I gave 10 to Area 1 in the first row since more people benefit from the operation of the power plant, and 8 to Area 2. I gave 9 to Area 2 in the second row as it is a cheaper solution and a 5 to Area 1 since it is much more expensive. Then I doubled the scores for the cost of the development of the power plant, since it is stated that the cost criterion is two times more important than the other one. Then I summed up. Area 2 gets 26 and Area 1, 20. So I recommend Area 2.

The fourth column of Table 11.1 presents the student gains from the pre-test to the post-test on the decision-making diagnostic assessment. Students' performance in the pre-test ranged from 0 to 2 pre-instruction. All students improved their performance after instruction. A paired-samples *t*-test comparing students' performance on the pre- and post-tests indicated a statistically significant difference [$t(1,12) = 4.500$, $P<0.001$]. However, students 4, 6, 9, 10, 11, and 12 belong to a high-performance group with an average gain of 6.83, whilst students 1, 2, 3, 5, 7, and 8 appeared to belong to a low-performance category, exhibiting an average improvement of their score in the test of only 1.17.

The second column of Table 11.1 indicates the pair to which each student belonged during instruction. For three of the pairs (groups 1, 4 and 5), both students demonstrated similar improvement in the diagnostic test, which was completed individually by each student. However, members of the remaining pairs collaborated less effectively. Each student demonstrated substantially varying gain scores on the diagnostic test (groups 2 and 3).

The performance of students on the post-test was lower than the performance in the group reports. A *t*-test carried out to compare performance in the reports and in the post-test indicated that the differences were not significant for this small sample size [$t(1,12) = -2.138$, $P>0.05$].

3.3 Environmental concern

A correlation analysis showed that the items of the questionnaire fell into four groups with significant correlations between the items of each group. The statistical correlation also makes sense in terms of the contents of the items. Thus, we concluded that these groups of items constituted four scales measuring different aspects of environmental concern. Specifically, the ‘nature exploitation’ scale explored students’ ideas regarding the use of nature to serve human needs (see Appendix 11.1). The ‘nature protection’ scale reflected the students’ ideas concerning the protection of nature and the consequences that follow from lack of protection measures. The ‘naturalist’ scale referred to the students’ wish and need to live close to nature. The last scale, the ‘economy first’ scale, sought to identify the students’ ideas regarding the economic aspects of the use of nature. On average, students improved their performance on the environmental scales within a range of mean difference of 0.3 for the ‘naturalistic’ scale and 1.4 for the ‘economy first’ scale (Table 11.1).

The results exhibit an interesting pattern, especially with regard to the ‘high-performance’ group in the decision-making skills test (students 4, 6 and 9–12). This group followed a fairly homogenous pattern of improvement in three out of the four environmental scales. Specifically, in the ‘nature exploitation’ scale, the ‘nature protection’ scale and the ‘economy first’ scale, all members of the ‘high-performance’ group increased their pro-environmental scores. In contrast, for each scale there were members of the ‘low-performance’ group who improved their performance and others who reduced it, or remained at the same level as before instruction. Additionally, no member of the ‘low-performance’ group exhibited a stable pattern of responses across the different scales. In conclusion, the ‘low-performance’ group was not characterised by the same homogeneity across scales and across the sample as the group of students with the highest levels of improvement in the optimisation test.

Correlation analyses revealed a statistically significant positive association between scores in the decision-making skills post-test and responses after instruction for the ‘nature exploitation’, ‘nature protection’ and ‘economy first’ scales (Pearson correlation = 0.691, $P<0.05$; 0.617, $P<0.05$; and 0.580, $P<0.05$, for the associations between post-test scores and scores after instruction for the ‘nature exploitation’, ‘nature protection’, and ‘economy first’ scales, respectively). No such significant association was found in the comparison of the corresponding data before instruction. Significant associations were also found when comparing the gains in performance between the pre- and post-tests and the difference in the answers on the environmental scales before and after instruction (Pearson correlation = 0.629, $P<0.05$; 0.712, $P<0.01$; and 0.580, $P<0.05$, for the associations between the score differences between pre- and post- tests and score differences before and after instruction for the ‘nature exploitation’, ‘nature protection’ and ‘economy first’ scales, respectively).

4. DISCUSSION

Many educational researchers and leading educational associations have stressed the need for students to become effective problem-solvers and decision-makers (NAAEE 2000; Arvai *et al.* 2004; Colucci-Gray *et al.* 2006). Within the framework of the present research, we developed and evaluated a curriculum for the improvement of decision-making skills in young children at elementary-school level, based on the principles of the optimisation strategy for decision-making. The learning environment proved to be reasonably successful in significantly improving the decision-making skills of the participating children. The results implied that students were able to apply what they had learned in unfamiliar contexts, as the test was specifically used to isolate the effect of the learning intervention from the particular context of environmental disturbance by using a different context (construction of a power plant). This is an important finding, as previous research has shown that when children learn decision-making strategies, they often do not apply them beyond the specific training paradigm (Grace and Ratcliffe 2002; Howse *et al.* 2003).

The work in pairs did not lead to positive outcomes for both students in the pair in all cases. In addition, students who elected to work alone did not demonstrate any disadvantage in their

Table 11.1 Students' groups, scores and score differences from reports, diagnostic texts and environmental scales

Student	*Group*	*Students' reports*[a]	*Optimisation test*[b]	*Environmental concern questionnaire*[c]			
				'Nature exploitation'	*'Nature protection'*	*'Naturalism'*	*'Economy first'*
1	g1	7	1	−0.2	−1.0	2	1.5
2	g1	7	2	0.4	0.2	−1	0.0
3	g2	9	1	0.4	0.0	0.5	1.5
4	g2	9	7	0.6	0.1	0	3.5
5	g3	7	1	0.5	0.0	1.5	2.0
6	g3	7	6	2.0	0.3	0	2.5
7	g4	8	1	−0.5	−0.3	1.5	0.0
8	g4	8	1	0.8	−0.5	−0.5	0.5
9	g5	10	7	0.8	0.5	−1	4.0
10	g5	10	5	1.4	2.0	0.5	1.5
11	g6	10	8	0.8	1.5	−0.5	1.0
12	g7	10	8	1.4	1.5	0.5	2.0

[a] Score (maximum possible score: 10).
[b] Difference in scores before and after instruction (maximum possible difference: 10).
[c] Difference in means before and after instruction (maximum possible difference: 5).

performance in relation to those students working in pairs. These results add to the discussion on the role of teamwork and its actual contribution to the educational improvement of each member of a team (Huber 2003).

The curriculum helped students change their ideas towards the relationship between human beings and nature, as they were expressed through the scales of the questionnaire. Students' performance on the environmental scales was in line with their improvement in decision-making skills. Decision-making should be connected to 'thoughtful' action. However, educational approaches often promote types of decision-making based on 'impulse' behaviours, i.e. specifying from the beginning the rights and wrongs of a situation, without allowing independence of decision (Jickling 2003). The proposed curriculum explicitly tried to avoid this specific pitfall. Although this study only had a small sample size, the results provide suggestions supporting the hypothesis of empowering and developing positive environmental attitudes through the development of people's decision-making skills. The fact that scores in the 'naturalist' scale did not follow the general pattern was attributed to the lack of opportunities within curriculum activities to develop positive experiences with nature, which is a prerequisite for the development of naturalistic attitudes (Stern 2000).

We consider that the structured, scaffolded framework of the proposed curriculum is the main reason for its success in improving the decision-making skills of the participating children, in contrast with other studies on the subject that have described failure to help students use evidence in order to support their claims or to help them develop criteria in order to weigh up alternative options (Hong and Chang 2004; Seethaler and Linn 2004).

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APPENDIX 11.1 SCALES OF ENVIRONMENTAL CONCERN

'Nature exploitation' scale

Wild animals are not useful for society.*

It is important to maintain rivers and lakes clean so that humans can have a place to enjoy water sports.*

The development of motorways is very important and justifies the cutting of forests and the destruction of grassland.*

The trees in the forests of Cyprus are not growing fast enough. When we have to cut them down, we should plant trees that will grow up faster.*

The main use of forests is the production of goods useful to humans.*

The main reason why we should preserve energy sources is to maintain a high quality of life.*

One of the most important reasons for preserving the environment is the protection of areas with wild life.

In some areas, humans cut down forests to make space for farming. This helps society to improve agriculture.*

'Nature protection' scale
There are laws for human rights. In the same way, there should be laws for animal rights.
Human beings cause huge catastrophes/problems in the environment.
Humans will survive on earth only if they respect and take care of the environment.
When humans interfere with nature, sometimes it leads to catastrophic consequences.
'Naturalistic' scale
I love walking in nature. I would love to walk more often on natural pathways.
Life on a farm is as interesting as life in a city.
'Economy first' scale
One of the most important benefits of recycling is saving money.*
It is better to have a large increase in car prices so that we can have fewer cars on the roads.

*Inversely rated items.

4

Student reasoning, scientific thinking and argumentation

12 A model for communication about biotechnology

John K. Gilbert[1] *and Bev France*[2]

[1]INSTITUTE OF EDUCATION, UNIVERSITY OF READING, UK; [2]FACULTY OF EDUCATION, UNIVERSITY OF AUCKLAND, NEW ZEALAND

j.k.gilbert@reading.ac.uk; b.france@auckland.ac.nz

In this study, the case for communication between biotechnologists and other distinct communities in the general public is made. Five practising biotechnologists provided written answers to questions of topical interest that had been identified from specialist magazines. These answers were analysed to identify the similarities and differences of perception between the public and the biotechnologists as perceived by the latter. This analysis provided guidance for the development of a novel communication model, which is presented. It is based on the premise that a communicating community is a relatively coherent social group engaging in communication within itself. Any community may have a 'view' on biotechnology that is made up of the following: its understandings of the nature of science and of biotechnology; its understanding of the key concepts and models used in biotechnology; its perceptions of the nature of risk relating to biotechnology; and its beliefs and attitudes about biotechnology. Conversations between communities that are attempting to communicate occur virtually within an intersection – a 'search space' – of the components of the 'views' of two communities, making use of argument and explanation. Where there are elements of the views that are in common between the two, communication in terms of these is possible. Where there is no general commonality, the degrees of understanding reached must be used to construct a mutual understanding that may evolve into an agreement.

1. RATIONALE

Public discussion about any new technology passes through three stages. Firstly, the 'eureka' stage, in which there is interest in and excitement over the new process or product. Secondly, the 'spaghetti' stage in which the technology and its applications are modified by producers and consumers to make it more capable of adoption by the public at large. Thirdly the 'black box' stage, in which the technology is adopted, culturally accepted and becomes socially invisible (Gradwell 1999: 256). Most of the biotechnologies based on genetic engineering are currently at the 'spaghetti' stage and are experiencing a situation where there is intense debate. The findings of the *Report of the Royal Commission on Genetic Modification* (Eichelbaum *et al.* 2001) and research (Hipkins *et al.* 2002) suggested that a distrust of science in general, and biotechnology in particular, among 'the public' might result from a lack of understanding of how science ideas are investigated, debated and resolved within the science community.

Whether the solution to this problem is to remedy this 'deficit' of public understanding about science or not, it has become apparent that improved communication between biotechnologists and other interested groups is needed. As Gradwell (1999) observed, the general public is sceptically alert to the potential and implications of any new technology, not least biotechnology. The two broad groupings involved in this dialogue (biotechnologists and the interested public) need to communicate effectively.

We believe there is a need to develop a model to facilitate dialogue between biotechnologists and 'the public'. At an early stage of our research, we were aware that building a model that enabled communication would not be a simple matter of ensuring the questions from the public being answered by biotechnologists in a form that the public would understand. Nor would it be a process of getting biotechnologists to tell the public what they thought the latter should understand. Rather, it would be the case of two parties being able to understand, evaluate and respond to the concerns and ideas of the other.

Our objectives were to:

- develop a theoretical model for communication between biotechnologists and other communities;
- identify the components of the model; and
- propose a thesis to explain the process of communication when these components intersect.

This communication model was developed inductively over 3 years using document analysis scholarship.

2. PROPOSAL FOR THE ENHANCEMENT OF DIALOGUE

The model was based on the premise that dialogue between biotechnologists and the public can only occur under specific circumstances, i.e. when there is a 'space' that allows the participants to ask questions of each other and allows them the scope to develop common understandings. This term was developed from the concept of 'problem space' used by Stankiewicz (2000). We postulated that communication would thus be enhanced if there were opportunities for participants to access information in a form that could be utilised by both groups. It was hoped that participants would be able to identify principles and/or concepts that supported their understandings and that these common ideas could be thought of as 'standing fast' (Wittgenstein 1969: 612). We proposed that during such communication these ideas could be used by the participants to construct new meanings for other words by exploring similarities and differences between the present situation and previous encounters.

We predicted that attempts at communication between groups would occur at the intersection of these information packages. We called the intersection of these virtual components a 'search space' and theorised that it was here that common understandings and differences could be identified and debated.

At this stage, we needed to identify the participants involved in the dialogue.

2.1 Characterisation of the communicating groups

We realised that, before we could think about the components of the model, we needed to have some understanding of the groups of people that could be involved. We identified two groups, the biotechnology community and the public, and postulated that they would have features in common that would facilitate communication. The characteristics of a communicating community are that they share a broadly agreed set of common goals, utilise mechanisms that permit intercommunication among members, use participatory mechanisms for information gathering and feedback, are able to utilise one or more genres, and have a vocabulary of specialist words (Swales 1990).

On first examination, 'biotechnologists' appeared to fit these criteria as they belonged to an organisation called NZBio (New Zealand Biotechnology) that publishes a journal and organises annual conferences.

The public was a less well-defined entity. Three distinct ways of describing the public in discussion have emerged from the literature. Firstly, the public can be described in terms of knowledge deficiency, for example, the dichotomy of public (laypeople) versus experts (Gutteling 2002). A second representation of the public can occur when it is segmented by evaluations of their knowledge of and attitudes towards science/technology. Such a segmentation was done by Hipkins *et al.* (2002) of confident science believers, concerned science supporters, educated cynics, the confused and suspicious, uninformed individualists, and the 'left behind'. A third, more fine-grained representation, is when the public are described according to a group membership that acknowledges a degree of commonality of understanding about science/technology as well as a shared evaluation about its use. Such groups may be permanent because of location or occupation, or have an ideological commitment, or may be transient based on a temporary common interest or need (Layton *et al.* 1986).

The grouping that best served the focus of our model development is the third grouping of 'public', which uses as its criteria the identification of a common social commitment that acknowledges some form of voluntary purposeful participation (Select Committee 2000).

At this point in our research, we did not have the capacity to identify the components of the model for a public group but were able to carry out a small-scale research project to identify them within the New Zealand biotechnology community.

3. RESEARCH TO IDENTIFY THE COMPONENTS WITHIN THE BIOTECHNOLOGY COMMUNITY

In order to identify what components might be relevant for biotechnologists, we decided to use a public forum (*New Zealand Biotechnology Association Journal*) to conduct a debate about biotechnology issues and to use the material to provide an initial guideline for the nature of components that should be included in a model of communication. The research had four phases:

- *Phase one: Setting the research agenda.* In order to provide a forum for communication about biotechnology issues, we published a research agenda in the *New Zealand Biotechnology Newsletter*. In this paper (France *et al.* 2001), we described this agenda and outlined the themes in public discussion that had been identified from articles that had been published in widely available non-specialist publications. The identified themes were food safety, reproductive technologies, transgenic animals, environmental concerns about genetically modified organisms and patenting. Biotechnologists were alerted to this research project and asked to provide feedback.
- *Phase two: Response elicitation.* Five practising biotechnologists were personally invited to write an article to answer the questions: What public concerns in your field need attention by the biotechnology community? Are these issues being researched? In addition, each biotechnologist was asked more specific questions about safety and ethics that would provide a context for their discussion. The responses were published in the *New Zealand Biotechnology Association Journal* and republished in France and Gilbert (2006).
- *Phase three: Analysis of articles and publication of findings.* The published papers were initially analysed to identify what issues of concern these biotechnologists had identified, as well as their suggestions for research and development. The research report was published in the *New Zealand Biotechnology Association Journal* (France *et al.* 2002).
- *Phase four: A secondary analysis for the development of a model.* The biotechnologists' responses provided information about their concerns, as well as indicating some commonality of beliefs. We postulated that these commonalities provided information about what ideas appeared to be

'standing fast' within some common areas. Further analysis of this data provided a direction for the development of the communication model.

4. IDENTIFICATION OF COMPONENTS

We argued that the cognitive status of any individual's ability to communicate about biotechnology can be described in terms of five components: (1) knowledge: understanding of key concepts and models of biotechnology; (2) an understanding of the nature of science and technology; (3) an understanding of the concept of risk; (4) the beliefs and attitudes to biotechnology held by the group; and (5) affect: the beliefs and attitudes that influence behaviour. We should make two things clear here. Firstly, that component 3 (risk) was not mentioned by the biotechnologists (perhaps this is significant in itself!). Secondly, the location of the components in the model is arbitrary and does not imply any hierarchy or dependence.

The first four components are identified in Figure 12.1 and will be described in turn. The fifth component (the beliefs and attitudes that influence behaviour) provided us with a direction to explore the act of communication and will be discussed when the model is presented in its entirety. Even though these components were identified from biotechnologists' contributions, the subsequent literature search has shown that it is fruitful to draw parallels with our other group, 'the public'. The following discussion will refer to both groups.

4.1 Key concepts and models of biotechnology

We postulated that communication would be enhanced if there was an opportunity for participants to become aware of the key concepts and models of biotechnology. Although a literature search revealed a range of attempts to identify a kernel of essential knowledge about biotechnology, we believe that these lists do little to inform and in fact provide more confusion than clarity.

What seemed more informative was the comment that 'people have limited knowledge about biotechnologies – and know it' (Fischhoff and Fischhoff 2001: 2). We concluded that this situation was an advantage for participants rather than a deficiency as it could create a need and opportunity for learning. Studies have shown that if specialist knowledge is needed to assess science and technology situations, the public is capable of accessing and understanding this information; for example Layton *et al.*'s (1986) study of parents of children with Down's syndrome.

Rather than providing information about concepts that could be considered to be 'standing fast' within the community, it may be more fruitful to develop an understanding of how to discuss the components of such knowledge in terms of the epistemological grounds on which it is generated and becomes socially accepted.

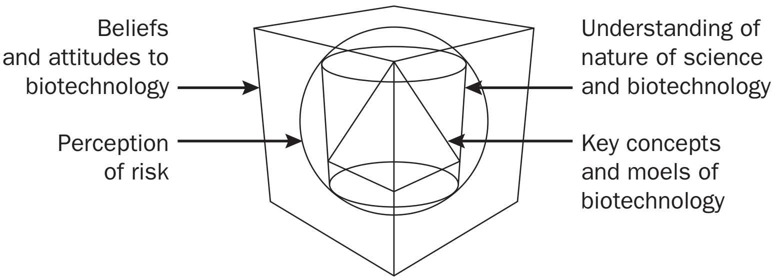


Figure 12.1 Identification of components

4.2 Understanding the nature of science and technology

The component that provides the capacity for participants to share an understanding of the nature of science and technology must be based on their epistemic cognition of this concept. Moshman (1998) analysed the public's epistemic cognition of the nature of knowledge across adolescence and adulthood, and identified three stages that he labels as objectivist, subjectivist and rationalist. He postulates that those individuals within the objectivist stage see knowledge as absolute and unproblematic, and accept justification as direct observation or from an authoritative source. A subjectivist stage is where a person has a view of knowledge that is deemed to be uncertain, ambiguous, idiosyncratic, contextual, and/or subjective. Justification is considered to be impossible and people in this stage may reject all scientific arguments. The rationalist stage of understanding the nature of knowledge is when a person believes that there are justifiable norms of enquiry, for example, scientific enquiry.

This analysis could appear patronising; this is not intended. It is important for scientists as well as the public to examine their beliefs about knowledge formation so that they can identify concepts that are 'standing fast' in their community, and at the very least biotechnologists need to identify reasons for their positioning.

In addition, we maintained that in discussing biotechnology one should have a viewpoint on the differences between the nature of science and technology, as well being able to identify how knowledge is validated in these disciplines. For example, the purpose of science is to 'explain' the natural world, whereas the purpose of technology is to 'intervene' in the physical world (Baird 2001). This difference in outcome provides a point of difference between science and technological knowledge validation. Thus, the epistemological basis of science is 'truth' that has its verification in empirical data (Smith and Scharman 1999), whereas in the process of technological knowledge validation it is 'functionality' that replaces 'truth' (Baird 2001). Because function is closely related to fitness for purpose, there is also a normative element from which technologies can be assessed (Bos 2000), which is in opposition to the objective directions that science may move towards.

We believed that it is necessary for participants to identify their position on the objectivist–subjectivist–rationalist continuum (Moshman 1998), and without such an opportunity there is little chance that meaningful communication can occur. We predict that such discussion could provide avenues for establishing perceptions of the nature of science and technology that may be 'standing fast' within this component.

4.3 Concept of risk

We postulated, albeit without direct evidence from the biotechnologists, that a shared understanding of risk is of major importance to any attempt at dialogue, and the difficulty in identifying concepts that are 'standing fast' could provide clues to these barriers. For example, the public are more interested in the personal consequences of risk, whereas experts' opinions are based on 'objective', statistical, actuarial data. These 'rival rationalities' may jeopardise communication between groups (Margolis 1996).

Slovic (1987) commented that the public worries most about risks when the perceived level of threat is high, the risk is unfamiliar, they cannot control the risk themselves, or exposure is involuntary. The public's view of risk was described by Peter Sandman as being a combination of 'hazard' and 'outrage' where 'hazard' was the actual risk and 'outrage' the public's perception (Eichelbaum *et al.* 2001: 73).

This disparity of views may be expressed in the bipolar notion that 'the wisdom of people is pitted against the brittle knowledge of experts' (Wynne 1992: 276). The expert's response to this disparity can be an assumption that the public is unable to appreciate the complexity of the situation. The public response, on the other hand, is that the instruments of measurement, taken from a technical positivist's repertoire, give a limited view of reality (Renn 1992).

In order for debate to occur between the public and experts, there needs to be trust, not only of the participants but also in the institutions that are carrying out the activities that promote a perception of risk or outrage. Slovic (1993: 677) has proposed a hypothesis to explain the process by which trust and distrust can develop within a community. He called it the 'asymmetry principle' where negative (trust-destroying) events are more visible and influential than positive (trust-building) events. This explanation has synergy with the public view of risk as hazard and outrage.

As a consequence, we postulated that the process of risk communication should facilitate understanding of these different perspectives, rather than being a passive one-way transmission of knowledge from expert to public.

4.4 Beliefs and attitudes to biotechnology

At their core, attempts at communication are linked with beliefs, attitudes and behaviours. Fishbein and Ajzen (1975) described attitude as a learned predisposition to respond in a particular manner. Thus, an attitude taken will govern the 'belief' the person has about that object (idea). For example, it may be assumed that a member of the biotechnology community has positive attitudes to genetic engineering because of their membership of that community. This disposition will lead to the adoption of beliefs about the positive value of the process and outcome, and it is likely that they will be receptive to explanations and arguments that are supportive. Conversely, they are likely to be unreceptive to explanations/arguments that are not supportive of genetic modification. However, they may be willing to listen to explanations/arguments as a prelude to refuting them.

4.5 Testing the relevance of the components

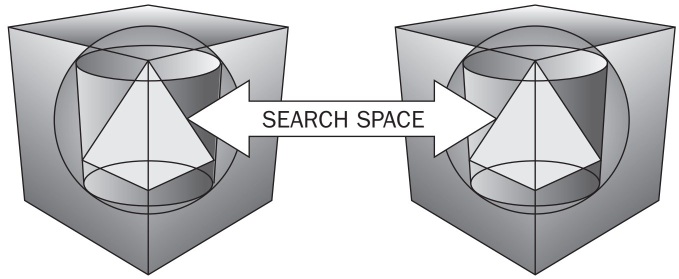
After identifying the components of our model, we needed to test their relevance for biotechnologists and the public. We carried out a small-scale research project where we used our identified components to analyse published data of dialogue between two stakeholder communities in a New Zealand biotechnology debate (France and Gilbert 2005). The participants in this debate were scientists involved in genetic modification research and members of the wider community involved in genetic modification interest groups (Cronin and Jackson 2004). The analysis provided us with data to demonstrate that these components were appropriate, and it was possible to identify the cognitive status of the participants in terms of them. Although this research confirmed that such components were present within a dialogue, it could not tell us about their relative size or their relationship. We recognise that our depiction of these components in Figure 12.1 is theoretical.

5. COMMUNICATION MODEL SHOWING THE PROPOSED LOCATION OF THE SEARCH SPACE

Figure 12.2 shows our drawing of the model and reintroduces the two major ideas of this model:

1. A communicating community of a relatively coherent social group engaging in communication with itself has a 'view' of biotechnology (concepts that are commonly held and are 'standing fast') that is found within the identified components.
2. A 'search space' as the intersection in a virtual arena of the components of the 'views' of two communities. This intersection is where common understandings are identified and in which cognitive dissonances are produced and/or resolved.

Figure 12.2 Model showing the proposed location of the search space



5.1 Linguistic issues that are central to communication

In order to unpick the communication processes that may occur within this search space, we explored the literature on the nature of language (Bazerman 1999), the making of meaning (Swales 1990) and forms of speech acts (Searle 1979).

Linguistics literature provided us with tools to analyse the process of communication. Essentially, we adopted a view of discourse as a conversation and that the act of discourse is made up of texts and behaviours occurring in an unfolding drama of moves and countermoves where the intention is to convince others (Bazerman 1999). We surmised that intercommunity discourse will be more complex than intracommunity discourse because the tools needed for mutual understanding are often absent. Furthermore, the process will take longer because there will be less opportunity for periods of interaction. To add to the complexity of intercommunity discourse, there are linguistic barriers, such as the way in which it is organised (genre), and the speech acts that provide linguistic purposes to provide communication clues for participants.

Although genre with its texts (spoken, written, or a combination) together with the 'tasks' that involve encoding and decoding procedures (Swales 1990) provides clues to the form of the discourse, making sense of what is said or written requires effort by the recipient. An example of a scientific genre is the 'experiment', which is an account of an experimental procedure and findings. The recipients' success in making sense of the 'text' is dependent on their understanding of the conventions of representation embedded within the scientific genre. The process of decoding provides the link between the formal schemata of the discourse (what the phrases within it mean) and the content schemata (the nature of the topic being communicated).

Non-scientists can have problems in understanding the genres used by scientists because they are not familiar with the decoding procedures that give rise to scientific statements. For example, an explanation about risk may assume that the recipient understands the 'technical' meaning of risk, which is the 'likelihood of something happening and the magnitude of the consequences if it did' (ERMA 2003: 1).

Another factor affecting discourse is the way that arguments and explanations are constructed and presented. Searle (1979) describes purposeful utterances as 'speech acts' and maintains that they can subtly affect the encoding and decoding procedures by recipients in a discourse. He has identified five generic types of speech act that range from assertives (which commit the speaker to personal agreement with something being the case); directives (where the speaker is persuading the hearer); commissives (which commit the speaker to future actions); expressives (stating an attitude to information); and declaratives (which bring about a correspondence between the content of the statement and the reality).

5.2 Nature of the intersection in the search space

There is one view that the best way through this communication impasse is for public communities to understand the outcomes of science and to learn the conventions of the genres used by scientists. We cannot accept this stance, as it reflects the view that the problem lies with the public rather than the biotechnology community.

Our thesis is that the public and the biotechnology community, however they are defined, need to communicate. A biotechnology community can be viewed as being engaged in discourse and uses particular genres of expression in which speech acts are embedded. Communication between a community of biotechnologists and any other community consists of the two groupings being able and willing to make meaning from what the other says.

Rather than assuming that successful communication will occur when non-biotechnology communities share biotechnologists' understandings about biotechnology and its implications, we believe it should involve both groups coming to see the common theme initially from their own and other groups' point of view. During this process, we conceive a 'search space' within the discourse in which groups can struggle to come to an agreed understanding in spite of their differences in beliefs, attitudes and behaviour.

We are also aware that there are issues of power involved when two parties are engaged in convincing each other of the correctness of their case. On the side of the biotechnology community, there is the power of 'established knowledge', which is often expressed in terminology that sets up barriers. On the other side, the public community may express power by the outright rejection of what is said to them.

If the two parties in the proposed dialogue have opposing views, we propose that the theory of cognitive dissonance may provide a route through (Festinger 1957). This theory is based on the idea that if it is apparent to the participant that there is an inconsistency between beliefs, there is a tendency to reduce this dissonance that motivates the individual to change one or more cognitive elements.

The process of persuasive communication involves participants being exposed to a series of 'belief statements' that link the object and attribute change (Fishbein and Ajzen 1975). This approach makes extensive use of the techniques of rational explanation and argumentation, through a medium that is common to all parties (Moshman 1998).

6. PRELIMINARY EVALUATION OF THE COMMUNICATION MODEL

At present our model is full of 'holes' where there is a lack of research to support our assertions. What research we have done indicates that we may have identified the components from which ideas and understandings that could be seen as 'standing fast' can be located. We can assume at this stage that the cognitive status of a member of the biotechnology community is comprised of particular understandings of the nature of science and technology and of the knowledge and skills that drive the biotechnology enterprise. In addition, this community has a particular understanding of the nature of risk that underpins their beliefs and attitudes to biotechnology. All of these components find a preferred expression in particular genres and speech acts. A member of the public will have differing cognitive status for these components and a search space can only occur when some commonality is achieved between the parties that are involved in attempted communication.

We firmly believe that, in all subsequent research, an identical valuation must be accorded to biotechnology communities and to public communities. The status of individuals and communities with respect to knowledge, nature of science and technology risk, beliefs and attitudes, and the language in which they attempt to communicate must be treated as having equal significance. There must be no suggestion that a biotechnology community is inherently 'right' and a public community is inherently 'wrong'.

There is a need to research both communities to find the genres and speech acts that are preferred, how acceptable explanations are constructed and the effectiveness of various techniques for promoting and resolving cognitive dissonance. Further research is needed to investigate the distribution of levels of 'epistemic education' (Moshman 1998), as well as the cognitive status of these groups with respect to the components we have identified. The most important area for research is the clarification of the idea of a 'search space'.

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13 Argumentation about biotechnology with Western Australian high-school students

Vaille Dawson

SCHOOL OF EDUCATION, EDITH COWAN UNIVERSITY, PERTH, WESTERN AUSTRALIA

v.dawson@ecu.edu.au

The aim of this research study was to explore high-school students' understanding and views about biotechnology, in particular, genetic testing, cloning and GM (genetically modified) foods. Despite significant public debate and concern regarding the use of biotechnology processes, it is not regularly taught in Australian high schools and there is little published information about students' argumentation about these topics. In a cross-sectional case study, data was obtained from semi-structured interviews with ten students aged 12–13 years (Year 8), 14 students aged 14–15 years (Year 10) and six students 16–17 years (Year 12). The interview transcripts were analysed using both Toulmin's (1958) argumentation pattern (TAP) and informal reasoning patterns (rational, emotive and intuitive) described by Sadler and Zeidler (2005a) as frameworks. The results indicated that there were no clear differences in argumentation and informal reasoning patterns across the year groups. Students of all year groups used intuitive and emotive informal reasoning more frequently than rational informal reasoning. Rational informal reasoning was associated with higher-level arguments. The implications for science teachers are to provide opportunities for students to develop their argumentation skills and promote rational informal reasoning.

1. INTRODUCTION

1.1 Informal reasoning and argumentation

Throughout our lives, we are faced with a myriad of problems, dilemmas and conundrums about which we need to make decisions and choices. We draw on our past experiences, our understanding of the issue, and our beliefs and values to decide how to proceed. In our modern society, many of these issues centre around the products of science and technology. We are faced with choices as individuals about issues such as whether or not to use a mobile phone, eat genetically modified (GM) foods or recycle our household waste. As a society, we make decisions about how to address global warming, soil salinity, population control, and water supply and quality. The choices are not simple. Individuals need to be able to weigh up risks and benefits, pose questions, evaluate the integrity of information and make decisions. The type of thinking that occurs when making these sorts of decision is called 'informal reasoning'. Informal reasoning is used to solve problems that are 'ill structured. . .with no definitive correct answers, the number and kinds of possible responses are open ended, and the information an individual can bring to bear on the problem is similarly unconstrained' (Kuhn 1991: 10).

Argument and argumentation skills play an important role in informal reasoning and 'are an external expression of informal reasoning' (Sadler and Zeidler 2005b: 72). While use of the term 'argument' in an everyday sense may conjure up images of conflict and anger, dialogic argument may be used as a form of discourse to reason about ill-structured and ill-defined problems (which is often the case with issues related to new or emerging areas of science and technology). Kuhn (1991: 12) defines an argument as 'an assertion with accompanying justification'. Toulmin (1958) developed a model of argumentation that outlines the 'parts' of an argument and can be used both to teach students (and their teachers) the skills of argumentation and to analyse or evaluate students' informal reasoning. The main components of Toulmin's argumentation model are 'claims' (the conclusion, proposition or assertion), 'data' (the evidence that supports the claim), 'warrants' (an explanation of the relationship between the claim and the data), 'backings' (basic assumptions to support the warrants), 'qualifiers' (conditions under which the claim is true) and 'rebuttals' (statements that refute alternative or opposing claims, data and warrants) (Osborne *et al.* 2004b).

1.2 Argumentation in science education

One of the essential outcomes of science education is to enable students to use their understanding of science to contribute to public debate and make informed and balanced decisions about socio-scientific issues that impact on their lives. Argumentation skills may be used when science students share their scientific knowledge with others in order to come to a decision or consensus about a socio-scientific issue. Socio-scientific issues are those that are 'based on scientific concepts or problems, controversial in nature, discussed in public outlets and frequently subject to political and social influences' (Sadler and Zeidler 2005a: 113). Addressing socio-scientific issues in science education using argumentation as a framework for debate and discussion may improve scientific literacy. Scientifically literate students are able to use their understanding of science to engage in scientific debate, draw evidence-based conclusions and make informed decisions (Hackling 2004).

One socio-scientific topic that will increasingly impact on the lives of students now and in the future is biotechnology. While the traditional areas of biotechnology such as cheese, wine and beer production may be acceptable, areas related to genetic testing for paternity, forensics and genetic diseases, genetic modification of plants and animals for food and drugs, and cloning of embryonic stem cells raise significant concerns in the community. However, despite the increasing use of biotechnology processes and products in our society, the topic is not regularly taught in Australian high schools, even though recent curriculum documents in biological science now have an increasing emphasis on genetics, gene technology, cell biology and cloning (Steele and Aubusson 2004).

1.3 Factors influencing argumentation and informal reasoning patterns

Through extended interviews, Kuhn (1991) compared argumentation skills in adolescents and adults about a range of social issues. Kuhn found that prior knowledge had no impact on argumentation skills. She also found that young peoples' argumentation skills did not vary as they progressed though adolescence. However, her research focused on social issues and did not examine the ability to argue about scientific or socio-scientific issues. A critical review of science education research related to informal reasoning and argumentation about socio-scientific issues conducted by Sadler (2004) revealed that the influence of prior knowledge on argumentation was by no means clear or straightforward. Research findings were often conflicting, due in part to different research designs. While some studies involving high-school-aged students seemed to demonstrate a positive relationship between reasoning and the degree of conceptual understanding, others did not. For example, comparisons between expert scientists and novice school students demonstrated clear differences in reasoning and decision-making, but the differences could not be specifically linked to prior knowledge. Sadler (2004) concluded that increased knowledge may lead to a quantitative increase in the number of justifications, but the quality of informal reasoning is unchanged. Thus, while intuitively a link between prior knowledge and informal reasoning about socio-scientific issues may be appealing, there is no strong evidence.

A number of US studies have revealed that adolescents' argumentation skills are poor. One study (Zeidler 1997) that examined the argumentation skills of adolescents reported a range of flaws in student argumentation including problems with: validity, naïve conceptions of argument structure (confirmation bias), core beliefs influencing argumentation (i.e. arguments consistent with students' beliefs are more convincing) and inadequate sampling of evidence. In a subsequent study, Sadler *et al.* (2004) also found that 15-year-old students tended to overvalue evidence that was consistent with their viewpoint. They also found that students had difficulty in distinguishing data from opinion in written information about global warming.

There is evidence that the teaching of explicit argumentation skills enhances performance in both conceptual understanding and argumentation. Zohar and Nemet (2002) reported on a case study of Year 9 (15-year-old) students from two schools in Israel who were taught a 12-hour unit on genetics that integrated explicit argumentation skills. The aims of the unit were to develop students' understanding of genetic topics (e.g. genetic counselling, inheritance, gene therapy and genetic cloning) and develop argumentation skills (e.g. developing and justifying arguments and counterarguments). An experimental group of 99 students was taught argumentation skills and bioethical principles, and practised using these skills while debating ten moral dilemmas. When they were compared with a comparison group of 87 students who were taught a traditional genetics topic (without argumentation or debate about dilemmas), the experimental group of students was more likely to use their biological knowledge to improve the quality of their arguments about bioethical dilemmas and they scored significantly higher (using a *t*-test) in a 20 multiple-choice question test.

1.4 Analysing students' informal reasoning and argumentation

In recent years, the science education literature on argumentation and informal reasoning has been primarily generated by Jonathon Osborne, Shirley Simon and Sibel Erduran in the UK, and Dana Zeidler and Troy Sadler in the USA. As far as the author is aware, there is no Australian science education research published on argumentation. Osborne *et al.* (2004a) reported on a study of the design, implementation and evaluation of argumentation skills (using Toulmin's model) in high-school science education. They produced a professional development resource called IDEAS (Osborne *et al.* 2004b) for teachers to help them develop students' argumentation skills. After providing continuous professional development and teaching resources to a group of 12 junior high-school science teachers, the teachers integrated argumentation into their teaching. The authors collected video- and audiotapes of 12–13-year-old students engaged in argumentation. The students' transcripts of discussion were classified into teacher talk, student claims, student claims and data/warrants, and student off-task talk. The quality of the students' argumentation was determined by examining the transcripts for instances of claims, data, warrants, backings and rebuttals. Levels 1–5 were assigned depending on the quality of the argument. The authors found that there was an improvement in the quality of students' argumentation, but it was not significant when compared with comparison groups. Rather, the quality of students' argumentation was more related to the extent to which the teacher provided opportunities for argumentation.

In the USA, Sadler and Zeidler (2005a, b) conducted interviews with 30 university students (half from natural science, half from psychology courses) about six gene therapy and cloning dilemmas. They analysed the transcripts for patterns of informal reasoning or argumentation. Informal reasoning patterns were categorised as rationalistic (cognitive, using reason), emotive (care and empathy) or intuitive (immediate gut reactions). Most students expressed a combination of responses depending on the scenario. The context of the scenario seemed to influence how individuals responded. They found that rationalistic informal reasoning was expressed in 88 per cent of the scenarios. Intuitive reasoning was used less frequently (25 per cent overall), but had a greater impact on the ultimate position taken by participants and was often the first response expressed. When comparing students with high levels of genetics knowledge (the natural science students) with those with low levels of genetics knowledge (the psychology students), there were no differences in the pattern of informal reasoning, although students with high levels of genetics knowledge were more likely to use their genetics knowledge in their responses.

The research findings reported in this paper are part of a larger research study to examine Western Australian high-school students' understanding and views about biotechnology processes (Dawson 2007). The study used a cross-sectional case study methodology (Stake 2000) to address the research question: What are high-school students' understandings of and views towards a range of biotechnology processes? Data was obtained from student interviews and written surveys of students aged 12–17 years.

The results indicated that students' ability to provide a generally accepted definition and examples of biotechnology, cloning and GM foods was relatively poor among 12–13-year-old students but improved in older students. Older students (Years 10 and 12) were better able to define biotechnology processes and more likely to use scientific terms such as DNA, cells and genes correctly when explaining their viewpoint. Most students approved of the use of biotechnology processes involving micro-organisms, plants and humans and disproved of the use of animals.

Students' views about a particular biotechnology process such as genetic testing or genetic modification depended on the type of organism used and the context. For example, students were more positive about the use of micro-organisms and plants than humans and animals, and cloning of adult cells and organs was viewed more favourably than cloning of embryonic stem cells and human cloning. Overall, 12–13-year-old students' attitudes were less favourable than older students', regardless of the context.

This paper extends that study by reanalysing the interview transcripts through the framework of informal reasoning and argumentation. Specifically, this paper reports on an analysis of the statements or arguments used by these students to explain their views of biotechnology processes. The research question for this paper was: What patterns of argumentation and informal reasoning are expressed by Australian high-school students aged 12–17 years when justifying their views of biotechnology processes?

2 RESEARCH DESIGN AND METHOD

2.1 Sample

For the study reported here, data were generated through semi-structured interviews with 30 high-school students from Year 8 (12–13 years; n = 10), Year 10 (14–15 years; n = 14) and Year 12 (16–17 years; n = 6). The interviews were conducted at the end of the academic school year and students were interviewed in groups of two or three for 30–60 minutes. The students were selected by their teachers using a purposeful sampling method (Patton 1990) that allowed for maximum variation in ability in order to perceive a wide range of students' views. The semi-structured interviews were audio-taped, transcribed and analysed. The students were asked questions about their understanding and views of biotechnology, cloning, genetic testing for diseases, paternity and forensics, and the production and consumption of GM food crops.

2.2 Analysis of transcripts

This paper reports on a reanalysis of the interview transcripts that were related to students' explanations and justification of their views about biotechnology processes. As described above, both Osborne *et al.* (2004a) and Zeidler and Sadler (2005a) used different classification methods to analyse informal reasoning and argumentation about socio-scientific issues. The transcripts were analysed using both Toulmin's argumentation pattern (described in Osborne *et al.* 2004a) and patterns of informal reasoning, which are described in Sadler and Zeidler (2005a).

Firstly, statements where students expressed and justified a viewpoint were identified. Each statement was then classified as rationalistic, emotive, intuitive or a combination. A description of each of these categories and examples from the interview transcripts are presented in Table 13.1. The statements were also classified from leve1 1 to level 5 (based on Osborne *et al.* 2004a) as described and exemplified in Table 13.2.

3. RESULTS

The interview transcripts contained 179 statements where students expressed their views about aspects of biotechnology: 59 in Year 8 (average 5.9 per student), 68 in Year 10 (average 4.8 per student), and 52 in Year 12 (average 8.7 per student). The statements from each year group were coded and analysed separately to determine whether there were any differences in the types of argument expressed. The number and percentage of each type of informal reasoning expressed is summarised in Table 13.3 and Figure 13.1. Some statements were unable to be classified and were designated NA.

Overall, rational informal reasoning or combinations with a rational component were expressed in about 25 per cent of the statements from all year groups. In the majority of statements for all year groups, students used intuitive or emotive arguments to justify their viewpoint. It would appear that there were no obvious differences in informal reasoning patterns among year groups, despite differences in understanding of biotechnology processes (Dawson 2007).

The number and percentage of each level of argumentation for the statements of students in Years 8, 10 and 12 is summarised in Table 13.4 and Figure 13.2. Again, there does not appear to be any difference in the percentages of each level of argumentation expressed in statements by students in Years 8, 10 or 12. All levels of argument are expressed equally by all year groups with level 2 statements predominating. Level 2 statements are claims with some accompanying evidence. It is worth noting that all of the level 4 arguments used rational informal reasoning or a combination that included rational informal reasoning.

4. CONCLUSION

4.1 Discussion

All year groups of Australian high-school students interviewed in this research (Year 8, 10 and 12) predominantly used intuitive (33 per cent overall) or emotive (28.5 per cent overall) informal reasoning when they made statements about the socio-scientific issues discussed in the interview (Table 13.3; Figure 13.1). Rational informal reasoning accounted for only about 18 per cent of statements (Table 13.3). We have not been able to locate other published research that examines patterns of informal reasoning with high-school students using the same classification scheme used in this study. We can, however, make some comparisons with data collected from college students in the USA (Sadler and Zeidler 2005a, b). The patterns of informal reasoning found with these Australian high-school students are quite different when compared with the patterns observed by Sadler and Zeidler (2005a, b) who found that rationalistic informal reasoning was the most common, followed by emotive and then intuitive informal reasoning. Our findings do indicate some incidence of the display of multiple reasoning patterns (see R/E, R/I and R/I/E in Table 13.3 and Figure 13.1), as did Sadler and Zeidler; however, with the younger children in this study, the incidence of multiple reasoning patterns was less frequent. If we sum the incidence of rational reasoning in Table 13.3 (i.e. R + R/E + R/I + R/I/E), we have a total of 26 per cent of statements that included rational informal reasoning compared with 88 per cent in the study of Sadler and Zeidler. Using the same procedure (i.e. E + R/E + R/I/E), 35 per cent of

Table 13.1 Categories, descriptions and examples of informal reasoning

Category	*Description*	*Examples*
Rationalistic	Logical; uses scientific understanding and language; weighs up risks and benefits, and advantages and disadvantages	I can see one problem with [GM foods] and that is if you make it so it's too specific to the environment so it grows really well and the environment changes it won't grow very well at all. (Year 12) I think it's really good like with genetically modified foods, there are so many advantages. I found out that most of the problems they have with genetically modified foods there's a solution within genetic engineering. (Year 10) If they genetically modify these crops so they're pest resistant, all the pests would die out and whatever feeds on them would die out and you're changing the ecosystem. (Year 10)
Intuitive	Gut feeling; immediate response; strongly held; often a negative response; personal, often precedes rational or emotive	Yes, [cloning] would be OK as long as they don't create monstrosities that could make a mockery of life. (Year 8) I don't have a problem with [GM foods]. As long as it's not dangerous. (Year 12) I'm pretty apprehensive about it because you look at today's age. We're living in a fast-food age where everything is manufactured, everything is processed and just adding genetic engineering to food, I think, is going just one step too far. (Year 12)
Emotive	Emotional response towards stakeholders; care; empathy; sympathy; concern for plight of those affected	I think [genetic engineering] would be OK as long as it is not done on animals because animals don't have to bow down to humans and do what they want. But if it is good for humans and doesn't hurt anyone and doesn't hurt the environment it should be allowed. (Year 8) I don't think everyone thinks of an animal and goes 'awww'. (Year 10) I'm not really too fond of genetically modified crops because it can have so much effect, not just on the environment. . .it's hard for farmers as it is now. You've got a really high rate of youth suicide and that can possibly get worse if you start introducing stuff that is going to affect the industry. (Year 10)
NA	Unable to be classified as above	I don't know. I have no opinion on that. I have nothing to say.

Table 13.2 Categories, descriptions and examples of argumentation patterns

Category	*Description*	*Examples*
Level 1	Claim (statement, conclusion, proposition only)	I prefer it how it is. (Year 8) I think it's wrong. (Year 8) I don't see a problem with [cloning]. (Year 12)
Level 2	Claim, data (evidence supporting the claim) and/or warrant (relationship between claim and data)	I think that [genetic testing] would be OK [claim] because you have a right to know if there is something wrong with your child [data]. (Year 8) I don't think it's [cloning] good [claim] because cloning another thing – there could be consequences to it, like side effects, like something going wrong [data]. (Year 10) It's good in some ways [claim] because if you genetically modify something to grow much bigger and better [data] you can feed all the poor people [warrant]. (Year 10)
Level 3	Claim, data, warrant, backing (assumptions to support warrant) or qualifier (conditions under which claims are true)	Genetic engineering shouldn't be done on humans or animals [claim]. It would be better to do it on plants altering DNA, or crops [qualifier] because then they wouldn't have to use chemicals [data] which would harm the environment [warrant]. (Year 10) I think they should do something else with genetic modification [claim] to solve some of the problems we have at the moment rather than trying to create new ones [data], so if they could do something like make a contagious strain of a virus that would be useful to rabbits, that would kill them off, that would only be passed to rabbits [qualifier]. But it would be dodgy to try and test that [claim] because you don't want to let it loose and kill numbats [Western Australian state animal] [warrant]. (Year 10) Well, Dolly the sheep died and aged really quickly (data). I can see that happening again for human beings, like people dying of diseases created by science [data]. Like in Gattacca, people get left out because they haven't been genetically modified [data, warrant]. It's OK to eradicate disease [qualifier] but cloning a whole human being I think's just wrong [claim]. (Year 12)
Level 4	Claim, data, warrant, backing and qualifier	I think it's a really good thing [claim] but I think there has to be so much more tests before they start applying it to industry [qualifier]. They can't have two agricultural industries with non-GM canola and GM canola because it doesn't work for the farmers [data]. One's only going to do each other out. It's not going to be good for industry and I think you find a lot of risks if you introduce mutated forms of animals or plant back into the ecosystems [warrant], because it's not natural [backing]. It's going to have effects all the way throughout the chain and without testing it, there's no sure way of testing it without doing

Table 13.2 *Continued*

Category	*Description*	*Examples*
		something that's going to be harmful. But if they do a lot of testing I think it's going to be really good [claim]. (Year 10) I think it is alright [claim] as long as thousands of clones aren't put into the public [qualifier] because then there would be two of the same physical body [data, warrant] but if it was used to clone animal meat [qualifier] and that could feed the world [backing], then I reckon it would be alright. (Year 8)
Level 5	Extended argument with rebuttals (refuting alternatives)	No examples given.

Table 13.3 Number and percentages of informal reasoning types expressed in statements by Australian students in Years 8, 10 and 12

Type of informal reasoning	*Year 8 statements (n = 10)*	*Year 10 statements (n = 14)*	*Year 12 statements (n = 6)*	*Total number of statements in each category (%)*
Rational (R)	10	16	6	32 (18%)
Intuitive (I)	16	20	23	59 (33%)
Emotive (E)	22	23	6	51 (28.5%)
R/E	5	0	4	9 (5%)
R/I	0	1	2	3 (1.5%)
R/I/E	0	1	2	3 (1.5%)
NA	6	7	9	22 (12.5%)
Total number of statements	59	68	52	179 (100%)

statements included emotive informal reasoning compared with 47 per cent, and 36 per cent intuitive informal reasoning (i.e. I + R/I + R/I/E) compared with 25 per cent in the study of Sadler and Zeidler.

Whether we present the data with or without the incidence of multiple reasoning patterns, intuitive was the most frequent form of informal reasoning, followed by emotive and then rational. While making direct comparisons between research projects may not be appropriate due to methodological factors (described below), it seems that the Australian high-school students in this study used rational informal reasoning less frequently than the older college students in Sadler and Zeidler's study, and that these students relied more frequently on intuitive informal reasoning. Sadler and Zeidler comment that, while intuitive reasoning was displayed in only 25 per cent of the total number of decisions made by their college students, intuitive reactions typically determined an individual's ultimate reason and was, therefore, a significant factor for the resolution of some socio-scientific scenarios. One possible explanation is that the Australian high-school students in this study were more likely to express their intuitive response and to make a decision based on that response, whereas older college students, such as those in Sadler and Zeidler's study, may express their intuitive

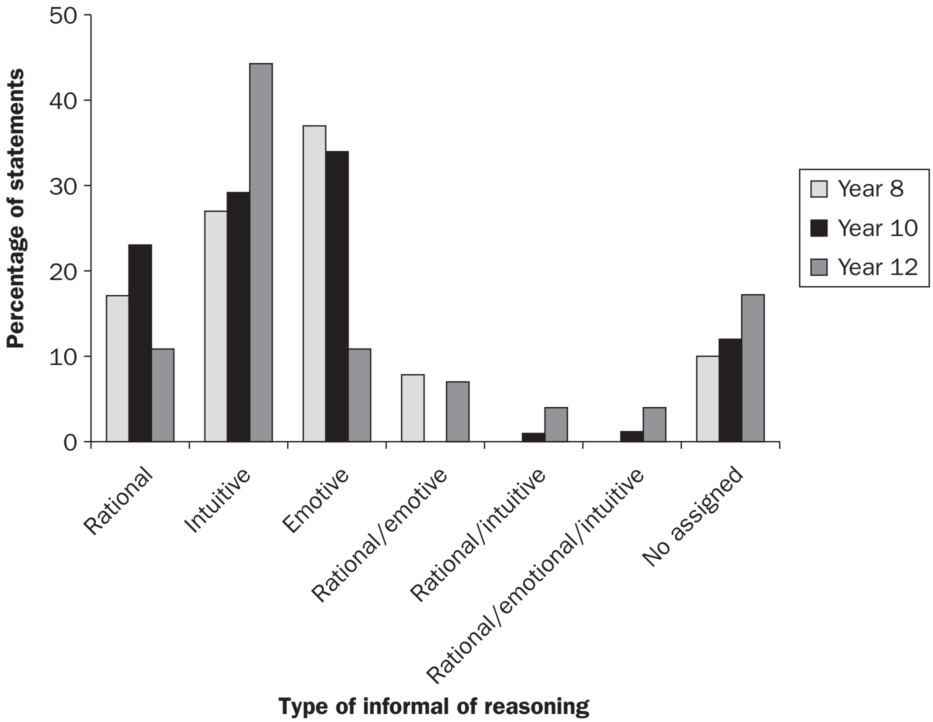

Figure 13.1 Types of informal reasoning expressed in statements by students in Years 8, 10 and 12

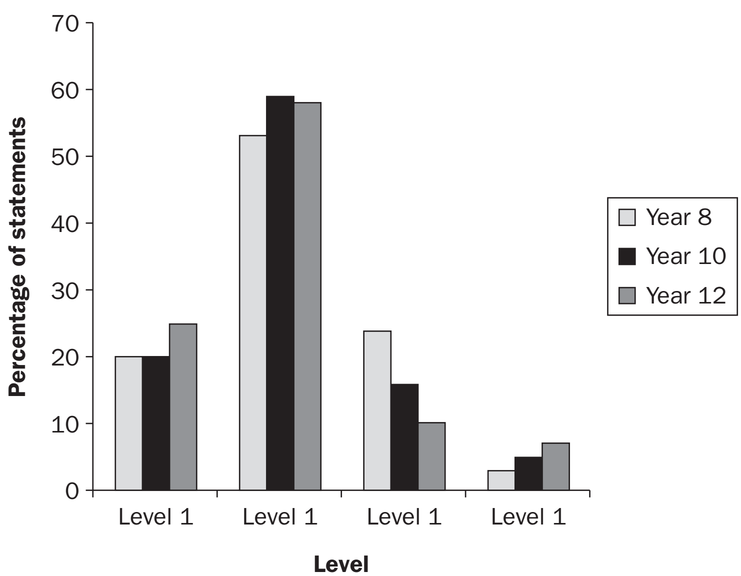

Figure 13.2 Level of argument expressed in statements by students in Years 8, 10 and 12

Table 13.4 Number and percentages of argumentation levels in statements expressed by students in Years 8, 10 and 12

Level of argument	*Year 8 statements (n = 10)*	*Year 10 statements (n = 14)*	*Year 12 statements (n = 6)*	*Total number of statements in each category*
1	12	14	13	39 (22%)
2	31	40	30	101 (56%)
3	14	11	5	30 (17%)
4	2	3	4	9 (5%)
Total number of statements	59	68	52	179 (100%)

response but then articulate further emotive and/or rational reasoning before making a decision or coming to a final conclusion.

The patterns of argumentation quality for the Australian high-school students in this study can be seen in Table 13.4 and Figure 13.2. For all year groups, level 2 argumentation was the most frequent (56 per cent of all statements), with levels 1 and 3 the next most frequent (at 22 and 17 per cent, respectively) and level 4, the most sophisticated level, the least frequent (5 per cent). Level 2 arguments included those statements with a claim and data (evidence supporting the claim) and/or a warrant (relationship between claim and data), but no backing (assumptions to support the warrant) or qualifier (the conditions under which the claims are true). In the UK, Osborne *et al.* (2004a) also found level 2 arguments to predominate in the high-school students they observed in discussion in small groups (38 per cent pre-intervention and 30 per cent post-intervention).

4.2 Implications

If our students are to be scientifically literate and contribute to public debate about issues associated with biotechnology, then processes such as cloning and gene technology should form an essential component of any modern biology curriculum. Biotechnology education should provide students with an understanding of the language of genetics, the underlying scientific concepts (e.g. concept of a gene, basis of heredity, and gene technology processes such as genetic testing and gene therapy) used in our society, and the social and ethical implications that they raise for individuals and society.

An important aspect of scientific literacy is using scientific evidence to make and justify conclusions. Students need explicit instruction in argumentation, practice and guidance from teachers. An understanding of the argumentation patterns (levels) and informal reasoning types used by students can help teachers who wish to develop their students' argumentation skills to reason about scientific issues. For example, students need to be aware of how to identify and use the components of a sound argument (claim, data, warrant, qualifier, backing and rebuttal) and the use of rational informal reasoning.

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14 Developing argumentation in grade 10 biology lessons in South Africa: implications for teachers' professional development

Martin Braund[1], Fred Lubben[1], Zena Scholtz[2], Melanie Sadeck[2] and Merle Hodges[2]

[1]UNIVERSITY OF YORK, YORK, UK; [2]CAPE PENINSULA UNIVERSITY OF TECHNOLOGY, CAPE TOWN, SOUTH AFRICA

mb40@york.ac.uk

Two types of argumentation lesson, one dealing with a socio-scientific topic and another with a pure scientific topic, were compared in this study. Critical incidents – key moments in teaching either supporting or hindering successful argumentation among students – were identified. Dialogue sequences attributable to these incidents are compared with the structure of argumentation described by Toulmin and rated on a five-level scale. The findings showed that, even though the two lessons were based on different biological contexts and argumentation types, there were common features that influenced argumentation levels. Differences in the nature of argumentation, with beliefs and attitudes being important in the socio-scientific lesson and facts and evidence in the more scientific lesson, resulted in different levels of argument. Implications for the development of a programme of Continuing Professional Development (CPD) are discussed.

1. INTRODUCTION

When a new curriculum was introduced in grades 10–12 in South African schools in 2006, considerable emphasis was laid on developing students' abilities as critical and creative thinkers. The South African Department of Education (2004: 46) recognised that a school science curriculum involves 'critical inquiry, reflection, and the understanding of [science] concepts and processes, and their application in society'. In biology (or 'life sciences' as it is known in South Africa), for example, students in grades 10–12 (typically aged 14–16) are required to 'understand the nature of science and the influence of ethics and biases in the life sciences' (South African Department of Education 2004: 28). One major area of critical thinking is considered to be the ability to formulate an argument, using evidence to support a claim and, even more importantly, to dislodge any counterclaim. Argumentation (the process of arguing) is a crucial component of critical thinking, because it requires students to engage with data and evidence, to make claims based on these and to weigh the extent to which other people's claims can be substantiated (Erduran et al. 2004). Research in classrooms with this age of students (14–16 years), however, shows a limited untutored ability to substantiate claims using a range of evidence (Pringle and Freedman 1985). Kuhn (1993) reckons that the ability for critical inquiry forms the basis of building up new scientific knowledge using evidence. Dealing with evidence in a critical way should therefore be central to the teaching of school science.

Several types of argumentation tasks can be distinguished. Glassner et al. (2005) differentiated between causal claims (e.g. the use of mobile phones during driving causes car accidents), deontic claims (e.g. we must limit one-storey house building to reduce environmental damage) and existential claims (e.g. global warming). Brem and Rips (2000) differentiated argumentation tasks according to the amount of evidence students self-generated or selected from; the more evidence provided explicitly, the more likely a claim will be supported by evidence and thus that it will constitute a higher-level argument.

Several schemes have been proposed for the analysis of argument and discourse. Toulmin (1958) developed a typology of argument structure in normal discourse and suggested a progression for different argument structures. Walton (1996) suggested a classification of arguments in scientific reasoning. He particularly focused on the role allocated to expert opinion within argument. Jiménez-Aleixandre and Pereiro-Munoz (2002) summarise Walton's scheme in two key questions: 'Who has the status of an expert in the argument?' and 'How consistent is the position of the expert with those of other experts and with evidence?' The role of the expert is pertinent for argumentation in the southern African cultural context as the local world views (George 1999; Jegede and Aikenhead 1999) attach considerable weight to the authority proposing claims. More recently, research has been reported on the teaching of argumentation (Newton et al. 1999) as part of supporting understanding in the major area of ideas about evidence (Osborne et al. 2004a). The same authors developed and tested sets of pre-written lesson materials fostering argumentation for the national curriculum in England together with professional development materials for the training of teachers (Simon *et al*. 2006).

2. PURPOSE OF THE RESEARCH

This study explored teachers' actions and classroom discourse within groups of students engaging with argumentation tasks in the life sciences. It compared and contrasted two types of argumentation lesson, one dealing with a socio-scientific topic and the other dealing with a pure scientific topic in two grade 10 biology classes in the same school, in Cape Town, South Africa. We looked for key features of teaching that were successful in promoting effective argumentation among students so that these could be communicated to other teachers involved in an on-going programme of Continuing Professional Development (CPD).

The following research questions were addressed:

1. What is the nature of the student interactions for different argumentation tasks?
2. What teaching interventions stimulate the use of higher levels of argumentation?

3. THE SCHOOL

Both biology lessons were taught at this school, a well-resourced school for gifted students. The school was started to increase the percentage of students who choose to do science and mathematics. Two qualified male science teachers taught the lessons.

4. THE LESSONS

The first teacher taught a socio-scientific lesson of his own design. The purpose of the lesson was to stimulate argument about organ trafficking. Thirty students were seated in groups of four. He started by informing the class that the purpose of the lesson was to develop their argumentation skills. He probed their concepts of what constituted a good argument. He displayed a structured diagram depicting the components of a good argument. Reading matter containing case studies about organ trafficking was distributed to the groups for them to read and understand through role play. Groups were asked to take part in discussions (which may or may not have involved argument) to list the pros and cons of organ trafficking. The teacher summarised group responses on the board. Students were then asked to reach a consensus in their respective groups about whether they supported organ trafficking. The teacher carried out a whole-class discussion in which groups were allowed to defend their position.

The second teacher taught a scientific lesson. The purpose of the lesson was to stimulate argument about the classification of the single-celled organism *Euglena*. The *Euglena* lesson was highly structured and was taken from activities devised by a team who have specialised in argumentation in England (Osborne *et al.* 2004a). The students (28) were seated in groups of four. Each group was issued with evidence cards containing characteristics applicable to *Euglena*. Students had to decide, as individuals, whether they thought *Euglena* was an animal, a plant or neither by placing the evidence cards in appropriate columns on a worksheet. The teacher recorded their responses on the board and carried out a whole-class discussion in which groups could defend their position.

5. METHODOLOGY

5.1 Observation and recording of the lessons

The two lessons were videotaped. The camera operator recorded salient features of the lessons, moving the camera to capture group argumentation under the direction of two researchers and the class teacher. Additional sound recordings were made where it seemed that students were particularly engaged or where discourse was prolonged and sustained. Field notes were made independently by the two researchers to capture interesting behaviours or actions of the teacher.

5.2 Analysis

Analysis was carried out in three stages. In the first stage, recordings were viewed independently by four researchers. Recordings and field notes were used to identify general features of the lessons in terms of a descriptive framework based on a constructivist model proposed by Driver and Scott (Scott 1987). The first element, 'preparation for learning', describes the physical environment and preparations made to ensure that conditions for learning are effective. The second element, 'agreeing learning outcomes', accounts for ways in which the teacher helps students appreciate the intentions of the lesson. The third element, 'construction of meaning', describes the main activities through which students construct new knowledge or understanding, whilst the fourth element, 'demonstrating new understanding', shows ways in which students declare their new learning, e.g. through group or individual presentations to the rest of the class. The final element of the framework, 'reviewing new learning', deals with meta-cognition, i.e. ways in which students reflect on new learning and whether or not they attained the outcomes set. This final part feeds back to the first thereby making the framework cyclic. Figure 14.1 shows how the two lessons on organ trafficking (OT) and *Euglena* (E) were mapped using this framework.

In the second stage, the outcomes of lessons were assessed using levels of argumentation devised by Osborne *et al.* (2004a); this scheme has been applied in other studies of argumentation in science (see, for example, Erduran *et al.* 2004; Scholtz *et al.* 2006) and is based on the extent to which different components of argumentation, identified by Toulmin (1958), can be recognised. In Toulmin's model, the ability to formulate a strong argument hinges on the effective use of evidence to support claims made and, at a more sophisticated level, to challenge the claims and supporting evidence made by others. Toulmin's general scheme recognises that there should be a claim (an assertion or conclusion), based on data (evidence that can be explicit information or views based on ethics or morals) supported by warrants (a reason for making the claim) in turn supported by backings (scientific models or laws). The claim may have a qualifier (limitation of the applicability of the claim) and be challenged with a counterclaim (an alternative assertion) or a rebuttal (a reasoned rejection of the claim, warrant or backing). The criteria for each of these levels of argumentation are set out in Table 14.1 below. These levels were applied to the outcomes of the two lessons taken as a whole rather than to individual statements or group discussions.

In the final stage of analysis, the videotape was viewed independently by researchers to identify critical incidents that might support or constrain argumentation and to explain why the outcomes of each lesson showed the levels of argumentation ascribed in stage two. A critical incident was defined as any action, statement or sequence of dialogue by the teacher or by the students that could contribute to or constrain the successful outcomes of argumentation. The critical incidents were discussed using an analysis of teacher behaviours in argumentation in science lessons devised by Simon *et al.* (2006). After discussing and comparing scripts identifying possible critical incidents, an agreement was reached as to which ones were key to understanding the argumentation in each lesson. These incidents (four in each lesson) are shown in the central column of Figure 14.1. Each incident was mapped against the framework for each lesson.

6. FINDINGS

6.1 Levels of argumentation

Levels of argumentation were substantially different for each lesson. In the organ trafficking lesson, rebuttals hardly ever occurred, limiting the outcome to level 2. In the main group discussion, students were required, in their groups, to list the pros and cons of organ trafficking rather than to argue about a specific claim or to take up a particular position, thereby limiting opportunities for more developed argumentation at levels 3 and above.

Only one (weak) rebuttal (in part 4: 'demonstrating new understanding') was made by a (male) student in response to the teacher exploring moral positions and possible clashes between religious beliefs and decisions on medical grounds.

In the *Euglena* lesson, examples of arguments containing rebuttals were more frequent. The overall level of argumentation was judged to be at least at level 3 and in many cases closer to level 4 on the Osborne scale. As for the organ trafficking lesson, arguments containing rebuttals were most noticeable in the whole-class discussions towards the end of the lesson. The need to draw an overall conclusion about the nature of *Euglena* forced group members to support their choices and rebut opposing views as illustrated below. This episode was identified as critical incident four (E4) for this lesson:

> Teacher: You want to put another point to support it being an animal?
>
> Student 1: It says here [refers to a data sheet] that animals are sensitive to their environment, they have sensory characteristics. And the *Euglena* is temperature sensitive, so that makes it an animal; it is sensitive to the environment.
>
> Student 2 (different group): On the topic of sensitivity to the environment: *Protea* seeds, they need heat to germinate. So that would make them temperature sensitive. So I said [*Euglena*] has more plant-like qualities, so it would be a plant. But I can surely move to a sort of fusion of a plant and an animal.

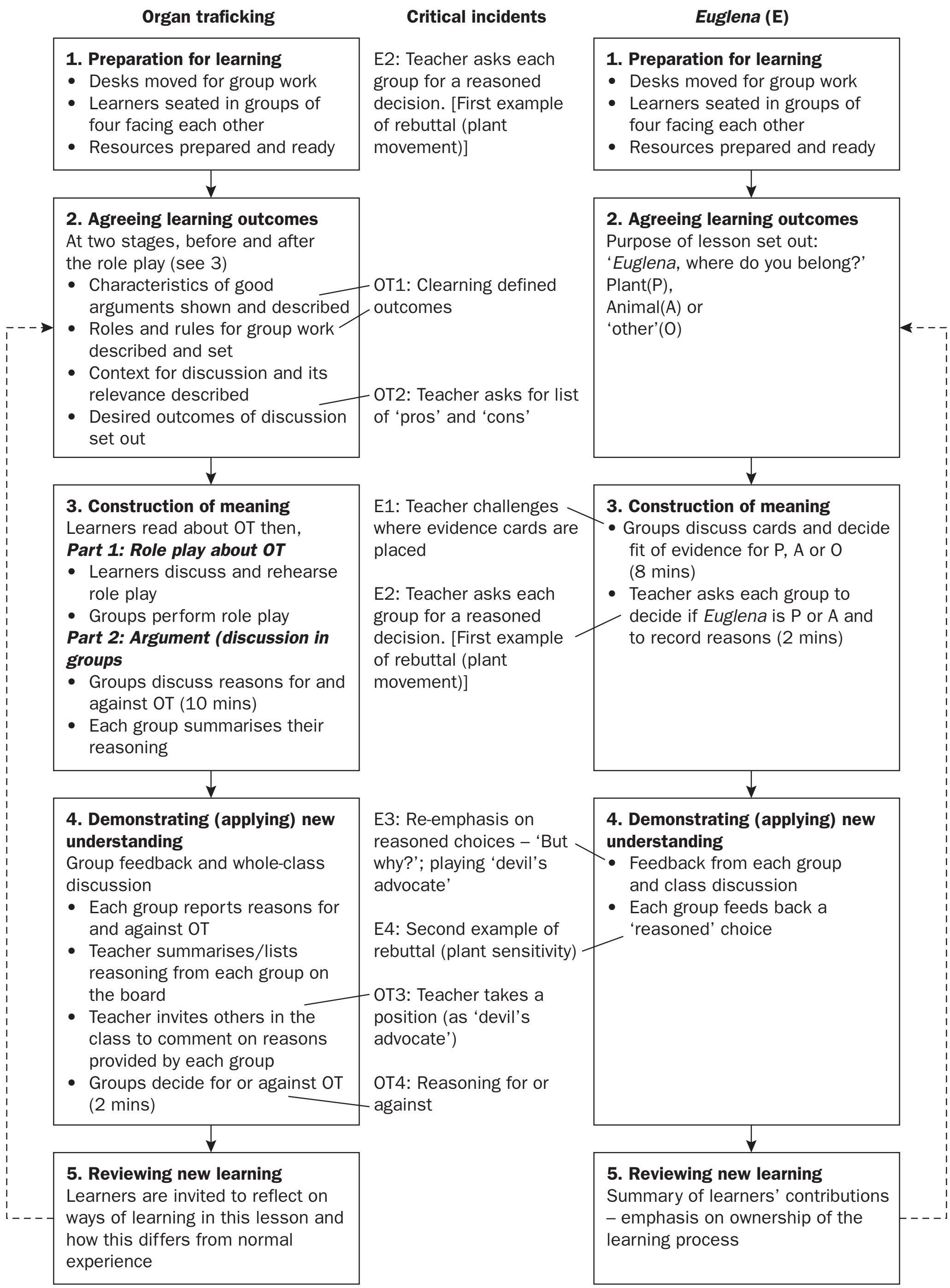

Figure 14.1 Structure of the organ trafficking and *Euglena* critical thinking lessons and critical incident analysis

Table 14.1 Levels of argumentation (from Osborne *et al.* 2004a)

Level	*Criterion*
1	Arguments that are a simple claim versus a counterclaim or a claim versus a claim.
2	Arguments consisting of a claim versus a claim with data, warrants or backings but no rebuttals.
3	Arguments with a series of claims or counterclaims with data, warrants or backings with the occasional weak rebuttal.
4	Arguments with a claim and a clearly identifiable rebuttal. Such an argument may have several claims and counterclaims.
5	Displays an extended argument with more than one rebuttal.

6.2 Critical incidents

Eight critical incidents (four in each lesson) were identified and agreed as being key moments and actions underpinning or hindering successful argumentation. These are described below for each lesson.

6.2.1 Critical incidents in the organ trafficking (OT) lesson

CRITICAL INCIDENT 1 (OT1)

The teacher spent time explaining what constitutes good argument by engaging the class in a sequence of questions to identify the purposes of argument. Later, the teacher identified a set of rules for group discussion, e.g. listening, taking it in turns to speak, etc., and each group was given 1 minute to decide how the roles of chairperson, recorder, reporter and timekeeper would be allocated. These actions were considered to be helpful in guiding and facilitating purposeful and sustained argumentation of good quality. In view of later incidents, it is doubtful that, taken alone, these actions were fundamental in assuring good argumentation.

CRITICAL INCIDENT 2 (OT2)

Immediately following the 1 minute allowed for groups to organise themselves for discussion, the teacher said to the whole class: 'Right, now every group must have views on both issues. . .in support or not in support of the trafficking of organs.'

At this point, the teacher provided a sheet of paper for recording the reasons for and against organ trafficking. These actions, at this point, were considered to have constrained argumentation, as the students were merely required to list sets of warrants to pre-ordained claims, i.e. that the trafficking of organs for transplant should or should not be allowed.

CRITICAL INCIDENT 3 (OT3)

The weak rebuttal concerning the moral dilemma of deciding (against religious beliefs) as to whether or not to donate an organ (kidney) to a relative was discussed in the previous section on levels of argumentation. The incident arose from the teacher choosing to raise this as an issue. This has been described as 'playing devil's advocate' (Simon *et al.* 2006). In this case, it was seen as beneficial as it provided opportunities for pupils to engage in more personal reflection than had previously taken place.

Critical incident 4 (OT4)

Immediately following incident OT3, the teacher said to the whole class: 'Now I want to get an idea of how you feel (about organ trafficking). Should we sell [an organ] or should we not sell? So each group, you've got 30 seconds to quickly decide yes or no. Yes or no – right? It's a *group decision* – quickly now! Democracy rules!'

At this point of the lesson, groups of students were noticeably more engaged than at any other time. For example, in one group, all four students, two of whom had made little or no contributions during the main discussion activity, were visibly engaged, so much so that their discussion continued for at least 30 seconds after the teacher had asked all groups to conclude the activity. Clearly, the appeal by the teacher for decision-making reaching a democratic (argued) and agreed position promoted debate that might have yielded higher levels of argumentation had it been allowed to continue.

6.2.2 Critical incidents in the Euglena (E) lesson

Critical incident 1 (E1)

In part 3 of the lesson, the teacher provided a set of evidence cards, each of which contained a statement relating to the structural features, life processes or actions of *Euglena*. Students' discussions and arguments centred around whether evidence was helpful or not in supporting claims that *Euglena* might be a plant, an animal, either plant or an animal, or neither. In this critical incident, the teacher challenged a group's decision to place the evidence card reading '*Euglena* is a single cell' into the column showing that it is neither a plant nor an animal.

> Teacher: Why is this (card) over here (in the column for neither a plant nor an animal) – '*Euglena* is a single cell'?
>
> Student 1: (Indistinct, more than one student speaking) It's a single cell so, not plant or animal, so. . .
>
> Teacher: OK, so. . .
>
> Student 2: Some characteristics [referring to the full set of evidence cards] are plant, um (indistinct, other students' voices seem to indicate agreement), like photosynthesis, so it needs light.
>
> Student 3: Yes, and it's light sensitive [as an additional backing for *Euglena* synthesising and therefore being a plant].
>
> Teacher: Yes, but when it talks about 'light sensitive', it means it looks for where light is and it can detect light and move towards it [rather than light being required for photosynthesis].

In this incident, the teacher challenges students' warrants and explains some of the science behind evidence statements. These actions helped the students make more effective use of evidence in their warrants and backings for claims about *Euglena*'s taxonomic status.

Critical incident 2 (E2)
Following the group activity above, the teacher asked each group to decide whether *Euglena* was a plant or animal:

> Teacher: Now, the last two questions [on the worksheet] say, 'After discussion with my group' – only *your group* – 'I came to the conclusion that *Euglena* is. . .' And now what you need to do is you need to quickly discuss in your group what you *individually* selected *Euglena* to be and you need to discuss in your group what *your group* thinks *Euglena* is.

Interestingly the time set for this activity was very short (2 minutes as opposed to 8 minutes for the main discussion), as was the case for critical incident OT4 in the organ trafficking lesson. Again, the amount of animated talk and facial expressions seen indicate that this activity stimulated a high degree of engagement.

Critical incident 3 (E3)
In part 4 of the lesson, the teacher invited a student from each group to say whether they thought *Euglena* was a plant or an animal. Initially, there were no responses and so the teacher deliberately took up a position (as 'devil's advocate') claiming therefore that all of the class must have decided that *Euglena* was an animal. Some laughter ensued, followed by this sequence of dialogue between the teacher and a student presenting his group's decision:

> Teacher: Who believes *Euglena* to be a plant? Give me a reason.
>
> Student 1: In the information given they [the scientists] clearly describe the different types of micro-organisms that have the characteristics of plants and animals and then they describe, um, first the ones that are plant-like and then they photosynthesise, and then ones that are animal-like. They go on about using flagella, and *Protozoa* are characterised as a subkingdom of Animalia – it's an animal.
>
> Teacher: So give me a *specific reason* – just why are you saying that yes, *Euglena*, you are an animal *because*. . .
>
> Student 1: It can move, and it can absorb food from the environment.

The significant element of the teacher's actions making this incident so critical is the strong steer for the student to reason (i.e. provide warrants and backings) to support the claim that *Euglena* is an animal. The teacher asks for a 'specific reason' and scaffolds the student's response using the word 'because'.

Critical incident 4 (E4)
This was the second recorded example of a rebuttal in this lesson and was discussed in the section on levels of argumentation.

7. DISCUSSION OF THE FINDINGS

Although each lesson was based on categorically different biological contexts and argumentation types, there were common features having a bearing on relative success. Firstly, both teachers invested significant effort to ensure that the students were conversant with expectations, roles and rules for group work and were aware that sound argument requires warranted claims. Secondly, both teachers provided argumentation in at least two phases (as can be seen in Figure 14.1): in a group phase and in a whole-class discussion. More negatively, both lessons contained episodes where higher levels of argumentation could have occurred but where time for discussion was constrained. For example, in the organ trafficking lesson, only 30 seconds was provided for groups to agree to support or oppose trafficking. In the *Euglena* lesson, a critical phase (E2) was where groups took *individual* decisions based on evidence provided to reach a *group* decision about *Euglena*'s taxonomic status. This produced high levels of engagement but again time was limited. Lastly, both teachers used techniques to invite rebuttals, counterclaims or qualifiers from students during whole-class discussions. These strategies were successful in both lessons and have been identified in other work (Simon *et al.* 2006). The first strategy (in the organ trafficking lesson) is known as 'positioning' and the second (in the *Euglena* lesson) as 'playing devil's advocate'.

The question remains as to why one lesson (*Euglena*) achieved an argumentation level so much higher than the other (organ trafficking). There are two plausible explanations, both having significance for the development of our CPD programme. In the organ trafficking lesson, a crucial limiting factor in the teaching design was the remit given to each group as the basis for their discussion (OT2). Instead of a request to develop different claims, each either in support of or against organ trafficking, students were required to list claims both for and against and then to submit these to the whole class. The style and presentation of the activity therefore limited opportunities for groups to reason using warranted claims. This is probably one of the reasons why a more heated exchange occurred when groups were finally asked to reach a decision (OT3). A more successful approach here might have been to allow time for a relatively free discussion about an open question (e.g. 'Should organ trafficking be allowed?'), followed by a more closed task focused around a number of different reasoned claims for and against trafficking. Such two-part tasks have been successful in other contexts such as genetics (Jiménez-Aleixandre *et al.* 2000).

One of the most striking differences, however, was in the nature of knowledge, beliefs and attitudes required in these two lessons, and hence the nature of the reasoning. The *Euglena* lesson had a simple design. What was required was to consider the status of various pieces of evidence (already provided) in supporting one of four opposing claims. As such, the task could be said to represent classic scientific evidence-based argumentation where the knowledge base allows plenty of warrants and backings. Even where knowledge outside that included in the task was brought into the discussion, as was the case with the example of *Protea* and the sensitivity of its seeds to heat (E4), this was easily integrated into the argument structure and indeed was one of the main reasons why this lesson occurred at a higher level. The *Euglena* lesson fits comfortably with Toulmin's model.

On the other hand, the argumentation and reasoning required in deciding whether to allow organ trafficking is an entirely different matter. Here, there are at least three aspects that affect reasoning: the scientific base, moral and ethical positions, and cultural standpoints including religious beliefs. Claims, warrants and backings that draw on the scientific base are complex in this context and add to the demand (Brem and Rips 2000). The biological concepts are complex: efficacy of transplants of different organs (heart, kidney, liver), functioning of the immune system, tissue matching and rejection rates, and use of cloning as an alternative source of tissues and organs. Added to these is an appreciation of the socio-economic aspects (as often debated in health science policies; see Zohar and Nemet 2000), the availability of organs, relative cost benefits, prioritisation of waiting lists for transplant surgery and so on. When it comes to cultural and particularly religious aspects, these would be complex in any cultural setting, but this study took place in a school in South Africa that draws students from a wide variety of ethnic and religious groups. The mix of backgrounds and therefore belief systems that are drawn upon in these sorts of debates in this school is very varied. Warrants made to support claims that are based on belief systems (particularly religious ones) are hard to provide evidence for and therefore to back, at least in the sense that a scientist might use evidence. For example one student might say, 'I just cannot accept that any organ can be put into another person because my religion says it is wrong.' In such cases, Toulmin's model of argument is harder to apply, and hence levels of argumentation based on his model are more limited.

These different features and outcomes produce something of a dilemma for educators promoting both types of argument as part of new science curricula. Unless we are careful, we could promote the view that higher levels of argumentation can be achieved by sticking to structured activities based on clear relationships between evidence to argue about competing claims rather than engaging in messy and complex debates about ethical, moral or socio-economic matters. To do so, however, would be dishonest and counterproductive, and would certainly be against the spirit and intentions of the new curriculum in South Africa.

8. IMPLICATIONS FOR THE CPD PROGRAMME

In this section, we have drawn on the findings of this study to suggest three ways in which arguments about ethical and moral issues in biological science might be improved.

8.1 Providing two-part tasks

What seems crucial here is to allow enough time (and therefore mental space) for students to compare individually reasoned claims and engage in group discussion to reach a consensus (or majority) view. Our previous work and that of others suggests, however, that a common feature of group discussions in African contexts is for inclusive discourse that drives towards consensus without the rebuttals, challenges and counterclaims that characterise the higher levels of 'Toulminian' argumentation. This tendency towards consensus draws on the cultural traditions of African peoples called 'ubuntu' (see Scholtz *et al.* 2008).

8.2 The use of role play

Role play, where group members take up different positions, has been used successfully in situations that have high science content but involve ethical and moral decisions. An example concerns justifications for the role of zoos (Simon *et al*. 2006). One problem can be if the allocated role clearly clashes with the student's own deeply valued perspectives and beliefs.

8.3 Anticipating counterarguments

Osborne *et al.* (2004b) advised the use of argumentation writing frames to help students anticipate counterclaims and rebuttals that might challenge their own position. This strategy is useful in supporting both 'scientific' (*Euglena*-type) and ethical/moral (organ trafficking-type) tasks.

9. CONCLUSIONS

The study poses a dilemma in that argumentation in purely science-based contexts could be seen as being easier and more successful than in the broader-based and more fluid arguments that emerge from discussions of ethical or moral issues. One suggestion that allows both types of argument to take place and co-exist is to strip away the science to form a two-part debate, first the science and then the ethical issues involved (see Simon *et al*. 2006). We would like to add a note of caution here. Such courses of action could promote the view of science being divorced from its cultural and social roots. This is what has often happened to science education in developed countries in the past, where the evidence is that many students perceive science as a cold-hearted, anti-social enterprise stripped of its humanity. In these countries, students are turning away from science (see, for example, the research of the ROSE project; Schreiner and Sjøberg, 2008). In contrast to this situation, the ROSE research shows that students in many developing countries (including South Africa) are better disposed towards science as an enterprise and as a subject to study. We do not wish to see the mistakes made previously in other countries repeated in a state education system in South Africa where there is a commitment to critical thinking as part of democratisation, engagement and inclusiveness.

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15 Exploring options for increasing the equilibrium size of a fish population in a lake: students' discursive activity towards the concept of carrying capacity within a computer-supported learning environment

Marida Ergazaki and Vassiliki Zogza

DEPARTMENT OF EDUCATIONAL SCIENCES AND EARLY CHILDHOOD EDUCATION, UNIVERSITY OF PATRAS, GREECE

ergazaki@upatras.gr; zogza@upatras.gr

This study aimed to highlight the computer-mediated discursive activity of two pairs of freshmen educational sciences students, each collaboratively exploring several options for increasing the equilibrium size of a fish population in a lake. Our focus was on students' attempts to come up with justified predictions about the adequacy of several options for maintaining a larger fish population, as well as on their attempts to refine or radically reconsider these theoretical predictions in the light of empirical data provided by software simulations. Thus, this study was particularly concerned with the construction of arguments on the level of the 'argumentative' (i.e. claims, justifications and challenges) and 'epistemic' (i.e. recognising assumptions and consideration of limiting factors) operations and the contribution of the software simulations in this process. According to the analysis of the students' discourse, both pairs seemed to engage in the construction of directly justified theoretical predictions by activating several epistemic tools, whilst only one seemed to reach the target concept of carrying capacity. Significant differences could be identified with regard to the two pairs' interest as well as capability in using the simulations as a meaningful feedback for their initial arguments. Implications about students' tendency to transfer the sterile culture of 'doing schoolwork' into problem-based collaborative learning environments, as well as their difficulties on both the conceptual level *and* the level of meaningfully integrating the software simulations in their argumentative reasoning, are discussed.

1. THEORETICAL FRAMEWORK AND OBJECTIVES OF THE STUDY

1.1 Theoretical framework

Science education research has recently been concerned with the use of 'argument' as a tool for constructing meaning in science classrooms (Driver *et al.* 2000; Jiménez-Aleixandre *et al.* 2000; Jiménez-Aleixandre and Pereiro 2002). A significant body of studies has attempted to shed light on educational discourse in various contexts and settings, and subsequently to inform the development of more effective learning environments and assessment tools (Driver *et al.* 2000). Part of these settings is supported by 'new technologies' (Hmelo-Silver 2003; Tsui and Treagust 2003; Pata and Sarapuu 2005), which adds an interesting dimension to the study of educational discourse by exploring in detail the ways in which the latter may be affected by the technological tools mediating it.

Building on this body of research work, the present study attempted to highlight students' argumentative reasoning within a problem-based, computer-supported learning environment on population ecology. What particularly concerned us here was the construction of arguments and the ways in which students used the empirical data of computer-generated ecological simulations while engaged in them.

Theoretically, this study draws on the Vygotskian model of 'social constructivism', which stresses the social and situated nature of learning: knowledge construction is both an inter- and intra-personal process taking place in social settings (Vygotsky 1978). Social interaction is also a key element of the associated theory of 'situated learning' (Brown *et al.* 1989), which emphasises the notion of learners' 'apprenticeship' in 'meaningful and purposeful' domain activity.

Given the central role that argumentative practices hold in the scientific enterprise (Driver *et al.* 2000), as well as the conceptualisation of scientific thinking as argument (Kuhn 1993), instruction in scientific culture includes instruction in scientific discourse; in other words, instruction in constructing arguments as well as refining or even rebutting them, in the light of new empirical evidence.

1.2 Objectives of the study

Our study addressed the question: How do students evaluate practical options for increasing the equilibrium size of a fish population in lake while collaborating within a computer-supported learning environment? In particular, we asked:

1. Are they engaged in argumentative reasoning and how?
2. Which conceptual and epistemic tools do they employ for constructing arguments towards their joint theoretical predictions about the adequacy of the practical options for increasing the equilibrium size of a fish population in a lake.
3. Do they actually draw upon the empirical data provided by the computer-generated simulations in order to validate, discount or elaborate their theoretical predictions, thus approaching the concept of carrying capacity?

Thus, the objective of the study was to highlight the construction of arguments in students' discourse by exploring their conceptual and epistemic features, as well as by identifying whether and how the empirical data provided by the computer-generated simulations were used in order to transform the students' theoretical predictions into new knowledge associated with the concept of carrying capacity.

2. METHODS

2.1 Background setting

A didactic sequence on essential population ecology was developed considering reported conceptual difficulties in the ecological domain (Magro *et al.* 2003), as well as certain aspects of 'situated-learning theory', in order to engage non-biology majors in actively constructing key ecological concepts such as population growth, carrying capacity, competition and predation in a 'meaningful and purposeful' context.

More specifically, first-year students of the Department of Educational Sciences and Early Childhood Education at the University of Patras, attending the course Basic Ecological Concepts were asked to participate collaboratively in a hypothetical project on upgrading the services of the recreational park. Thus, they were assigned the four-task, computer-supported mission of studying the intra- and interpopulation dynamics of the park lake and make it appropriate for fishing.

In a student-centred setting, students collaborated in pairs to create joint answers to each task, supported by the educational software biology explorer, which provided them with simulations of the population dynamics in the park lake. According to the structure of the worksheets, students were required to come up with their own joint predictions mainly on 'what if' questions before starting to interact with the software simulations, which were based on graphs or pie charts. The teacher's role was restricted to providing additional technical support (the worksheets included detailed guidance) or providing hints where necessary, and conducting a closing whole-class discussion.

2.2 The task

Our focus in this study was on the second task of the didactic sequence, which engaged students in exploring several options for increasing the equilibrium size (Neq) of a small fish population in a park lake and introduced the concept of carrying capacity (K).

At the outset of the project, the park lake was supposed to host only a population of algae. After having started a new, algae-eating fish population with 12 individuals, studied its growth in the park lake and identified its equilibrium size (Neq) in the first task of the sequence, the students then needed to find out whether it was possible to increase this size and maintain more fish in the lake.

Thus, students explored 'what would happen to Neq, if. . .' they increased (option A) or decreased (option B) the initial size ($N_{initial}$) of the fish population or they systematically reinforced the population while at equilibrium, by adding more fish to the lake (option C). Finally, they were asked to make their own proposal in order to meet the requirement of the park administration for a fishing lake with more fish.

2.3 Overview of the analytic procedure

The two discussions of the second task presented here were produced by two pairs of female students. It was noted that all four students had studied ecology as part of their preparatory biology course for entering the university, were familiar with the use of computers as they had already successfully attended a relevant course and had never received any formal training in argumentative reasoning.

Each of the two discussions was tape-recorded, transcribed and broken down into 'message units' (Mason 1996; Kelly *et al.* 1998). Our next step was to locate the sequences of message units that functioned as the students' arguments for or against specific predictions about the effect of the different options for changing the equilibrium size of the fish population and also to identify the 'argumentative operations' within these sequences.

Drawing on the schemes proposed by Pontecorvo and Girardet (1993), as well as those of Resnick *et al.* (1993), we identified the argumentative operations of 'claims', 'justifications', 'oppositions', 'concessions' and 'challenges', whilst we defined 'argument' as any justified premise (claim, concession or opposition) that was particularly to do with one of the options in question. We then identified the conceptual and epistemic tools upon which students constructed their 'what if' arguments by considering the schemes of Pontecorvo and Girardet (1993), Mason (1996) and Jiménez-Aleixandre *et al.* (2000).

Finally, we narrowed our scope down to the arguments that the students constructed during or after their interaction with the software simulations, focusing particularly on whether and how they used the empirical data from these simulations in their argumentative reasoning.

3. FINDINGS

3.1 Students' arguments before engaging in the computer simulation: options A and B

By using analogy, both pairs initially made and warranted predictions about ending up with more fish in the lake if they started with more (option A), or with fewer if they started with fewer (option B). These predictions were subsequently negotiated and finally reversed by both pairs, mainly by activating the epistemic operations of 'consideration of limiting factors' and 'recognising implicit assumptions'.

According to the initial argument of Pair I, 'If we start the population with 40 fish, we will end up having more fish in the park lake than we did when starting with 12 (Claim: prediction A1), as more results in more' (Justification: using analogy). This argument was challenged by the second member of the pair by invoking the issue of food availability as limiting for the population's N_{eq}: 'The amount of algae will be the same; shouldn't we think of that as well?' (Challenge: consideration of a limiting factor).

The challenge resulted in rebuttal of the pair's first argument: 'The 40 fish cannot result in a larger population' (Opposition: to prediction A1) 'as the "algae food" is still the same' (Justification: consideration of a limiting factor). Moreover, it triggered the construction of a second argument, which argued *for* the opposite prediction on the effect of option A: 'The 40 fish will result in a smaller population' (Claim: prediction A2); 'fish may become more than before initially, but then deaths will increase and fish numbers will drop even lower, because there won't be enough food' (Justification: consideration of a limiting factor).

Although, when compared with the first argument, this second argument showed some understanding of food as a limiting factor for the population's N_{eq}, it also seemed to involve the problematic assumption (Assumption 1) that, when starting the population with more fish, the food will eventually be enough for even fewer fish than before. This assumption – which was not recognised by the students – was possibly to do with a reasoning strand according to which 'after growing a lot initially, the fish population consumes a lot of food, which makes the food stock smaller and finally adequate only for fewer fish than before'. Thus, this indicated that the students thought of algae as a 'food stock for fish' rather than as a population of living organisms following similar dynamics itself.

For Pair II, we traced the same initial argument for option A, which was also challenged in the same way as before. However, this time the response to the challenge was a quasi-rebuttal constructed upon the idea that the time lag until the food starts functioning as a limiting factor would offer the population enough to reach a larger $N_{eq:}$ 'The fish population will manage to increase its size and become even larger this time, before food availability actually becomes a problem' (Challenge rebuttal: consideration of a 'limiting factor-free phase'). The students seemed to make a new arbitrary assumption according to which 'maintaining a larger fish population at equilibrium will not be an issue despite the food constraints within the lake' (Assumption 2). This may indicate their possible difficulty in grasping the dynamic character of a population's equilibrium phase, which they seemed to think of as the 'end' of a dynamic growth process: 'After the population has reached its larger N_{eq}, the limiting factor of food cannot affect it: the population growth has reached an "end".'

Nevertheless, this assumption was not left unrecognised by the pair. On the contrary, the challenge rebuttal was now itself challenged, due to the recognition of this tacit assumption: ‘But aren’t they going to start dying when food problems appear? Won’t they become fewer and fewer?’ (Challenge: recognising an assumption – Assumption 2). Finally, Pair II also arrived at the opposite prediction of ‘a smaller N_{eq} from a larger $N_{initial}$’ (Claim: prediction A2); this – as explained above for Pair I – was associated with the assumption that ‘in case of more starting fish, the food will be eventually enough for even fewer fish’ (Assumption 1), which is indicative of the problematic conceptualisation of the algae population as a ‘food stock’ for fish.

Moving on to option B, it was noted that both pairs came up with a similar argument by examining the food availability exclusively with regard to the population starters:

> Pair I: If we start the population by adding only five fish to the lake, we’ll get *more* fish than before [Claim: prediction B1]; algae that is fish food will now be in excess as the same amount of algae will be shared among fewer fish [Justification: using analogy].
>
> Pair II: By having the same amount of food to be distributed among fewer individuals, food will be in excess [Justification: using analogy]; so we’ll get a larger population [Claim: prediction B1].

What we actually have here is the reappearance of the assumption that ‘the grown population won’t have any problems in maintaining its larger size at equilibrium, despite the food constraints in the lake’ (Assumption 2). Thus, the students’ difficulty in conceptualising the dynamic character of the equilibrium phase was indicated once more.

3.2 Students’ arguments while engaging in the computer simulation: options A and B

Having completed their theoretical predictions about options A and B, each pair observed and discussed the relevant simulations within the environment of BIOLOGY EXPLORER. Significant differences could be identified concerning the students’ interest as well as their capability of using the simulations as a meaningful feedback for their initial arguments.

Pair I, although clearly experiencing a conflict between the predicted and the observed – using the software simulations – relationship of a population’s initial and equilibrium sizes, were simply interested in filling in their worksheet with what they observed, and made no effort to explain their observations or to identify what was wrong with the argument *for* their initial prediction:

> Student 1: It is 212 again, the same. What’s happening here? Let’s try it with 5.
>
> Student 2: The same. We gave the wrong answers. The graph shows the same size.
>
> Student 1: OK, let’s keep this. . .the right answer and move on. We still have plenty to do.

In contrast, Pair II became seriously engaged in integrating the simulations into their argumentative reasoning:

> Student 4: 212 in all three cases? This is not possible.
>
> Student 3: Well, it is totally different from what we thought!
>
> Student 4: Yes, but why? Our answer was reasonable.

> Student 3: Well, this is reasonable too [Concession: plausibility]. We have to think of a small village or a room fitting ten people. No matter how many we try to put in it, it will still fit only ten, right? [Justification: consideration of a real fact].
>
> Student 4: Yes, but still. . . Let's run it again with 40 . . . OK . . . the same curve and always up to 212. The food is enough for 212 fish . . . and so it is room or oxygen. . .

More importantly, Pair II also engaged in reconstructing their prior arguments accordingly and they finally approached the target concept of carrying capacity:

> Student 3: If the food constantly remains enough for 212 [Justification: recognising an assumption – Assumption 2], there is no reason for the fish to become fewer as we thought, right? [Opposition: to prediction A2].
>
> Student 4: The mistake was here [Claim: evaluating prediction A2]. Anyway, according to the graph, the lake food is enough to keep 212 fish alive [Justification: using the graph]. So any number of fish will grow into a population of this size [Claim: distinguishing N_{initial} and N_{eq}].

Nevertheless, it is noteworthy that, even when the students realised that they were wrong in their Assumption 1 ('ending up with less food, with more starters') and successfully reconstructed their initial argument, they did not get to the source of their fallacious assumption. However, this was consistent with the way they explicitly recognised the benefit of their work with the software: 'The good thing with the simulations is helping us find *where* our mistakes are.'

3.3 Students' arguments before engaging in the computer simulation: option C

Moving on to the option of reinforcing the fish population while at equilibrium (option C), Pair I used the same false argument as in option A: 'Adding fish during equilibrium results in a smaller population' (Claim: prediction C1) 'as there won't be enough food' (Justification: consideration of a limiting factor). In contrast, Pair II consistently applied what they had just learnt from simulating options A and B within the software BIOLOGY EXPLORER: 'No matter how many fish we add, there won't be a constant change. The final number will always be 212' (Claim: prediction C1). 'We have shown that the lake has food for 212 fish' (Justification: using the graph).

3.4 Students' arguments while engaging in the computer simulation: option C

While simulating option C with the software (Figure 15.1), Pair I restricted themselves to simply describing what they observed, without trying to explain any of it or use it to reconsider the initial predictions:

> Student 1: With plus 80, it goes up, then is steady again at 212. We said it would drop more.
>
> Student 2: With plus 100, it goes up, then drops down and then up again to reach 212.

Even after witnessing extinction of the fish as a result of adding an extremely large number of fish to the lake, Pair I did not start a critical discussion.

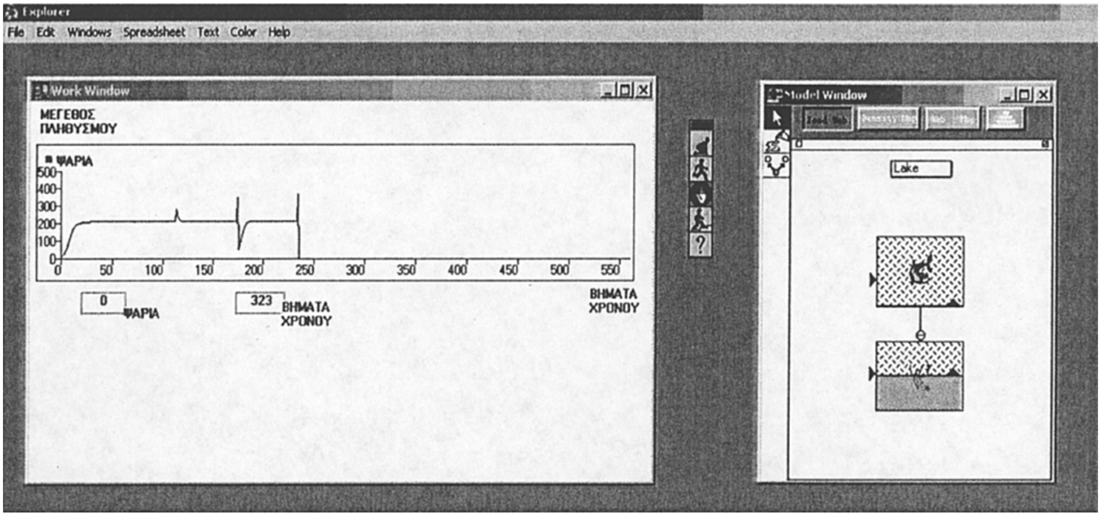

Figure 15.1 Exploring option C within BIOLOGY EXPLORER

Using the slider in the upper 'box' of the 'Model Window' (see on the right) that represents the fish population, students can change the population size while the simulation is already running and then observe the effect in the graph in the 'Work Window' on the left.

> Student 2: 'Slider at 130, OK run. What's this now? All the fish are dead! Did you see that?
>
> Student 1: 'OK, they're dead. We said they would die, at least some of them [laughs].
>
> Student 2: [Laughs] This is a massive disaster. . .but anyway, shall we fill in the worksheet?

In contrast, Pair II, apart from confirming the predicted inadequacy of option C for increasing the population's N_{eq}, also engaged in explaining the simulated possibility of the fish extinction that they observed. However, it should be noted that they did not manage to fully integrate this possibility into their argument against option C:

> Student 3: Oops. . .They're all dead now. . .Why?
>
> Student 4: Maybe we added too many. . .
>
> Student 3: Too many for the lake, for its food [Justification: consideration of the ecosystem's capacity].
>
> Student 4: This was a bad idea. We only made it worse [Claim: evaluating option C].

3.5 Students' arguments for their own proposals

When making their own proposals to meet the requirement of the park administration for a fishing lake with more fish, Pair I had a rather superficial understanding, whilst Pair II clearly showed an understanding of the idea of the ecosystem's carrying capacity.

Thus, what the students of Pair I proposed was actually a new version of the already explored option C; namely, adding a small number of fish to the grown population but less frequently, so that the food was not rapidly consumed before fishing takes place.

> Student 2: The less frequently we add some fish . . . [Claim: proposal]
>
> Student 1: . . . the less extra amount of algae will be needed as food . . .
>
> Student 2: . . . so the fish death rate will not increase rapidly . . . [Justification: consideration of positive/negative death rate]
>
> Student 1: . . . and visitors can go fishing and remove the extra fish.

In contrast, Pair II came up with the proposal of enlarging the lake in order to eliminate a series of constraints for the population growth; namely, to deal with limiting factors such as food, room and oxygen:

> Student 3: What if we add more algae? [Claim: proposal]. This means more food for the fish. Shall we run a simulation to check it out?
>
> Student 4: No [Opposition]. There is still the same amount of room and oxygen. Food isn't really the only thing to worry about [Justification: consideration of additional limiting factors].
>
> Student 3: So, can we really do something?
>
> Student 4: I think we have to enlarge the lake [Claim: proposal] so we'll have more food, more room, more oxygen and more fish [Justification: consideration of the ecosystem's capacity].

It is noteworthy that, although they seemed to have established the concept of carrying capacity, the students still showed difficulties in grasping algae as a dynamic population itself rather than simply as a food stock for fish. This was indicated by the fact that the idea of adding more algae to the lake was not rejected by consideration of its own inadequacy in dealing with the limiting factor of food, but by the need to deal with extra limiting factors. It was further supported by the fact that the students completely left out the dynamics of the algae population in their discussion when finally running a simulation of reinforcing the algae population while at equilibrium (Figure 15.2). In fact, they only pointed to the effect that this option had on fish without making any comment on the effect that it would have on the algae.

4. DISCUSSION

Our analysis indicated that both pairs engaged in argumentative discourse by activating a rich set of epistemic tools in order to collaboratively cope with the task. More specifically, students drew upon their epistemic 'tool kit' – which appeared to include significant operations such as using analogy; an understanding of limiting factors or a 'limiting factor-free' phase; recognising implicit assumptions; using plausibility, real facts and 'properties' such as the ecosystem's capacity' or a positive/negative rate and dissociating factors; and using a graph – for the construction of 'directly justified' (Kelly *et al.* 1998) predictions, as well as for their elaboration in *some* of the cases where these predictions were challenged either theoretically or in the light of the software simulations.

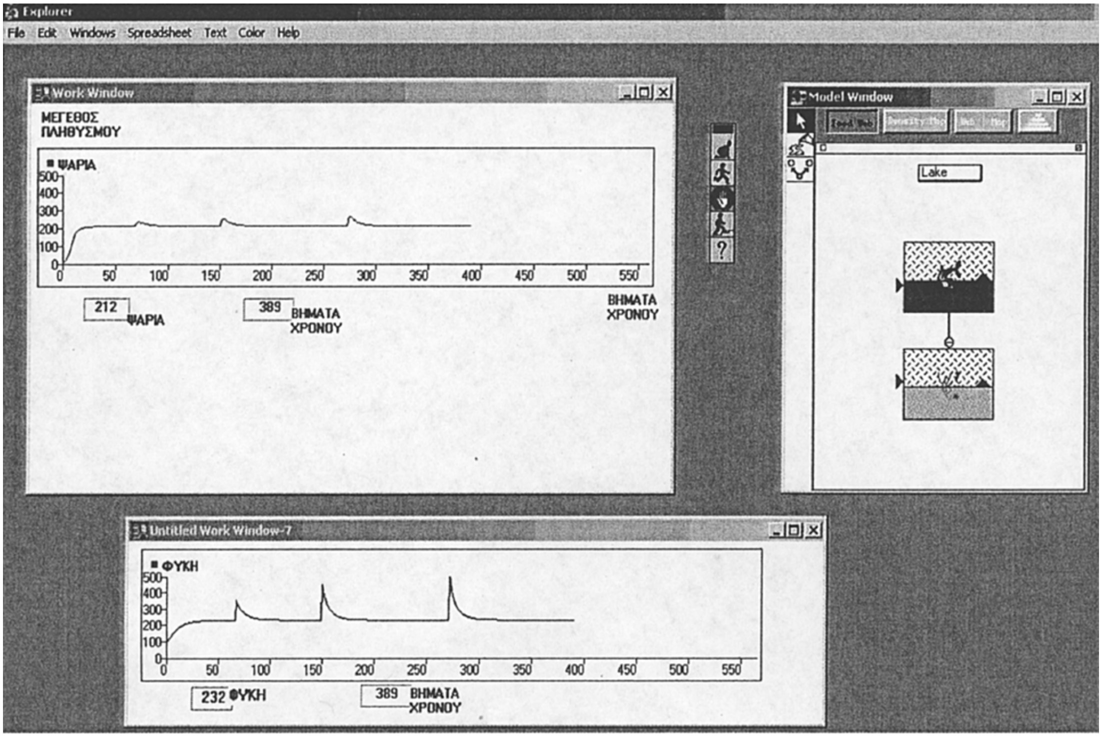

Figure 15.2 Simulating the idea of reinforcing the algae population

Using the slider in the lower box of the 'Model Window' (see on the right) that represents the algae population, students can change the algae population size while the simulation is already running and observe the effect on both algae and fish populations in the two graphs in the 'Work Window'.

It is worth noting that, when grounding their arguments on problematic implicit assumptions that remained unrecognised in the discussion, the students actually came up with false predictions. In contrast, explicit recognition of such assumptions may serve as a challenge to the associated arguments and possibly result in their further elaboration. Thus, the epistemic operation of recognising assumptions – activated either theoretically or in the light of simulation-provided empirical data – seems to be quite significant for enhancing the quality of arguments. This actually implies a need to be capable of recognising any arbitrary assumptions that implicitly lie at the basis of the constructed arguments, which in turn implies a need to train students accordingly.

Regarding the conceptual level, it was noted that only one of the pairs (Pair II) finally managed to gain some understanding of the target concept of carrying capacity; in fact, it was the students consistently committed to using the simulations as meaningful feedback on their initial predictions about the effect of the different options on the equilibrium size of the fish population. Moreover, similar conceptual difficulties seemed to emerge from the analysis of both discussions. The first of these was to do with grasping algae as a dynamic population in itself, rather than simply as a food stock for the fish; in other words, it was to do with consistently applying the concept of population to cases of both animals *and* plants. The second difficulty identified by our analysis concerned the equilibrium phase and its dynamic character. By perceiving equilibrium as the 'end' of a dynamic process such as population growth, students find it hard to attribute a dynamic character to this phase. Consequently, there is a need to place additional emphasis on both of these issues when presenting inter- and intrapopulation dynamics.

Finally, as already shown, computer-generated ecological simulations may support students in their argumentative reasoning, provided the students themselves are willing to construct meaning out them and that they are also capable of doing so. Nevertheless, the tendency to transfer the ineffective 'doing schoolwork' culture into alternatively designed learning environments, as well as the inherent difficulty in using simulations as cognitive and meta-cognitive tools, clearly indicate a need to motivate and also systematically train students to adapt a more creative 'doing science' culture and – to borrow from Jiménez-Aleixandre and Pereiro (2002) – start transforming themselves from 'knowledge consumers' to 'knowledge producers'.

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16 Transformation of everyday language into scientific language in primary school children's explanations

Alma Adrianna Gómez[1] *and Neus Sanmartí*[2]

[1]UNIDAD MONTERREY, CINVESTAV, MONTERREY, MEXICO; [2]DPT DIDÀCTICA DE LES CIÈNCIES I LES MATEMÀTIQUES, UNIVERSITAT AUTÒNOMA DE BARCELONA, BARCELONA, SPAIN

agomez@cinvestav.mx, neus.sanmarti@uab.es

In this paper, we report on the results of an analysis of teachers' and students' discourse in a science classroom of a 5th form of a primary school (children aged 10–11), in which they were studying what happens to living things when there is a fire in a forest. The aim of the analysis was to follow the process of transformation of everyday language into scientific language. We identified a four-phase process: (1) generating a new idea; (2) choosing a new word or phrase to designate the new idea, which we named a 'bridging term'; (3) using and regulating the bridging term; (4) incorporating the scientific term and substituting it for the bridging term. This method of language transformation in the classroom is similar to that found by Clive Sutton (1992) in the incorporation of new scientific terms in the history of science, where words were initially used to interpret (bridging terms) and the labelling system (scientific word) was only introduced afterwards. On the other hand, bridging terms establish a link between everyday and scientific language, supporting generalisation processes, as described by Vygotsky (1962) in the case of the formation of scientific concepts in childhood. The use of bridging terms has several implications for teaching, which are discussed in this paper.

1. THE PRODUCTION AND USE OF SCIENTIFIC LANGUAGE: THEORETICAL BACKGROUND AND OBJECTIVES OF THE STUDY

One of the aims of biology teaching, and of science education in general, is that students meaningfully incorporate scientific language that permits them to have a theoretical view to explain natural phenomena. To achieve this, the new language should be associated with new ways of thinking and acting and should become part of a system of ideas that are intertwined to form a hierarchy and to relate to life experiences. This allows interpretation of a diversity of phenomena and the establishment of relationships within the school scientific model that works as a reference (Izquierdo and Adúriz-Bravo 2003). This view of biology teaching implies that children, when learning biology, gain access to a different culture.

According to Tyler (1969), a culture consists of organised semantic domains. Any two cultures differ by virtue of the fact that they do not share the same semantic domains and they have different methods of organising them. We could say that scientific culture and children's culture differ, and this leads scientists and children to see and organise biological phenomena, e.g. living organisms, around different semantic domains.

Starting from the viewpoint of children's culture implies understanding how they organise those domains in order not to impose categories generated from outside, but rather to construct them with students. Making students see the way in which they arrange their own experiences and helping them propose new views will slowly lead to the generation of new semantic domains.

Gradual transformation implies organising ideas and concepts within school scientific theories. From an 'elementistic' view of knowledge construction, such as that assumed by associationism and information processing, reality is considered to be decomposable into parts, and concepts can be defined by a list of traits or attributes (Pozo 1999). On the other hand, from a holistic perspective, such as that of Vygotsky (1962), we start from the analysis of units that are more specific, where the whole is more than the sum of the parts. In this latter perspective, concepts are defined from other concepts by their meaning, within a theory or general structure (Pozo 1999).

Taking this into account, we analysed the introduction of scientific language into classroom explanations, seeing it within a network of ideas. In order to do this, we resorted to two areas: psychology, specifically with Vygotsky's contributions on the development of scientific concepts in childhood, and the history of science, following Clive Sutton's work on the incorporation of scientific language (Sutton 1992).

The way in which scientific language is introduced to children, and the relationships between their scientific and everyday language, were initially studied by Vygotsky. In 1934, Vygotsky first published his book *Thought and Language*, in which he devotes a section to the development of scientific concepts in childhood (Vygotsky, 1962). Vygotsky remarked that scientific language is always introduced and mediated by other concepts; this allows a rudimentary systematisation that is transferred to everyday concepts, supporting their organisation. Vygotsky thus established a relationship in the structuring of scientific and everyday concepts in children: the former support the systematisation of the latter.

In contrast, Sutton (1992, 1996) studied the ways in which scientists introduced new scientific language in the history of science. He found that the new terms introduced by scientists to talk about new ideas were in many cases derived from everyday words or were created from them. These terms then underwent a test phase during which they could be modified; finally they were accepted, spread and used within the scientific community. Sutton differentiates between words used as an interpreting system, aimed at giving new meaning to experience and where language works as a flexible and active thinking tool, and words used as a labelling system, where each term has a precise meaning. In the interpretative system, scientists look for words and images that are suitable for orientating scientific thought; there is creative effort and progression, as the initial uses are provisional. Language is analogical or metaphorical, and therefore imprecise; it works as a flexible and active instrument of thought.

Using the theoretical references previously described, we aimed in this work to analyse the process of incorporation of scientific language in primary science classes. Our research questions were:

1. What are the ways in which scientific language is introduced during interactions between the teacher and students in the construction of children's explanations and what role does the teacher play?
2. Is there a relationship between everyday language and scientific language? What type of relationship do these two kinds of language have?

2. METHODS, PARTICIPANTS AND DATA SOURCES

In order to follow language transformations, we analysed the discourse in 13 instructional sessions of a 5th form class of primary school (aged 10–11). In these sessions, the participants interpreted what happens in a forest when there is a fire. We worked at the school Coves d'en Cimany (Barcelona), in the autumn of 2003. The working group included two teachers: the regular teacher of the course, Teresa Pigrau, together with Adrianna Gómez, the first author of this paper, who in previous years had integrated herself in the work in this school in order to discuss with children the topic of environmental disturbances. The class had 22 students.

For the analysis, we recorded the interactions between students and teachers in each class session and transcribed them. We identified discussion sequences delimited by the level in which students' observations were located (Gómez *et al.* 2006). For each sequence, we analysed: (1) the introduction of new ideas; (2) the regulation of ideas and use of terms – this comprised the moments when teachers or students made a suggestion, explanation or exemplification to improve an idea; the regulation also included instances when students or teachers corrected the pronunciation or the use of a term; and (3) fragments of the discussion when the students used scientific language.

3. PROCESS OF LANGUAGE TRANSFORMATION: RESULTS

Data analysis showed a gradual process of transformation of the students' everyday language into scientific language. We identified four phases in this process. In the following example, the four phases are described for the introduction the new term 'stimulus'.

3.1 Phase 1: generating a new idea

In phase 1, starting from students' ideas, teachers ask questions or propose activities in order to start a debate and generate new ideas, thereby introducing a process unknown to the students until then or recognised by the students but not yet systematised. In the examples shown below, teachers asked students questions about what defines living animals. The students had carried out an exercise to identify the characteristics that they considered common to all living animals. Taking movement as one of the characteristics defined by some students and introducing the question of whether plants also move, the teachers promoted a discussion on the topic of 'the movement of living organisms'. After the discussion, a new idea on the meaning of 'moving' when referred to living organisms was generated; this new idea included movement in plants.

Living animals move, but do plants also move?

Teacher 1: Now, they move – let's think of plants.

Tony: If someone grabs it and takes it with them, it moves.

Teacher 1: What would be the difference between animals moving and a plant being taken and moved?

* * *

Teacher 1: Do plants never move?

Ali: Yes, when they grow.

Teacher 1: They grow up in size, but do they move?

Abraham: There are some that move towards the sun; some move on the walls looking for light.

Teacher 1: Take a look at this plant, for instance [points at a plant in the classroom]. Can you see how all its leaves face the light?

Lou: Yes!

Teacher 1: There is a flower called a sunflower. . .

* * *

Teacher 1: Then it's not that it moves, that it changes place or that it walks.

Ali: That it moves towards something.

Peter: That it turns.

Teacher 2: There was a plant that closed at night.

Teo: The carnivorous one too.

Teacher 2: If a fly or another animal touches it, they suddenly close. It's because they receive something from the outside and they immediately respond.

* * *

Teacher 1: There are some flowers that close at night and open at sunrise.

Carlos: The 'buenos días' ['Good morning' in Spanish].

Teacher 1: It opens in the morning – it seems to says 'Buenos días.'

Carlos: There are 'buenos días' [Family: *Asteraceae*] in my country.

(Analysed activity: 1)

3.2 Phase 2: choosing a new word or expression: the 'bridging term'

In phase 2, the students propose various suitable terms as an interpretative system for the new idea. In order to do so, they choose terms that are understood by everyone, even outside the classroom. A bridging term is a description of a process that includes verbs, agents or the destination of the process. Sometimes it can be a metaphor or analogy. For example, we found the use of the term 'electric cable' as a bridging term for the scientific word 'nerve'. It can also be an explanation for part of a process, with the use of verbs, such as 'receiving information from the environment' as a bridging term for the scientific word 'stimulus'. There are many scientific terms that are nouns that refer to a process; the process of transforming verbs into nouns and their use in scientific discourse is know as nominalisation (Halliday and Martin 1993).

The teachers' role is to help the students choose a new word or expression that encompassed the new idea generated during phase 1 and that can work as a 'bridge' or intermediary, facilitating the subsequent introduction of the scientific term.

In the examples shown below, the new idea of movement in plants and animals is associated with the information that living organisms receive from the environment. The class suggested using the expression 'receive information from the environment'. The bridging term is introduced to name the new idea about movement in plants and animals generated by the class.

Living beings 'receive information from the environment', and therefore they move.

Teacher 1: Look at the diagram that we are going to do. One of its characteristics is that it's going to help us, but if we give it to a friend, to our dad or our brothers and sisters, it could also help them. If we put ‘they move’, they are going to think in terms of animals walking or of a plant being carried around. How can we put it so that more people can understand it as we do, so that they do not get confused when reading it?

Lou: They turn around.

Teacher 1: We must include the flower that closes its leaves.

Sal: They protect themselves.

Teacher 1: It must also include what animals do: they move not only to protect themselves but also to look for food, for a mate. What else do you imagine, that can work for plants and animals?

Lou: Movement.

Abraham: They change place.

Teacher 1: What do plants do?

Leti: They change place.

* * *

Carlos: When it is day. . .

Teacher 1: Some when it is day, others when it is night, others when they are touched by an animal. Then how can we name this? They change place when they feel. . .

Ali: . . .that there is something out there.

Luis: . . .when something is felt.

Teo: . . .when something comes closer.

Teacher 1: Let’s think. When we touch them, when. . .

Michela: . . .when they feel.

Teacher 2: What do their senses tell them?

[Plant do not strictly have senses; the teachers uses this word to try and obtain new children’s words and to help them select the bridging term.]

Luis: Thoughts.

Michela: Reactions.

Teacher 1: And what’s the meaning of all this?

Teacher 2: Yes, when they say something to us, what do they give us? Do senses tell you anything?

Anna: Yes.

Teacher 2: And what’s the meaning of that, what they give you?

Michela: Information.

Teacher 2: Then what do you think if we change to ‘information’? Now, it is useful for plants and animals.

Several students: Yes.

Several students: They give information to each other.

Teacher 1: Well then, the sunbeams are information that tells the plant where the sun is and the plant moves – will this be useful for animals and plants?

Michela: I think so.

Teacher 2: OK, do we agree then that this may be useful for animals and plants?

Several students: Yes.

Teacher 1: Let’s write it down.

(Analysed activity: 1)

3.3 Phase 3: using and regulating the bridging term

In this phase, students use the bridging term when interpreting different phenomena. Constant regulation from teachers and self-regulation by students occurs. The meaning is generalised by applying it to different examples. Terms become more precise by distinguishing between similar terms and by correcting attempts in which the term is used incorrectly, confused with others, mispronounced or incompletely uttered, until the class reaches a more complete and correct use, with a higher degree of generalisation. The bridging term is then used to talk about diverse phenomena. In the example below, some conversation fragments illustrate the regulation process. The students have discussed reproduction in animals and they have talked about the information that is transmitted from parents to children. They have generated another bridging term in which they have also used the word ‘information’. The bridging term is regulated. Specifically, we have illustrated differentiation in the use of the word ‘information’, which students are introducing in two different bridging terms.

Living organisms receive information.

Teacher 1: And how are we going to tell the difference? Because Michela says that living organisms can receive information from outside, how are going to distinguish between this information that goes from ancestors, from parents, and this information. What would the difference be? Because we are using the word ‘information’ twice – and remember that this needs to be useful not only for us. . .

* * *

Ali: That the information arriving is. . .you receive it through the. . .

Teacher 2: You hadn’t said before how you receive this information from outside.

Esteban: Through touch.

Teacher 2: And what are those?

Michela: Senses.

(Analysed activity: 3)

3.4 Phase 4: progressively incorporating the scientific term to substitute for the bridging term

In the final phase, the teacher suggests the scientific term to designate the same idea. Later, a gradual use emerges, where both the bridging term and the scientific term are used; finally, the latter is preferred. This implies regulation processes promoted by the teachers and by fellow students. Examples are illustrated in the following three extracts:

Living organisms receive 'stimuli'.

Use and regulation of the scientific term: In the conversation, teachers remind the class of the ideas that students should use in their arguments during the activity that follows, which is the simulation of a fire in a three-dimensional scale model of a forest.

Teacher 1: We said three things – which three things are important for living beings?

Luis: Nutrition.

Abraham: Reproduction.

Teacher 1: What else?

Several students: [comments].

Pablo: Excretion.

Monic: They excrete.

Teacher 1: excreting is part of what?

Monic: of nutrition.

Teo: this thing about receiving information.

Teacher 1: receiving information from the environment – what did we call that information?

Paula: [comments].

Anna: Sti. . .s. . .

Teacher 1: S-ti-mu-li.

Abraham: We forgot the name!

(Fragment 1; analysed activity: 6)

Use of the scientific term: Conversation revolves around the changes that the class has introduced in the scale model of the forest when they simulated its regeneration after a fire.

Teacher 1: For instance, you have put this insect here – how does this insect know that there is food there?

Leo: Through its instincts.

Anna: Through its senses.

Michela: It is a relation.

Teacher 1: We have relation, nutrition and reproduction – how does this insect know that there is food there?

Michela: Because it has received the stimuli that there is food.

Teacher 1: What has it received them with?

Toño: Through smell.

Pablo: With its sight.

Gaby: With its smell.

(Fragment 2; analysed activity: 12)

Students use the scientific term appropriately: In this conversation, which took place in one of the last activities, students compared two possible environmental disturbances in the forest.

Paola: There wouldn't be insects and animals because they wouldn't have food.

Teacher 1: Good.

Anna: Animals would also receive stimuli.

Teacher 2: They receive stimuli such as that there is a mate, right? Ooh, there's a beautiful little fly here, or is there? Ooh, I like the little fly. And it receives the stimulus of what it looks like, and its brain tells it: it's beautiful, isn't it? OK?

Anna: Yes.

Teacher 1: And what could the reaction be?

Pablo: Look for the mate, and if there is a mate, the species does not die out.

Anna: The same as Pablo.

(Fragment 3; analysed activity: 13)

4. DISCUSSION AND EDUCATIONAL IMPLICATIONS

The four-phase process that we have described was also seen with superordinate concepts, such as 'functional relationships', in which the term 'stimulus' was incorporated. This system of ideas belonged to yet another system of higher order, corresponding to 'living organism'; e.g. 'living beings, like insects, can receive stimuli and respond to the changes in the environment; they have relationships with the environment' (Gómez 2005). We can state that bridging terms establish a link between everyday and scientific language, giving support to generalisation processes. The results that we found exemplify Vygotsky's proposal of how the incorporation of scientific concepts is mediated by less-general concepts, in our case, the bridging terms, which are in time mediated by other less-general concepts, the students' everyday language. We think that this way of introducing scientific terms may give support to the structuring of broad concept nets in students.

When we refer here to more general terms, we are following Vygotsky's ideas (1962: 88–89):

> Our own experimental studies suggest that the child becomes aware of differences earlier than of likenesses, not because differences lead to malfunctioning, but because awareness of similarity requires a more advanced structure of generalisation and conceptualisation than awareness of dissimilarity. In analyzing the development of

> concepts of difference and likeness, we found that consciousness of likeness presupposes the formation of a generalisation, or of a concept, embracing the objects that are alike; consciousness of difference requires no such generalisation – it may come about in other ways.

In the case that we have described, one of the key elements for the first phase is that the teacher supports the identification of resemblances; in our example, a resemblance between movements in animals and plants. During phases 3 and 4, the processes of regulation in the use of the bridging term and the scientific term are related to the incorporation of different experiences in the use of words, especially to explain a diversity of phenomena that become unified precisely through their resemblances. In our example, students generalise in relation to the different times at which living organisms, both plants and animals, can receive stimuli, and with the diversity of stimuli that are, in all cases, information for the living organism about what is happening in the environment. We can then say that bridging terms are establishing a link between everyday and scientific language, giving support to generalisation processes.

On the other hand, the four-phase process we found differed from Vygotsky's ideas in relation to the introduction of scientific terms in school; he understood that the scientific terms are presented at the beginning of instruction in the form of precise verb definitions. Vygotsky thought that the difficulty with scientific concepts lay in their 'verbalism' (Karpov 2003). In the four-phase process, we found that scientific terms were presented at the end of instruction, when children understood at least part of their meaning and were able to use them to explain natural phenomena. In this way, we could say that the introduction of bridging terms deals with the problem of 'verbalism' in scientific language.

It must be taken into account that the introduction of the scientific term does not end the process of structuring of the ideas and of the organisation of experiences, but rather shows a moment when it is resumed (not only to give more meaning to the words but also to introduce new processes). In the case of the word 'stimulus', which was constructed considering animals and plants, it is still necessary to gradually introduce the possibility of stimulus reception in other living organisms. In the same way, in the process of stimuli reception by living organisms, it is necessary to introduce the specific mechanisms of reception, the systems of information transport, etc. These are topics that we are now working on through the development of innovative instructional sequences. It is also necessary to interpret more phenomena using the constructed ideas and, at the same time, to construct other new ideas that in due course will be associated with scientific terms, expanding the network of ideas of the theoretical model of living organisms and consequently deepening the understanding of the phenomena it explains.

In addition, this way of transforming language in the classroom is similar to that found by Sutton (1996) in the incorporation of new scientific terms in the history of science, where words are initially used as an interpretative system (bridging terms) and the labelling system is only introduced afterwards. Sutton recommends making students understand this process of transformation of scientific language, which has in its origin an interpretative aim and a human choice of language. In our case, we could do this by proposing in the classroom a metacognitive reflection on the process followed by students in language transformation, and then establishing a parallelism with the process described by Sutton.

In the introduction of scientific language in the classroom, the use of intermediary bridging terms may be recommendable. This could be justified by the following arguments:

1. The results that we found exemplify Vygotsky's theoretical proposal of concept mediation. As Solsona (1999) has stated, theoretical models permit us to give unity to different experiences

that were previously seen by students as disconnected. This way of structuring of ideas by means of bridging terms implies a new way of organising students' experiences.

2. The educational implications of the use of bridging terms during the process of incorporation of scientific language are related to the use of language as an interpretative system rather than as a labelling system. When interpreting, science is a communicative activity of meaning negotiation aimed at sharing and comparing ideas. The use of bridging terms as an interpretative system, as Sutton (1996) suggests, has the aim of giving flexibility to thought and helping the process of regulation of ideas. The challenge for teachers is how to favour new experiences and support the construction of new ideas that require students to propose new terms.
3. Some scientific terms (such as 'stimulus' or 'relation' in the example that we have discussed) are nouns that in fact point to processes; nevertheless, the processes alluded to are 'packaged' within the words (Halliday and Martin 1993). According to Dik (in Moya and Albentosa, 2001: 380; our translation), 'verbs indicate processes, whereas nouns refer to entities; therefore, a process that has been nominalised refers to an entity that consists of a process'. In the nominalisation process, valences or number of arguments of the verb are reduced: personal elements (agent, patient, destination of the process) are omitted; this gives scientific discourse the objectivity and precision that is usually attributed to it. Nominalisation permits the concentration of information and its use in a 'packaged' form.

As Moya and Albentosa (2001: 384; our translation) state:

> Nominalisation permits us to think as objects, as things, areas of thought that in general refer to processes (expressed by verbs), qualities (realised through adjectives), or circumstances (expressed through adverbs). Nominalisation permits to present realities, facts or statements as inalterable, or at least out of discussion.

This makes it more difficult for teachers to introduce meaning negotiation and application in examples in class. The straightforward introduction of the scientific term, without associating it with regulation processes, could lead students to using it without understanding it.

According to this, the function of the bridging term is to evoke the process and agent 'package' in a scientific word. On the other hand, bridging terms, as we have shown, enunciate what has been studied in class, besides being suggested by students themselves. As we have discussed, these two aspects facilitate the processes of regulation of ideas. Introduction of a scientific term, in the form of a noun, takes place at the end of the process, and not at the beginning as in traditional teaching. Gradual transformation through this four-phase process permits packaging of information and can lead to a process in which scientific terms are used to organise other terms and processes of construction of meaningful use of scientific language.

In the application of strategies that lead to the conformation and regulation of bridging terms, the challenge for the teacher is to manage the activities and conversation in the classroom: firstly, by generating debate and controversy ('generating differences', in terms of Ogborn *et al.* 1996) in order to identify and understand new processes; and secondly, in the design of activities to get students arguing and making decisions; in this environment, regulation of ideas is possible so that the scientific terms are later introduced to generate new spaces for regulation, both of ideas and of expressions and actions.

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17 Confirmation bias revisited

Maike Ehmer[1] and Marcus Hammann[2]

[1]IPN-LEIBNIZ INSTITUTE FOR SCIENCE EDUCATION AT THE UNIVERSITY OF KIEL, GERMANY;
[2]INSTITUTE FOR BIOLOGY DIDACTICS, UNIVERSITY OF MÜNSTER, GERMANY

ehmer@ipn.uni-kiel.de; hammann.m@uni-muenster.de

Students' tendency to confirm their beliefs through experimental data rather than by objective testing has traditionally been regarded as a matter of beliefs about the scientific content and as an irrational argumentation in order to keep current conceptions. In this paper, we argue that confirmation bias, especially students' tendency to interpret experimental data in line with their beliefs and to plan experiments in order to confirm rather than disconfirm their beliefs, cannot be divorced from considering students' conceptions about the method of scientific experimentation. Thus, confirmation bias cannot be reduced to an individual's problematic response to anomalous data in an experiment (i.e. confirmation bias as an attempt to avoid cognitive conflict at the level of science concepts), nor to an individual's failure to seek disconfirmation when planning an experiment (i.e. confirmation bias as a flawed strategy in planning experiments). This study offers proof that students often deal with anomalous data and do not ignore them, but fail to address them adequately because they lack knowledge about the scientific method of experimentation and possess alternative reasoning strategies, which differ from scientific conventions and determine the students' unscientific understanding of experimental data.

1. INTRODUCTION

Students' performance in experiments differs from accepted scientific methods in many ways. In particular, students plan experiments without an experimental control (Carey *et al.* 1989; Schauble *et al.* 1991), manipulate variables unsystematically (Tschirgi 1980; Schauble *et al.* 1991; Mayer 1999; Klahr 2000) draw illogical conclusions (Schauble *et al.* 1991; Hammann *et al.* 2006;) and state unproven causalities (Carey *et al.* 1989; Schauble *et al.* 1991; Hammann *et al.* 2006), often in line with their expectations, causing the impression of illogical reasoning (Chinn and Brewer 1998).

Science education research has dealt extensively with these problems and uses two major explanatory concepts: the confirmation bias and the engineering mode of experimentation. Firstly, confirmation bias is made responsible for the so-called 'theory-preserving responses', which are used by individuals to discount anomalous data, i.e. data that are in conflict with the students' beliefs, in order to protect a favoured alternative theory. In this aspect, confirmation bias can be understood as an individual's desire to maintain the concepts that have been found useful in the past. This research strand points towards using anomalous data as a means for promoting knowledge change in science students (Chinn and Brewer 1998).

Secondly, lack of knowledge about methods of scientific experimentation – or rather methodological student conceptions that differ from scientific methods of experimentation – is seen as another reason for these deficiencies. In a seminal study on children's understanding of the aims and processes of scientific experimentation, Schauble *et al.* (1991) showed that students often work within the so-called 'engineering mode' of experimentation, which is characterised by the goal of manipulating variables in an experiment in order to produce a desired effect, instead of systematically testing causal relationships between variables. The different purposes of experimentation also entail a different handling of methodological aspects. In particular, the positive testing strategy – the failure to seek disconfirming data – is premised upon the attempt to produce a desired effect. In contrast, the control of variables strategy and the inclusion of an experimental control – major principles in scientific investigation – are not used. Moreover, students in the engineering mode of experimentation often do not test hypotheses and plan inconclusive experiments (Schauble *et al.* 1991). Generally, this area of research points towards promoting students' methodological competencies, in particular explicitly teaching knowledge about the method of scientific experimentation (Carey *et al.* 1989).

Traditionally, both aspects, i.e. aspects relating to the content knowledge and to the method of experimentation, have been investigated separately. However, in the last decade, studies have increasingly dealt with the mutual interactions between them. Findings suggest that domain-general skills in practical experimentation such as designing unconfounded experiments or making valid inferences are biased by domain-specific knowledge about the biological area of research. In other words, methodological skills are influenced by students' conceptions of the object of investigation of the particular experiment (Klahr 2000).

2. AIMS

In this study, we investigated to what extent confirmation bias is rooted in students' conceptions about the method of experimentation. Chinn and Brewer (1993) briefly alluded to the possibility that beliefs about the method of experimentation might influence people's responses to anomalous data. However, methodological aspects of experimentation were only peripheral to their analysis of the factors that influenced confirmation bias. This was particularly evident in their taxonomy of eight possible responses to anomalous data (Chinn and Brewer 1998). The authors examined the influence of different beliefs, but methodological aspects were only included insofar as individuals were found to discover flaws in perfectly well-planned experiments in order to avoid explaining anomalous data. In the light of confirmation bias, a person's methodological knowledge – here, the person's critique of the experimental design – was interpreted as a theory-preserving response.

We undertook a more comprehensive analysis of the relationship between confirmation bias and students' conceptions of the method of experimentation. Against the background of research on the engineering model of experimentation (Schauble *et al.* 1991), students' conceptions about the method of experimentation can be expected to be an important source of their misinterpretation of anomalous data, perhaps even an important aspect of confirmation bias.

Defining the relationship between confirmation bias and methodological student conceptions has important ramifications for science education. On the one hand, light can be shed on the position that students' handling of anomalous data represents illogical reasoning. Chinn and Malhotra (2002) contrasted scientists' rational non-alignment with students' irrational non-alignment of interpretations with observation. However, students' rejection of scientific facts could still follow rational principles, provided that their reasoning follows an alternative rationality that differs from the scientific one.

3. RESEARCH QUESTIONS

This study investigated the question of whether confirmation bias is rooted in students' conceptions about the method of experimentation, in addition to the factors already described by Chinn and Brewer (1993). As a subordinate research question, we investigate why students assume cause and effect relationships between variables, even if the data reveal that the variables are independent.

We expected the students to be able to detect methodological flaws – e.g. lack of an experimental control – and to reject illogical conclusions on the grounds of their methodological knowledge, even if the false conclusions were supported by the students' beliefs. In cases where their methodological conceptions impaired their understanding of the experimental data, we intended to gain insights into the accompanying reasoning strategies.

4. PARTICIPANTS

Five grade 8 students from an integrated comprehensive school in Neumünster, in northern Germany, took part in the interviews. They comprised three boys and two girls (between the ages of 12 and 14) from the same class, who were chosen by their biology teacher. Selection criteria were willingness to participate, sufficient literacy and their parents' consent. Experimentation was one of a number of methods taught in their previous years of science education and had not been given special emphasis so far.

The small number of participants was due to the overall purpose of this study: the study was planned and conducted as a case study in order to gain qualitative insight into students' argumentation with experimental data and was used for the development of methodological training within an intervention study for enhancing student competencies. For this reason, this paper provides detailed descriptions of the argumentation of the five participants, which will be substantiated quantitatively in a separate study.

5. TEST MATERIAL

We conducted semi-structured interviews about four different experiments on seed germination in order to probe the students' understanding of experimental design. In contrast to previous studies, the probes in this study consisted of experiments with simple flaws – for example, the lack of an experimental control – in order to probe the students' abilities to identify built-in flaws. An interview guideline ensured that the same questions were used consistently in the different interviews. However, additional questions were used if necessary to probe the students' individual argumentations further. The biological topic of seed germination was chosen in order to address the students' confirmation bias. Previous tests of our research group have shown that grade 5 and 6 students possess rather strong beliefs about the factors that cause seed germination. In particular, many students believe that light is an important factor for seed germination, which is scientifically incorrect for most plants, e.g. broad beans. For this reason, the topic of seed germination appeared to be advantageous for the purpose of provoking confirmation bias in the participants.

5.1 The experiments in detail

As diagnosing errors in experimental designs requires methodological knowledge, our probes were intended to assess the students' methodological knowledge. Moreover, the probes used in this study contained instances of confirmation bias in pre-formulated conclusions in order to investigate students' argumentation strategies in response to it. Our probes thus differed from previous studies, which used tasks to elicit confirmation bias insofar as our students were confronted with confirmation bias in order to test their response to it. In particular, we asked the students whether they agreed with the conclusion containing a confirmation bias and encouraged them to explain it to us. In all cases, the probes contained experimental evidence necessary for correcting the misinterpretation of data.

In each experiment, the factors light, temperature, soil and water were used, but only temperature and light were varied in the different experiments. The first two experiments served as tests for the students' methodological knowledge, whereas experiment 3 addressed their beliefs about the causal factors of seed germination. The fourth experiment, which did not contain any flaws, allowed the final comparison between flawed and scientifically correct aspects of experimentation.

5.1.1 Experiment 1

Experiment 1 was set up without an experimental control (Carey *et al.* 1989; Schauble *et al.* 1991) and illustrated successful seed germination using the factors soil, water, light and a temperature of 22°C (Figure 17.1). The conclusion that 'the experiment worked' given in the description suggested that the production of the effect was the main goal of the experiment.

Students who accepted the experiment's design and agreed with the conclusion that a solitary experiment sufficed to determine the factors necessary for seed germination revealed that they lacked methodological knowledge about an experimental control and its logical function in an experiment.

Soil/water/
light/22°C

Figure 17.1 Experiment without an experimental control

5.1.2 Experiment 2

Experiment 2 addressed more specialised methodological knowledge, i.e. the control of variables strategy as the logical prerequisite for drawing unambiguous conclusions from experimental data (e.g. Tschirgi 1980; Mayer 1999; Klahr 2000).

The experiment contrasted two planting dishes in order to examine the question of whether bean seeds need both light and warmth for germination. Dish 1 was identical to the dish from experiment 1; dish 2 in contrast lacked the factors light and had a temperature of only 10°C (Figure 17.2). The experiment was confounded as two factors – light and temperature – were changed simultaneously, i.e. it was impossible to determine from the experiment which factor(s) caused the effect. However, the conclusion stated: 'It is clear now that the seeds need both warmth and light for germination.'

Students who accepted the conclusion and defended it with evidence from the confounded experiment lacked the methodological knowledge that it is necessary to control variables and were ignorant of the preconditions for drawing unambiguous conclusions from experimental data.

Dish 1 Dish 2

Soil/water/
light/22°C

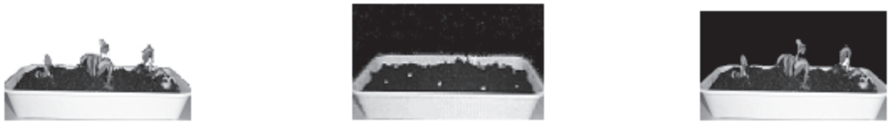
Soil/no light/
water/10°C

Figure 17.2 Confounded experiment

5.1.3 Experiment 3

Experiment 3 was designed to address the students' confirmation bias (e.g. Chinn and Brewer 1998), to have participants rethink their beliefs and to make their reasoning with confirmation bias visible. It consisted of three parallel experiments examining the question of whether both light and warmth are necessary for seed germination. Dish 1 again included all four factors, dish 2 differed in that it lacked light and warmth (6°C), whilst dish 3 lacked only light. In dishes 1 and 3, successful seed germination was illustrated, but in dish 2 there was no growth (Figure 17.3).

Dish 1 | Dish 2 | Dish 3



Soil/light/ water/22°C | Soil/no light/ water/6°C | Soil/no light/ water/22°C

Figure 17.3 Three parallel experiments with confounded and unconfounded features

The design of the experiment featured two special characteristics. Firstly, it appeared to present a false conclusion (Schauble *et al.* 1991), namely that light is necessary for seed germination, which supported the students' beliefs, but was not substantiated by experimental evidence. On the contrary, comparison of dishes 1 and 3 showed that germination is possible both with and without light, i.e. if the question is interpreted scientifically, it reveals this factor's irrelevance. The contrast between the students' beliefs and the scientific method was created deliberately in order to evoke the students' argumentation strategies when defending their preferred belief.

Secondly, the experiment contained both confounded and unconfounded comparisons, as dishes 1 and 2 differed in the two factors light and temperature simultaneously, whereas comparison of dishes 1 and 3 and comparison of dishes 2 and 3 differed only in one factor each. A valid conclusion would be based on the contrasting comparison of two experiments that differed only in the focal factor, whereas invalid conclusions related to confounded experiments. Thus, the experiment offered the opportunity to examine further the students' methodological knowledge about the control of variables and the logical requirements of conclusions.

5.1.4 Experiment 4

Experiment 4 was a flawless set-up with three parallel dishes also testing the question of whether bean seeds need both light and warmth for germination (Figure 17.4).

Dish 1 | Dish 2 | Dish 3

Soil/light/ water/22°C | Soil/no light/ water/22°C | Soil/light/ water/6°C

Figure 17.4 Flawless set-up of three parallel experiments

6. RESULTS

All participants revealed severe methodological weaknesses: none of them detected a missing experimental control; instead, all five drew conclusions on single variables from a solitary experiment.

The reasoning of two of the participating students corresponded to common aspects of students' experimentation, which have been described extensively previously (see Introduction). The other three students, however, namely Mike, Lisa and Claudia, revealed an alternative logical reasoning that included new aspects of students' argumentation with experimental data and will be discussed in detail. The basic principle of the reasoning will be introduced with examples from Mike's interview. Its ramifications will be discussed with reference to Lisa's interview. Claudia's argumentation, which exhibited the same way of reasoning, did not provide any new insights. For this reason – and for reasons of the limited length of this version of the paper – it is not included here.

In the presentation of the results, the main focus was on the students' argumentation with experiment 3, as this was best able to reveal the students' alternative reasoning strategies. However, the other experiments are included in order to develop further or clarify the characteristics of the students' rationality.

Mike's handling of the experimental data differed significantly from the scientific conventions. In experiment 1, he willingly accepted the effect-related conclusion and explicitly approved of the set-up without an experimental control. In fact, on being asked the question of what he thought about the experiment, he answered: 'Well, I find it quite good in order to see if it works.' This indicated that he lacked insight into basic concepts of scientific experimentation, but thought in terms of the engineering mode of experimentation.

In experiment 2, his ignorance concerning the control of variables strategy was revealed further. Instead of criticising the lack of explanatory power of the confounded experiments, which differed in both light and warmth simultaneously, he considered this comparison to be especially clear and meaningful because it contained an extreme contrast, i.e. both factors of interest that are assumed to be necessary for seed germination were included in one experiment and were excluded in the other.

> Interviewer: If you compare both items [experiments 1 and 2] with each other, what do you think is good in them and which one do you think is better?
>
> Mike: Well, personally I like this one [experiment 2] better, because she proved two things with it, I mean that beans need light and also a certain temperature, and also that they can't grow with no light with little temperature. He didn't do that, Ian [experiment 1], because he just did the one experiment and so just proved that they need water, light and warmth.

For Mike, the two experiments offered the opportunity of proving two different aspects independently, but they did not function as an experimental control in the systematic examination of the effect of one variable.

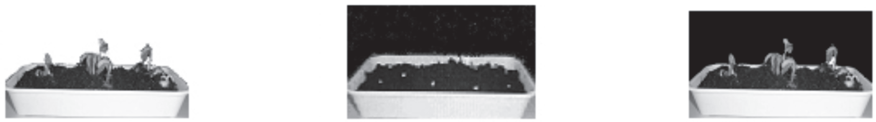
Whilst in light of this question alone Mike's argumentation seems problematic only in terms of the neglect of the control of variables strategy, Mike's reasoning with the evidence presented in experiment 3 revealed that his logic included further characteristics that were not revealed in his response to experiment 2.

In order to make Mike's alternative reasoning more accessible, it is necessary to recollect the basic principles underlying the design of experiment 3. Its purpose was to evoke the students' argumentation strategies in the light of their confirmation bias by addressing commonly held student conceptions directly. Essentially, the scientific interpretation of the experimental data differed from the given conclusion, which was based on commonly held student conceptions about seed germination.

Figure 17.5 on the following page shows the experimental results of experiment 3 and the conclusion of the fictitious classmate Tim.

In the previous argumentation with experiments 1 and 2, Mike revealed that he too believed in light being necessary for seed germination. As expected, in experiment 3, he followed the given false conclusion, which supported this belief. When asked to substantiate the conclusion with evidence

Dish 1 Dish 2 Dish 3



Soil/light/water/22°C Soil/no light/water/6°C Soil/no light/water/22°C

Tim's conclusion: 'The experiment shows that bean seeds need both light and warmth for germination'

Figure 17.5 Experimental design and conclusion of experiment 3

from the experiments, he used a reasoning strategy that differed significantly from scientific reasoning, but which allowed him to conclude that light is indeed a causal factor in the germination process.

In this strategy, which we called the 'principle of presence', Mike did not make contrastive comparisons between experiments that differed only in one variable, but he observed for each experiment separately which factors were present in 'successful' experiments, i.e. experiments in which the desired effect occurred, and which factors were absent in 'unsuccessful' experiments, in which the effect failed to occur. This approach neglects the possibility of a factor's irrelevance, as it does not include the observation of whether an effect occurs despite the absence of a certain factor. In the following excerpt, Mike explains the results of experiment 3, which are illustrated above (Figure 17.5), using the principle of presence.

> Mike: In dish 1, they germinated, because they just had light, water and 22°C. In dish 2, since they didn't have light and had only 6°C, well, nothing happened, because, I think, they had too little temperature, well only 6°C, and no light either. And in dish 3, they didn't have light either, but they had a temperature of 22°C instead, and that was just enough to make the beans come out of the soil then.

Thus, from dish 1 Mike concluded that light and warmth are necessary for seed germination as the effect occurred when both factors were present. He found this conclusion to be confirmed by dish 2 where the effect failed to appear when both factors were absent. The most interesting part of the argumentation, however, concerns dish 3. Here, the effect occurred in the presence of the factor warmth, although the factor light was absent. However, for a student who reasons according to the principle of presence, this experiment does not show the irrelevance of the factor light. Mike only observed that the effect occurred in the presence of the factor warmth, but he did not draw any conclusions about absent factors from this experiment. This was evident in Mike's final conclusion: 'Well, that actually shows that bean seeds need light as well as warmth for germination.'

Thus, Mike kept his beliefs about the relevance of the factor light intact because he attributed the effects to the factors present in the experiment but did not make inferences about the absent factors. For a scientific argumentation, however, one must distinguish between the test variable and the control variables, and one must be familiar with the convention that cause-and-effect relationships can be explained unequivocally only if the test variable alone is changed. Mike's misinterpretation derived from ignorance of the conventions and an alternative reasoning, but he did not deliberately ignore the scientific evidence in order to defend his beliefs in an irrational way.

He also continued to reason in terms of the principle of presence when asked to interpret the flawless experiment 4. This was remarkable as the experiment's structure offered even plainer scientific evidence for each factor's relevance: both factors (light and temperature) were present in dish 1 and then varied separately in dishes 2 and 3, which showed clearly the relevance of temperature and the irrelevance of light for the seed germination process. However, Mike again ignored the fact that light was absent in dish 2 although the effect occurred nevertheless.

> Mike: Well, in the first dish the seeds just germinated after 7 days, because they had just light and the 22°C, which they need. Then with dish 2 just without light, but again the 22°C and just warmth and so the beans have germinated then, and in dish 3 he had light, but no warmth and only 6°C and so the beans didn't germinate, because they need a certain warmth for germination. And well, the experiments show then that beans need that warmth in order to germinate, otherwise they don't come out of the earth.

Only when directed to the factor warmth by the interviewer who asked him to pay attention to all of the factors did he re-examine the evidence and come to the scientifically correct conclusion.

A further aspect of reasoning in the principle of presence was revealed in Lisa's interview. In experiment 3 (Figure 17.5), when asked to substantiate her conclusion that both light and warmth are necessary for seed germination, like Mike she concentrated on the factors present in successful experiments while ignoring the fact that the effect also occurred in darkness.

> Lisa: Well, it worked, you know. I mean in the third dish they germinated with no light and [with] warmth, and also in the first dish they germinated with light and with warmth and in the second dish then only, they didn't germinate then, and because there was no light and not enough warmth.

She overlooked the fact that according to the experimental evidence light cannot be the cause of seed germination (as the comparison of dishes 1 and 3 shows that the process is possible both with and without light) but concentrated instead on the factor warmth.

Apparently, the scientific argumentation was less plausible for her than the principle of presence, which prevented her from realising that the data actually opposed her belief. It took several inquiries from the interviewers before she found her belief to be refuted and she understood that light is irrelevant.

Besides its influence on a person's data evaluation strategies, her further argumentation suggests that the principle of presence might also have an impact on the planning of experimental designs: at the end of the interview, Lisa was asked whether she still considered experiment 1 to be well planned for examining the effect of the factor warmth. Surprisingly, she did not suggest an additional experiment, e.g. with a lower temperature, but she recommended simply repeating the experiment in darkness instead, justifying this decision with the recent cognition that light is not relevant for the process.

> Interviewer: He wants to find out whether warmth is necessary for germination. Do you have a quick tip now what he could do differently?
>
> Lisa: He could, well, hmmm, actually it didn't matter whether he had put the tray with the plants into the light or in darkness.
>
> Interviewer: So you would suggest the same again, only in darkness?
>
> Lisa: Well, yes, that he could repeat the same again, only then not in the light, but in darkness.

From a scientific view, the experimental design suggested by Lisa comes as a surprise: Lisa plans another experiment that leads to successful seed germination but that does not allow any conclusions concerning the factor warmth. Instead, the experiment contains all of the factors that are necessary for the process, given the insignificance of controlling the factor light. Bearing in mind that in the principle of presence the focus is also on factors present in successful experiments, Lisa might change the factor light just because it is irrelevant, i.e. in order not to impair the variable that is supposed to cause the effect.

Only when redirected to the focal variable, i.e. temperature, was Lisa able to focus on the factor temperature and to suggest the appropriate experiment that could serve as an experimental control.

7. DISCUSSION

The aim of this study was to examine possible relationships between confirmation bias and students' conceptions about the method of experimentation. Although the results of this study did not allow a person's confirmation bias to be attributed solely to their methodological conceptions, we found mutual interrelationships between a person's beliefs about the object of investigation and their conceptions about the method of experimentation. In our study, the students' understanding of the experimental data was guided by both their expectations about the relevance of the factors responsible for seed germination and their beliefs about the method of experimentation. We defined an unscientific, but nonetheless perfectly rational, reasoning strategy that we call the 'principle of presence', which entails students attributing effects to the factors that are present in an experiment and assuming cause and effect relationships between variables, although the scientific interpretation of the data reveals that such relationships do not exist.

The interrelationships between students' beliefs about the science content and about the method of experimentation suggest that both aspects need to be considered in science teaching. For instance, when experiments are used to illustrate important concepts such as seed germination, teachers need to consider the impact of methodological student conceptions and address student conceptions about the experimental method in order to support students' ability to interpret the experimental results. Likewise, when methodological knowledge and skills are being taught in practical experimentation, the role of individual conceptions about the scientific topic needs to be addressed. In particular, even if the students have made the connection that their beliefs influence their reasoning, the actual influence happens unconsciously, so that it is still difficult for both teachers and students to notice it in concrete situations.

The prevalence of the principle of presence in several instances in the interviews in which students were asked to interpret experimental data across different experiments suggests that the strategy is a fundamental element of the students' rationality that underlies their reasoning in experiments. It has been neglected previously because the principle of presence is hard to diagnose – for teachers and researchers alike. It leads only to unscientific conclusions if a factor's irrelevance is examined while the students believe in its relevance. If the factor under examination is relevant for explaining a phenomenon – i.e. the factor is present if the effect occurs and is absent if the effect fails to occur, like the factor warmth in this study – then the interpretation of the experimental data corresponds with the scientific interpretation. For this reason, the principle of presence can stay unnoticed quite easily, especially in school science where little time is usually spent on testing factors that the teacher knows are irrelevant.

Our findings complement research both on confirmation bias and on the engineering mode of experimentation. On the one hand, we suggest that students' conceptions about the method of experimentation affect their interpretation of data and should be considered as an additional factor when analysing students' biased responses to so-called anomalous data. On the other hand, methodological flaws associated with the engineering mode of experimentation (Schauble *et al.* 1991) can be understood more fully against the background of the alternative reasoning strategy described in this paper. In particular, the principle of presence explains why students focus on extreme contrasts between variables (Schauble *et al.* 1991). The students analysed in this study shed light on this because they contrasted the presence and the absence of variables in order to test their effects while ignoring the possibility of the factors' irrelevance.

A further comment needs to be made on the issue of whether the students' failure to seek disconfirmation can be rationally explained within the principle of presence. For a scientist, the positive testing strategy is criticised as an attempt to produce a desired effect because it fails to produce the evidence necessary for potentially refuting initial beliefs. Within the principle of presence, however, the presence of a factor while the effect occurs is considered as evidence for its causality, whereas the relevance of a factor's absence is only considered if it prevents the occurrence of the effect. Consequently, in the students' rationality, a single experiment is sufficient to explain all cause-and-effect relationships if the experiment contains all of the factors that are considered relevant for the production of an effect.

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5

Teaching: teaching strategies, teaching environments and educational technology

18 Towards understanding ecosystem behaviour through systems thinking and modelling

René H.V. Westra, Kerst Th. Boersma, Elwin R. Savelsbergh and Arend Jan Waarlo

CENTRE FOR SCIENCE AND MATHEMATICS EDUCATION, UNIVERSITEIT UTRECHT, UTRECHT, THE NETHERLANDS

r.h.v.westra@phys.uu.nl

This paper reports on the development of a learning and teaching strategy that contributes to students' systems thinking and modelling, and aims at understanding ecosystem behaviour as derived from a modern complex and dynamic view of the concept of ecosystem. In our strategy, we use a concept–activity–context approach, where a context is defined as a social practice. A problem-posing approach was used to keep the students willing to participate in the learning activities. The learning and teaching (LT) strategy was developed by means of developmental research. Throughout two field tests, the LT processes were monitored in detail. The design of the LT sequence was structured by three contexts in which the complexity and dynamics of ecosystems played an important role. The results showed that students were aware of similarities and differences between the levels of organization of organism, population and ecosystem. They understood the factors that were important for and the mechanisms of their influence on the quantities being focused on in ecosystems. Most students were able to explore the required computer models. However, for most of them it remained problematic to build models themselves and also to describe the nature of the relationships between factors, to quantify these relations and to validate the outcomes of their models.

1. RATIONALE AND OBJECTIVES OF THE STUDY

1.1 Learning aims and relevance for high-school biology

Secondary education should provide a basic understanding of ecology as a preparation for further study, as well as for citizenship. From a citizenship perspective, ecological viewpoints play a role in public debate about land use, large-scale fishing, sustainability, climate change and so forth (Carlsson 1999).

The traditional treatment of ecology in upper secondary school has a strong focus on static aspects, whilst providing a limited view of dynamics as reversible fluctuations around an equilibrium state, superimposed on a development towards a climax system. In the light of modern views on ecosystem behaviour, this representation falls short as a basis for well-informed decision-making about the issues mentioned above. In order to become 'ecologically literate', students have to be aware of these modern views.

1.2 Research question

The challenge of our study was to select several ecosystem-related practices – in the sense of authentic practices or social practices, in which participants perform goal-directed activities, using knowledge, symbols and tools, and sharing meanings and values (Edelson and Reiser 2006) – that were transparent enough for students to carry out meaningful systems thinking and modelling in order to grasp the dynamics and complexity of ecosystem behaviour. Thus, the following research question was consequently asked: How can ecosystem behaviour be taught through modelling and systems thinking in authentic practices?

In order to answer this question, we used the method of a validated learning and teaching (LT) strategy. In accordance with the above, this strategy had to meet the following criteria:

1. It had to provide a valid representation of modern ecological insights.
2. For systems thinking and modelling:
   - Students should concepts from systems theory to clarify the situation at hand.
   - Students should explore/build a computer model to represent the situation, generate predictions about the situation and interpret these outcomes correctly.
3. For problem posing and authentic practices:
   - Students should be motivated to solve the problem in hand.
   - Students should use the demands posed by the practice problem to guide their problem-solving process and to evaluate their outcomes.
   - In moving from one practice to another, students should make productive use of conceptual knowledge from one practice to the next

The chosen criteria will be described further in the following paragraphs.

1.2.1 Modern views on ecosystem behaviour

For a long time, one of the difficulties with the study of ecosystems was that their behaviour was not in accordance with frequently used cybernetic models. However, during the last few decades, understanding of the complexity and dynamics of ecosystems has increased considerably, as its behaviour can be described and understood by means of the dynamic systems theory and can be modelled with computers. Ecosystems are considered to be open and complex adaptive systems, in which the parts (populations, functional groups of populations and abiotic factors) influencing themselves and each other in non-linear ways, giving rise to dynamic patterns over time (Townsend *et al.* 2003).

1.2.2 Conceptualising ecosystem dynamics through systems thinking and computer modelling

It is not enough to rewrite a chapter in biology textbooks to introduce ecosystem dynamics.

Many students appear to have problems in understanding complex and dynamic behaviour and predicting changes that will occur in an ecosystem, e.g. when some external factor ‘disturbs’ it (Munson 1994; Magntorn and Helldén 2003).

In order to use modern ecological theory productively in a concrete ecosystem, one first has to establish a match between this ecosystem and the theory. In a broad sense, this process can be referred to as ‘modelling’, stressing the process of redescribing and reducing the concrete ecosystem. It has been claimed that systems thinking and computer modelling could help students to gain a productive understanding of ecosystem dynamics (Hogan and Thomas 2001; Westra *et al.* 2005).

Systems thinking can be helpful in directing attention at particular features of the ecosystem such as the distinction of hierarchical levels, feedback and temporal delay, which cause dynamic, often cyclic, but sometimes chaotic patterns, or open versus closed systems (Booth Sweeney and Sterman 2000). Research suggests that students learn more about systems behaviour by building or using computer models than by simply creating static depictions of systems relationships (Kurtz dos Santos and Ogborn 1994). In our view, modelling is an essential part of systems thinking. Models draw on a number of theories to help understand a specific problem, arising in a particular setting or 'context'. They never contain all of the features of reality, only those that are essential for the specific problem.

Computer modelling is attractive from a didactic point of view, as it may depict the changes occurring in a complex, dynamic ecosystem, caused by internal or external factors. A computer model can be started, stopped, examined and restarted under new conditions in ways that are impossible in the real setting (Holland 2000).

1.2.3 Sustaining student involvement and creating flexible knowledge by using a problem-posing approach with authentic practices

Our approach differs in some respects from more traditional context-based approaches. In those approaches, a context is defined as a situation, and is used to relate concepts to prior knowledge acquired by students in their social environment. In considering concepts apart from contexts, rather than as embedded in contexts, it emphasises only the didactical meaning of contexts. If it is accepted that a concept is situated in a context (Henessy 1993; Wenger 1998) and that its meaning is at least to some extent determined by it, it makes no sense to select concepts and contexts independently. We therefore prefer to select concept–context combinations.

According to the activity theory (Vygotsky 1978; Engeström 1991), contexts are defined as social practices in which participants perform goal-directed activities, using knowledge, symbols and tools, and sharing meanings and values. Furthermore, a situated perspective implies that biological concepts may have different meanings in different social practices. As the aim is for students to acquire concepts that can be used in different social practices, they should learn to recontextualize (Van Oers 1997, 2001) concepts in new social practices (Figure 18.1).

For education to be effective, it is important that students should be willing to participate in the learning activities. As a concrete didactical strategy to attain this, we have adopted the problem-posing approach (Lijnse and Klaassen 2004). This is a didactical strategy that aims to involve students actively in the learning process. The claim is that students participating in an LT unit that is structured according to this approach will always know what they are doing, why they are doing it and how they are going to proceed. This claim is elaborated by focusing on the development of the student's general and local motives. The general motive concerns the desired learning outcomes; the local motives concern the participation in the next learning activity. In most studies, the general motive is expressed in a general steering question that can be answered after completion of the LT unit. The general

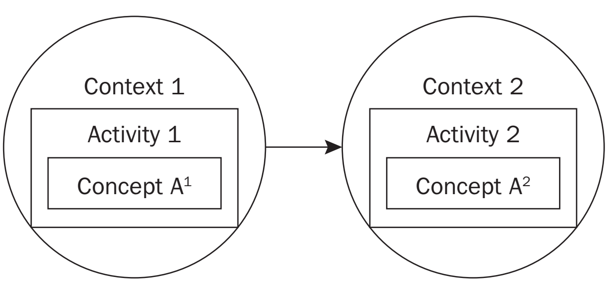

Figure 18.1 Relationship between scientific concepts, activities and contexts according to a concept–activity–context approach. A^1 and A^2 refer to different conceptions of concept A

steering question leads to the first learning activity. Generally, an LT unit consists of a number of problem-posing cycles, each consisting of a questioning phase, an activity phase and a reflection phase. In the reflection phase, students reconsider what has been done, answer the partial question, make up their mind and look forward to the next learning activity.

2. RESEARCH APPROACH

In our study, an LT strategy was developed using a developmental research design (Figure 18.2). In developmental research (or design research, e.g. Cobb *et al.* 2003), theory-driven, creative and practicable solutions to LT problems are designed in iterative consultation with experienced teachers. Researchers and teachers cooperated in testing the developed LT strategy in classroom settings (Lijnse 1995). In the explorative phase, literature was studied, data were collected on the state of ecology education in secondary schools and ecologists were consulted to acquire updated knowledge of ecology and ecological research. Based on the data and insights acquired in the explorative phase, three research cycles were planned. Each cycle consisted of the following sequence of research activities:

1. Development or adaptation of an LT strategy, based on data and insights collected previously.
2. Elaboration of the LT strategy in a scenario that describes and justifies in detail the LT activities and expected learning outcomes.
3. Development of LT materials, based on the scenario, by testing the LT materials and the scenario in classroom, with extensive data collection, including questionnaires, notes, sketches and computer models from the students, transcription of all audio and video recordings and analysis of all data.
4. Focusing on deviations in the scenario per LT activity and finding explanations for it.
5. Determining the required adaptations of the LT materials, the scenario and the LT strategy.

Ideally, research cycles were planned until further development of the LT strategy no longer resulted in better learning outcomes. In practice, two or three cycles resulted in a satisfactory final LT strategy.

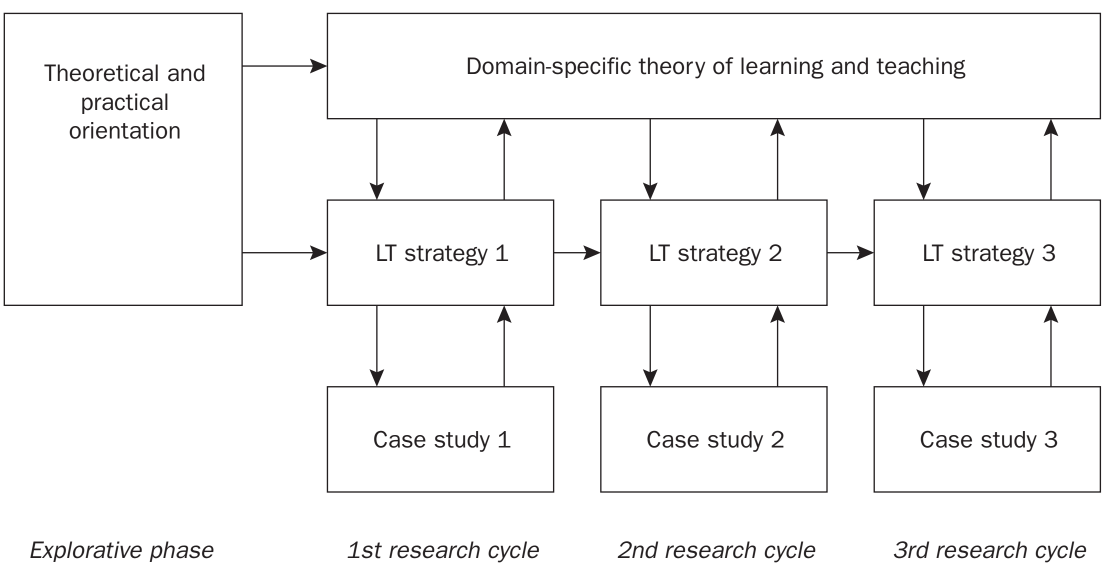

Figure 18.2 Design of developmental research (after Boersma *et al*. 2005)

The first cycle of the LT strategy was field tested in four 5VWO (A level, 16–17 years) classes in 2004. The second cycle was tested in two classes in 2005. The results of these tests are presented in this paper. The LT strategy will be tested in a final cycle in the future.

3. THE LT STRATEGY

3.1 Selecting appropriate authentic practices

A practice needs to show the complexity and dynamics of an ecosystem. Therefore, it is necessary to study the quantitative development of such a system over time, in which selected organisms or populations are transformed by various factors and influenced by each other and/or by factors from outside the system. In order to recontextualize the initial conception of the concept, it will be necessary to introduce more practices.

As a first practice, we selected some ecological research of the NIOO (Netherlands Institute of Ecology) on optimization of the yield (dry weight in grams) of mussels in the Easter Scheldt estuarine, on behalf of local mussel breeders. This research was interesting because of its economical interest and human impact. It also allowed the development of an initial concept of an ecosystem with reduced complexity, as it concerned only one (mussel) population and the most important biotic and abiotic factors influencing it. One of the activities of the NIOO researchers is computer modelling, because it is too time-consuming and expensive to test the dynamics of the population in practice.

As a second, more complex practice, we chose a nature management context of a non-recovering rabbit population after an epidemic in a water resource area in the dunes. Again, this practice called for computer modelling, where the context was even more complex.

Finally, we used a third practice about the management of an expanding population of elephants in Africa to assess students' understanding of ecosystem behaviour. This context has much in common with the second in terms of complexity, but was less familiar to the students.

It will be evident that the purpose of the introduction of the three contexts differed: the first was used to acquire an initial conception of the concept of ecosystem, the second for extending the initial conception into an extended conception, and the third for testing the student's abilities to use this extended conception in an unfamiliar context. This practice was only used as a test: the introduction of an article about the practice, followed by a number of questions that had to be answered. No computer modelling was involved. In this paper, the results of the test are not discussed.

Figure 18.3 shows the sequence of concept–activity–context combinations of the LT strategy. Each change of context required recontextualization.

3.2 Problem-posing approach

In our LT strategy, two problem-posing cycles were defined, coinciding with the first and the second context. In these two cycles, the reflection phase was used to conceptualize the models, resulting from the student's computer-modelling activities, towards the various conceptions of the concept ecosystem.

3.3 Systems thinking

In the first context, students started studying a mussel (organism level) and participated in a number of computer-modelling activities at the organism, population and ecosystem level. In the second and third contexts, the students alternated between the population level and the ecosystem level. By conceptualizing the student's computer models in the reflection phases, the levels of biological organization were made explicit. Furthermore, their behaviour as an open, dynamic system was discussed.

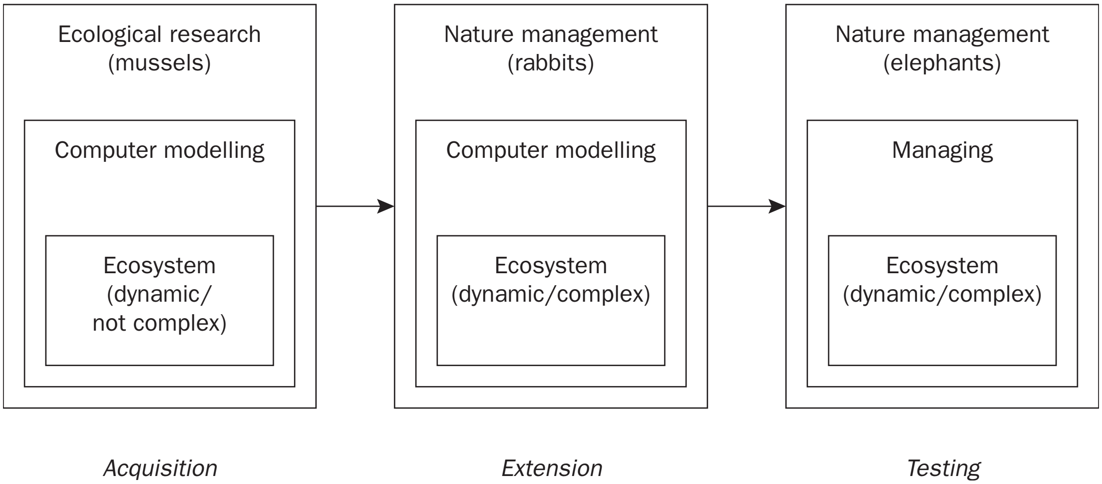

Figure 18.3 Sequence of concept–activity–context combinations in the LT sequence and their functions

3.4 Modelling

For computer modelling, Powersim Constructor Lite, a graphic modelling tool, was used. Graphic tools appear to be more suitable than text-based tools, especially for students who are not very skilled modellers (Löhner 2005). In a graphic modelling tool, students do not start using a programming language with different types of formulas. Instead, they sketch a model. This results in a screen showing an overview of the relevant factors and the relationships between those factors (Figure 18.4). The resulting model is suitable for exchange and discussion. After the construction of the structure of the model, values and formulas are inserted. The required mathematics are quite easy to handle and less prominent than in text-based models. Students are able to construct, evaluate and adjust their model.

Earlier experiments using modelling with Powersim, together with the results of the first test of our study, showed that students have difficulties in relating the abstract Powersim model to a concrete biological object, in this case the mussel. Inspired by the emergent modelling structure for the

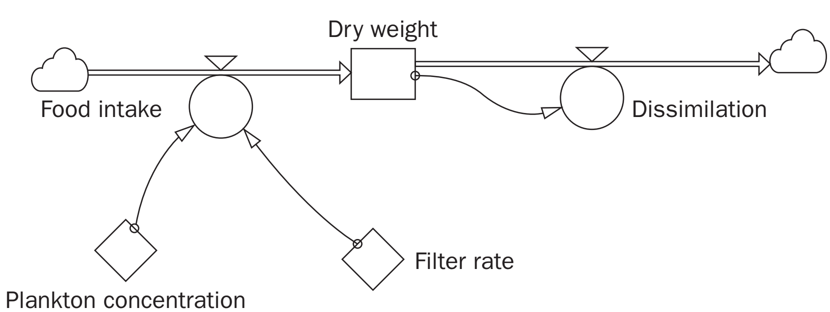

Figure 18.4 A Powersim screen of one of the models used. In Powersim, a rectangle symbol is used for a stock to which something can be added or subtracted, a circle for a variable, being dependent on some other factor(s), and a rhombus for a constant that is not dependent on some other factor(s)

development of mathematical reasoning (Gravemeijer 1999), it was decided to distinguish the following sequence of modelling steps:

1. Practical assignment with a biological object, the mussel.
2. Representation of the mussel as an open systems model with a system border, input, throughput and output.
3. Reconstruction of the open systems model of the mussel in a qualitative Powersim model.
4. Elaboration of the qualitative Powersim model into a quantitative Powersim model.

An overview of the didactical structure of the LT strategy is presented in Figure 18.5; it shows how didactical structures for systems thinking and modelling and the problem-posing approach are embedded in the concept–activity–context approach.

4. RESULTS

The results are presented using the three criteria that were described in section 1.2. Authentic citations or other results used are coded as FT (first test) and ST (second test), and with a number marking the actual lesson out of a series of 9. A symbol was added (see Table 18.1) to show the method used to record the results. For example, FT-3C means that citations that were recorded in the third lesson of the first test.

4.1 Modern ecological insights

In our LT strategy, we introduced the dynamics of an ecosystem by using computer models in which the quantities of importance (dry weight of an individual mussel, density of a population of rabbits) varied over time. In both tests, students appeared to be able to understand the influence of changing environmental factors, such as the varying amount of food or the varying numbers of predators.

4.2 Systems thinking and modelling

Students were able to detect a number of factors that influenced the development of a mussel. They were also aware of the relationships between these factors and the mussel, and the mutual relationships:

> Teacher: What factors did you enter in your scheme with the mussel?
>
> Marjeleine: Sea currents.
>
> Teacher: Do they influence the mussel?
>
> Marjeleine: Yes.
>
> Teacher: What else?
>
> Jessie: A sufficient amount of algae.
>
> Teacher: Any more?
>
> Edwin: The presence of other marine animals.
>
> Teacher: Why?
>
> Edwin: Well, like crabs and starfish, they eat mussels.
>
> Lisanne: Food, temperature of the water – they cannot live in cold water, I think. Also depth.
>
> Teacher: Why depth, does a mussel need light?

<table>
<tr><th></th><th>Concept–activity–context</th><th>Phases of the problem-posing cycle</th><th>Systems thinking (levels of biological organization)</th><th>Nature of modelling activities</th></tr>
<tr><td rowspan="7">Acquisition</td><td rowspan="7">Ecological research (mussels)
Computer modelling
Ecosystem (dynamic/ not complex)</td><td>Questioning phase</td><td></td><td></td></tr>
<tr><td rowspan="5">Activity phase</td><td rowspan="3">Organism</td><td>1. Biological object</td></tr>
<tr><td>2. Open systems model</td></tr>
<tr><td rowspan="3">3. Powersim model</td></tr>
<tr><td>Organism</td></tr>
<tr><td>Ecosystem</td></tr>
<tr><td>Reflection phase</td><td></td><td></td></tr>
<tr><td rowspan="4">Extension</td><td rowspan="4">Nature management (rabbits)
Computer modelling
Ecosystem (dynamic/complex)</td><td>Questioning phase</td><td></td><td></td></tr>
<tr><td rowspan="2">Activity phase</td><td>Population</td><td rowspan="2">3. Powersim model</td></tr>
<tr><td>Ecosystem</td></tr>
<tr><td>Reflection phase</td><td></td><td></td></tr>
<tr><td>Testing</td><td>Nature management (elephants)
Managing
Ecosystem (dynamic/complex)</td><td></td><td>Organism/population and ecosystem</td><td></td></tr>
</table>

Figure 18.5 Didactical structure of the LT sequence

Table 18.1 Codes for the various types of registration

Type of registration	*Video- or audiotaped citations*	*Text or drawings on worksheets*	*Interview with students*	*Questionnaire*
Symbol used	C	W	I	Q

Jop: No, but phytoplankton does.

Edwin: The soil, the currents.

Jop: Currents do influence the soil, I think? And I think salt content, especially near the coast.

(FTC-2)

In the first test, most students had difficulty with the idea that an organism can be seen as an open system, with selective boundaries. When confronted by their teacher with this systems idea in the concrete situation of an individual mussel, most of them were able to give accurate descriptions of factors that could or could not pass these boundaries. In the second test, we asked them to draw arrows from factors that c could or could not pass the borders of the system. Most were able to draw correct arrows and give correct descriptions for various factors moving to or into a mussel, or a population, or an ecosystem.

Erik: The boundary of the mussel can be passed by water, food (in) and waste products (out). The border of the Easter Scheldt can be passed by the sunlight (in), water (in and out to and from the North Sea).

However, not everybody agreed:

Jonna: Water and food can pass the border of the mussel (in) and waste products also (out). But there are no arrows that can pass the border of the Easter Scheldt.

(STW-2)

We started with models at the individual level. Students understood the transfer to the population and ecosystem levels, and could name factors that were specific for one level. They also understood the influence of factors in population and ecosystem levels on lower levels:

Teacher: Which factors are specific to the population level?

Iris: Competition for algae, reproduction.

Teacher: And what is the effect of introducing more mussels?

Hilde: The higher the density of mussels, the less each mussel can eat

(STC-4)

They could tell that when birds forage on mussels, this has a negative effect on the density (population level), but a positive effect on the dry weight of the remaining mussels (individual level). However, not everybody agreed that this was positive:

> Fabian: The more mussels are eaten by the birds, the better for the remaining individuals. Their dry weight increases.
>
> Josine: Oh, but what is the benefit of that for the eaten ones?
>
> (FTC-7)

Students were able to use the organization levels they had learned in the first context and were aware of the starting level in the second one, which was the population of rabbits.

Most students were able to explore computer models and to derive new biological implications from their models. They were able to express ideas about effects on the individual, population or ecosystem level. They seemed to be aware of (quantitative) effects of, for example, the population level at an individual level. However, when it came to designing and implementing their own models, students still experienced difficulties. In particular, finding out what factors to implement into the model, introducing formulas in relationships between factors and validating were difficult.

In the first test, we discovered that most students did not link their modelling activities to the 'real world'. Some of them made a mistake in a formula, which nevertheless resulted in a 'running' model, but which lead to the dry weight of a mussel being more than 1 kg, without the student being perturbed. Part of this difficulty may have arisen from their being focused on creating a running model. Once this goal had been established, the students were satisfied. However, a deeper obstacle may be that the students do not perceive the biological world in terms of numbers; for instance, in the first test, they did not have any expectation on a plausible range for the dry weight (i.e. the biomass) of a mussel. Thus, in the second test, we introduced a weighing activity, in which the students could determine the actual dry weight of mussels. This resulted in questioning of their models when the outcome was far too high. In fact, students asked the teacher what to do, because their model did not fit with reality.

The students had serious problems constructing models completely by themselves. In the first test, they seemed not to know where to start at all when they had to construct a population model, starting with a ready-built model of an individual mussel. Thus, in the second test we offered them the various factors that were needed in the model as a sort of jigsaw puzzle. This resulted in the majority of the students successfully constructing a qualitative model. The next step, formalizing the relationships in this model to be able to make it quantitative, was still problematic. Most students could not decide between multiplying, dividing, adding or subtracting two factors that influenced a specific process.

In the more complex ecosystem of the rabbits, as in the first test, the students had difficulties constructing the models themselves. This resulted in intense activities, but no working models. Thus, in the second test, we constructed some complex models ourselves, stressing exploring and understanding what was happening to the rabbits in the dune reservation. In this situation, most students were able to explore these models, but a large number still did not relate their findings to the 'real world'. When asked, they said that they acted automatically.

Nevertheless, on reflection, the students described the value of modelling as making it clearer how nature works over a particular time scale and the advantages of using a model first.

However, most of the students did not think that these models were adequate for use in 'real world' situations, as in their view the models were not complex enough.

4.3 Problem-posing approach and authentic practices

In the first test, the initial enthusiasm of the students declined. Their interest in the mussels was not enduring, and in retrospect, they would have preferred to move on to the second (rabbit) context earlier. In addition, they were confused about the practice, as it was in fact a mixture of two practices: that of mussel breeders and that of NIOO scientists.

Thus, in the second test, we started by making it clear that in the first test we were concentrating on the NIOO scientists' problem: how can the mussel culture be optimized, taking into account all kinds of interfering factors? And we questioned the choice of investigating mussels first. The students argued that the mussel context was not as complex as that of the rabbits. In an evaluation, 55 per cent of the students agreed with the decision to start with the mussels (STQ-1). After this discussion, there were no further complaints about the order of introduction. In addition, there was no longer any confusion about the practice: the students understood the role of the ecological scientists.

Even if the students had become interested in the subject, there still appeared to be many points where their level of involvement faded away. There are various critical steps in the LT strategy that require explicit attention and reflection in order to keep the students involved. In particular, the students had difficulties during the activity phase and reflection phase. To maintain a relationship between computer modelling and the 'real world', in the activity phase students' activities were not just modelling activities, but also activities with real mussels, such as drawing their food tract.

Thus, in the second test, we repeatedly stressed in the reflection phase the 'leading question': 'Can we go back to the mussel breeders with our results, and if not, what do we have to investigate more?' We also asked: 'Can we use what we have learned at the organism level at the level of the population?'

The students understood and valued the more complex practice of the dune management people, the difference from the mussel practice and the value of the modelling activities.

The students demonstrated, in the questioning phase, their understanding that in this case the focus was not on the individual but at the population level, and that a different time scale was needed.

> Teacher: How long was the time scale in the model about mussels?
>
> Jop: 550 days.
>
> Teacher: And in this model with rabbits?
>
> Daan: 10 years.
>
> Teacher: Why is that?
>
> Stefan: Rabbits live, on average, longer. And they will reproduce. The mussels are just dumped in the Easter Scheldt. This reproduction takes time. With the mussels, you do not have to look so long, because they do not live long and after these 550 days, they are just harvested.
>
> Teacher: But a rabbit does not live for 10 years, does it?
>
> Stefan: No, but the population does.
>
> Teacher: And the mussel population?
>
> Stefan: Well, the mussel population, the difference is, the rabbits are just part of nature, people do not take them out, but mussels, they are dumped and later harvested, but the population does not reproduce itself there.
>
> (FTC-7)

5. CONCLUSIONS

The use of authentic practices, combined with a problem-posing approach, systems thinking and modelling, seems promising in giving students an idea of the dynamics and complexity of ecosystems. They understand the usefulness and meaningfulness of their activities, but only if they are well aware of what they are doing, why and the significance of the order of the activities. These scenarios, the LT strategy and the LT materials will be adapted for use in the third test. In particular, the modelling part needs more attention, because students still have major problems constructing models, validating them to 'real-world' situations and using the modelling syntax in new situations.

For the third test, we are planning to make smaller steps in modelling activities and to put more emphasis on exploring, creating more time for gaining insight into the dynamics and complexity of ecosystems, at the cost of losing insight into the exact (mathematical) background of the processes. In addition, we will use more time for reflection on the models and their relationship to the real world.

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19 The interplay of context and concepts in primary school children's systems thinking

Rosemary Hipkins, Ally Bull and Chris Joyce

NEW ZEALAND COUNCIL FOR EDUCATIONAL RESEARCH, WELLINGTON, NEW ZEALAND

rose.hipkins@nzcer.org.nz

There is growing recognition of the importance of helping children to develop the ability to think about biological and environmental issues in terms of systems interactions and impacts. Several progressions have been published that suggest how their conceptual understandings may develop over time. However, these are not necessarily as informative for teachers as they are for researchers or specialist resource developers, nor do they take account of 'moment in time' interactions between an individual's contextual and conceptual knowledge. This research aimed to develop examples to support assessment for learning by helping teachers to recognise students' next learning steps in relation to interactions between the components of an ecosystem (both conceptual and contextual) with which the children had varying degrees of familiarity.

1. INTRODUCTION

This paper describes an exploratory investigation of one aspect of children's systems thinking. Assaraf and Orion (2005) identified this as an important type of thinking to develop if science learning is to prepare students to become responsible citizens – an outcome that most science education researchers would surely see as important. The 'Science for All Americans' project also identified systems thinking as one of the most powerful ideas in science and recommended beginning the development of an understanding of systems from the kindergarten grade (Rutherford and Ahlgren 1990).

Developing an understanding of important biological and environmental issues requires children to have opportunities to learn about systems interactions and impacts (Assaraf and Orion 2005). Learning about systems, in turn, challenges educators to help children experience the real-world stories behind conceptual knowledge (Mayer and Kumano 1999), i.e. to bring contextual and conceptual knowledge into a rich interplay with each other. Mayer and Kumano (1999) recommend more field work, a focus on *both* parts and wholes, and greater attention to narrative and contextual description. The latter is a challenge that can easily be overlooked (Hipkins 2001), as curriculum planning traditionally focuses on 'facts' (or perhaps concepts) to be learned. But how does such *content* development interact with children's knowledge of, and familiarity with, the *context* of the system in question?

1.1 The potential of ecosystems as a study topic

Ecosystems is a commonly studied topic in the New Zealand primary school curriculum and hence provides an opportunity to explore children's systems thinking in a familiar type of learning situation.

Field trips to the ecosystem of choice are typical and traditional components of the learning provided. Studies of the rocky shoreline, or of one of the many rivers and streams that cut across the geologically active land, are perennial favourites. The latter context is well supported by a resource called 'Waterways', managed by the Royal Society of New Zealand. This resource aims to promote proactive care of our rivers and streams, by direct actions such as riparian planting and water-quality monitoring, as well as by educating children about these environments as dynamic but vulnerable ecosystems.

This topic provided the research team with an opportunity to investigate the interaction between growing contextual familiarity with a waterway and children's understanding of the targeted concepts of direct and indirect relationships between components of the chosen ecosystem. One emphasis of the resource is on understanding and an awareness that what you do as an individual may impact on a waterway out of your sight (for example, putting toxic substances such as oil or paint in street-side storm-water drains, which in New Zealand tend to enter waterways without first passing through treatment plants, in contrast to grey water and sewage). Here, one action could begin a series of events, some of which might be predicted if relationships between physical water quality and the living things in the ecosystem are understood. Effects that flow on from the initial perturbation also require an understanding that change to the population of one living thing can impact on other species. Typically, children first encounter this in the systems concept of food chains, and these too are a common focus of ecosystem learning in the New Zealand primary school.

1.2 Challenges for supporting the development of systems thinking

Several progressions have been published that suggest how, given appropriate learning experiences, an understanding of systems interactions may develop over time. Assaraf and Orion (2005) proposed eight stages in the conceptual development of children's systems thinking, whilst the American Project 2061 proposed four broadly similar stages of development (American Association for the Advancement of Science 1993). Assaraf and Orion's first level is 'naming parts and processes'. Next, they specify the identification of 'processes that create relationships between parts'. Feeding relationships would probably be a simple beginning point for developing this concept in the context of a waterway as an ecosystem. Third comes 'building up a framework of relationships' such as food chains and webs. The fourth step of the progression is 'making generalisations about relationships', for example knowing that all food chains must start with a plant. Next comes 'understanding that some relationships can impact on other relationships' – the 'indirect relationships' component of the waterways resource. The sixth step is 'knowing there can be hidden dimensions that affect the system', for example the role of microscopic decomposers, or, in a waterway, microscopic producers. The final stages have temporal dimensions: 'understanding that many systems go in cycles' and 'recognising that systems can change over time, sometimes slowly and sometimes quite quickly'. At every stage, rich contextual knowledge is added, and many more possible links can be identified, along with increasing complexity of concepts.

With the level of detail to be remembered, such progressions may not be as informative for teachers as they are for researchers or specialist resource developers. Furthermore, whilst these indicators of progression are certainly helpful, the explicit focus is largely on concepts, once the necessary contextual groundwork has been laid. However, teachers need to be able to relate ideas about progression to the actual work children produce, and such work seldom fits neatly into pre-planned categories; indeed, it is likely to show messy contradictions between conceptual understandings and contextual familiarity. In any case, if children's work is to provide evidence for making judgements about next learning steps, as is widely proposed in the formative assessment literature (see, for example, Black and Wiliam 1998), the *learning* implications must be the teachers' decision-making focus. However, this intent may be easier said than realised, and has been seen by some as the 'Achilles' heel' of the formative assessment reforms (Olson 2005). With limited time and a whole class to attend to, the teacher needs accessible, practical curriculum guidance that allows planning for the whole class, not just for each separate individual (unless the class is exceptionally small). Producing such practical advice was the focus of this research.

1.3 The research questions

This paper describes an investigation of Year 7 and 8 (ages 10–12) children's ideas after taking part in the Waterways project. The researchers worked with one classroom teacher to explore the following questions:

1. Are there identifiable patterns in ways children express their understanding of relationships between the components of a familiar ecosystem in drawing and in words?
2. Is there evidence that their contextual knowledge about the ecosystem interacts with their level of conceptual understanding of relationships?
3. Is it possible to identify helpful next learning steps that take account of any such interactions, whilst still providing practical teacher guidance on supporting children to extend their learning?

2. METHOD

The method used to address these questions was itself 'strongly influenced by systems theory' (Boulter *et al.* 2003). The researchers explored how children's personal narratives about an ecosystem and its component parts (their contextual knowledge) interacted with their learning about *relationships* between the components of that ecosystem (their conceptual knowledge). The findings reported here are part of a wider study that investigated a range of teaching strategies and assessment questions. The focus here has been narrowed to one class, and indeed largely to three students in that class, so that the complexity of concept/context interactions can be described in some detail.

2.1 Research tools

Following a method described by Assaraf and Orion (2005), the children in one chosen class (around 25 students in total) added details to a simple outline sketch that represented several familiar elements of a stream and its surroundings (see figures below). The children also wrote answers to three short questions about relationships they could see in their drawings:

1. From your picture, describe a relationship between two things in the water.
2. From your picture, describe a relationship between one thing on the bank and one thing in the water.
3. Describe some ways human activity can upset relationships in and around this waterway.

This phase of the research produced sets of drawings annotated by the children, with accompanying answers to the short questions. A small sample of students was subsequently interviewed by two of the researchers. They talked about what they had learned and why they had drawn what they did. These interviews added useful additional insights into the children's thinking at the data analysis phase.

2.2 Data analysis

Each child's drawings and written responses formed one data set. Using the available progressions as a broad theoretical reference, the researchers explored various ways of grouping the children's responses to identify characteristic indicators of the overall level of understanding of concepts and awareness of contextual detail that each child showed. The researchers' emergent reasoning was checked against what the interviewed children had said, and later checked with the classroom teacher, who had a much better knowledge of the children as individual learners.

The analysis revealed mismatches between children's conceptual understanding and their familiarity with (ability to describe in words or images) the context of the waterway. At first, the individual data sets seemed to comprise a bewildering array of idiosyncratic narratives, combining concepts with varying contextual detail in as many different ways as there were participants. After some hours of intense exploration of different suggestions for patterns, the researchers finally identified three broad types of understanding amongst the children in the group. These are illustrated below, using the work of three specific children.

3. HOW CONCEPTS AND CONTEXTS INTERACT IN CHILDREN'S WORK

Although existing research on progression informed the analysis, the focus here was somewhat different. The researchers wanted to know how concepts and contexts interacted in this ecosystem, at this moment in time. Thus, an important caveat to the descriptions of the three broad patterns that follow in section 4 is that the researchers saw these as snapshots of learning, at this point in time and in this context, and not necessarily as indicators of some overall forward progress or 'development' that each child had made. Whilst in-the-moment and overall learning development are obviously not unrelated, the focus here was to find ways to support teachers as they make formative comments that prompt each child to focus on what to attend to next, not to report on overall learning progress over time.

3.1 Emergent awareness of the components of the system

Some children produced busy pictures, seemingly impressive at first glance, that actually gave very little indication that they understood the concept of relationships between the naturally occurring components of an ecosystem. Figure19.1 illustrates this with Leona's drawing. It was accompanied by the following written ideas about relationships:

1. The duck feeds on the bread.
2. The sheep drinks the water.

In response to the third question about the impact of human activity on relationships, Leona (aged 11) again had plenty of ideas to share. Connections between human actions and possible impacts on the naturally occurring components of the ecosystem were hinted at but not fully developed:

> Went swimming and lost a shoe.
>
> Washing the car with the hose.
>
> Went pinicing [picnicking] and spilled some juice to cause the stream to change colour.
>
> Farmer feeding sheeps [sic] and looking after them. The sheeps having waste.

Leona's contextual knowledge of the waterway is very general. This knowledge allowed her to identify a number of parts in the ecosystem in her drawing, but possible relationships were implied rather than explicit. The identification of a hole in the tree for possums implied a shelter relationship

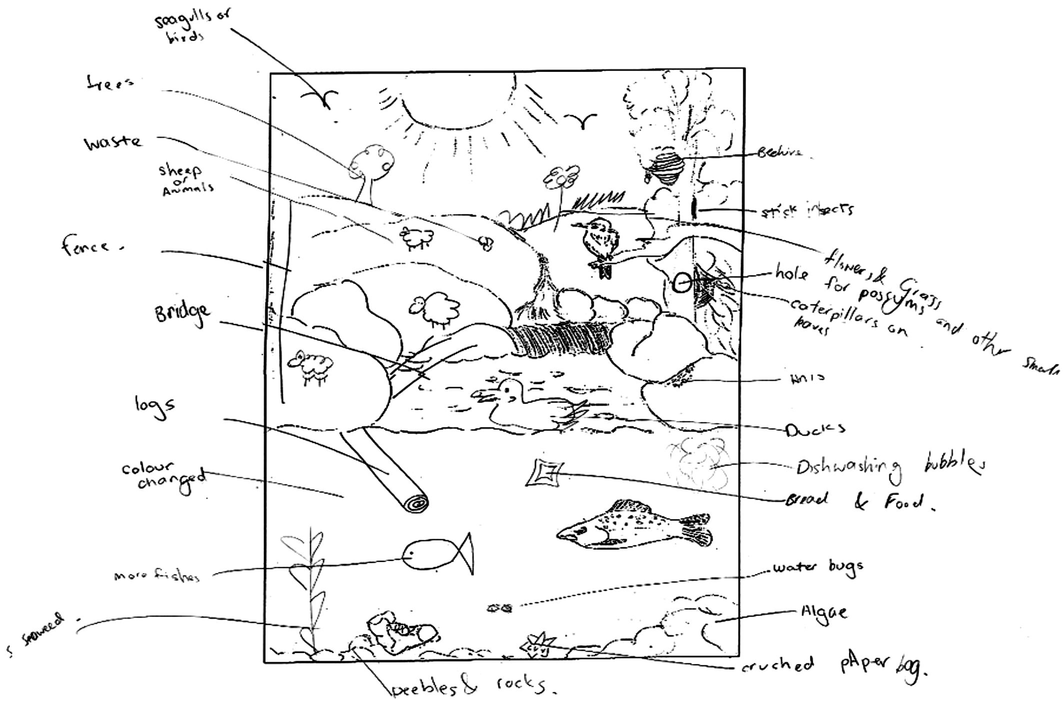

Figure 19.1 Leona's drawing is busy but lacking in specific ideas about relationships

between the possum and the tree. A feeding relationship was implied by the placement of the caterpillar on the leaf, but again this was not elaborated. By identifying that bread is food, Leona implied that some human actions are positive for other species.

Like most of the children, Leona identified more parts in the surroundings than in the stream itself. She had only a very general awareness of specific types of animal (e.g. waterbugs, seagulls or birds) and may not develop a more focused understanding of the concept of relationships until she knows more about the actual things between which such relationships could potentially form. Thus, her lack of a rich contextual knowledge of the naturally occurring components of the ecosystem may well be a barrier to the intended conceptual learning.

Leona's written response about a picnic illustrates an interesting link between holding a rather generalised understanding of the context and a misrepresentation of the scale of the effects described. This resonates with Boyes and Stanisstreet's (1996) findings concerning the sweeping generalisations children are likely to make about the effects of pollutants if they overgeneralise these – for example, by talking about 'air pollution' rather than a specific pollutant. In this research project, even children who could correctly describe some relationships in the ecosystem could misconstrue the scale of effects if they did not have a sound awareness of contextual detail.

3.2. Direct relationships can be described

Figure 19.2 shows Zoe's drawing. Compared with Leona, she accurately identified more naturally occurring parts of the ecosystem, including plants, animals and inorganic components, together with some processes and direct relationships. Zoe (aged 12) was more aware of specific life forms in the

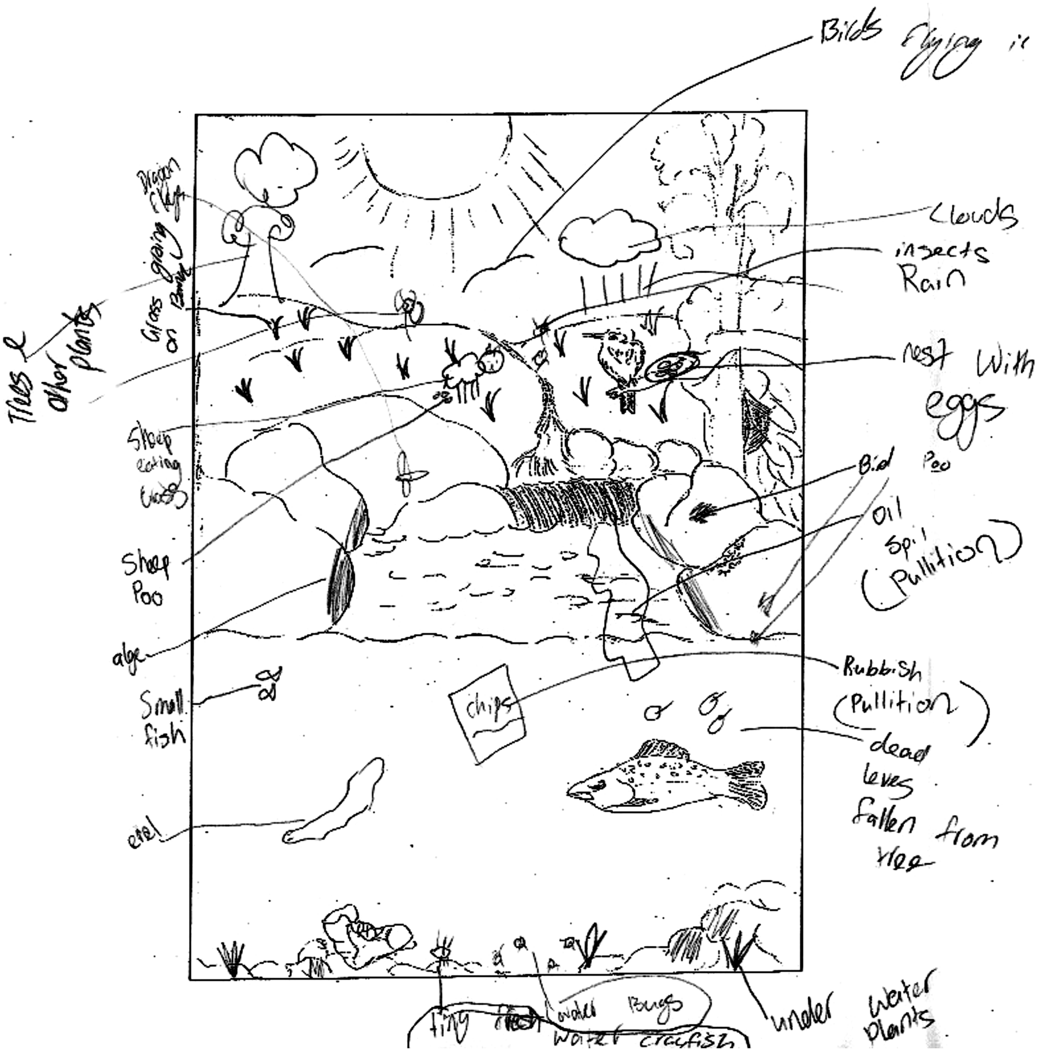

Figure 19.2 Zoe's drawing shows more accurate awareness of contextual detail

water (eels, freshwater crayfish). She showed some awareness that the water cycle will impact on the stream – an idea that very few children introduced.

Zoe's written responses were as follows:

1. The fish eats the water bugs that also live in the water.

2. The dead leaves have fallen off the tree into the water.

3. People can tip paint or oil down the storm water drain and it could end up in this stream. People who are taking a walk down the river might drop some rubbish and it can be blown into the stream. Both of these pollut [sic] the stream and can kill the wildlife.

The direct relationship is correctly described although again it is general rather than specific in its contextual detail. A fish of some sort eats water bugs of some sort. Whilst Zoe was aware of a simple interaction between plants on the riparian edges and the waterway itself (which is an explicit focus of the Waterways learning activities and interventions), she did not extend this to describe a dynamic effect. Again, the comments about pollution were overgeneralised and Zoe made no distinction between the consequences of a potentially very damaging action and a rather more innocuous one.

3.3 More advanced conceptual understanding with weaker contextual knowledge

Compared with the above examples, Matt's drawing (Figure 19.3) named a wider range of specific animals and plants found in and around the waterway (tree frog, trout, water spider, kingfisher, reeds) and he included some of the 'hidden' components (algae, leeches). The placement of the leeches near the legs could be inferred as a suggestion of a feeding relationship. Like most students, Matt (aged 12) named more animals than plants. He indicated some technological elements that impact on parts of the ecosystem, for example the factory, although he was not clear about how this would impact.

Matt wrote clear descriptions of direct relationships in response to the first two questions:

> 1. The algae is eaten by the eel.
>
> 2. The rainbow trout feeds on the reeds.

Although Matt clearly understands the concept he was asked to exemplify, both relationships were incorrect in their contextual detail. Neither eel nor trout are herbivores. Similarly, Matt was able to describe a complex, dynamic change to the waterway that included a chain of events as the result of one human action:

> 3. Companies by water drop oil waste into waterways therefore killing the trout and other fish. The reeds will overgrow, algae will spread and this will cause blockage of drains.

Here Matt demonstrates that he understands the impacts on plants (and therefore the ecosystem) when animals that feed on them are removed. His response is a conceptually ambitious attempt to describe dynamic relationships, combined with an inaccurate knowledge of the actual feeding relationships that are possible in the stream. There is an implication that 'trout and other fish' all eat reeds and/or algae. Trout are, of course, insectivores and herbivorous fish are not common in New Zealand waterways. (The ecological consequences were potentially disastrous when an attempt was made to control introduced water weeds by introducing koi carp, for example.)

3.4 Contextual knowledge may need more attention

Overall, the children's work suggested that contexts are indeed in need of explicit attention when teaching for systems thinking. The children shared a poor contextual knowledge of:

- Relatively common New Zealand birds: the kingfisher was included in the drawing outline and named in the instructions, but some children assigned this label to the large fish already drawn in the stream.
- Freshwater fish species: apart from eels, few fish species were named.
- The difference between freshwater and saltwater species: crabs and seaweed featured in some drawings. Ironically, the research team made a mistake of this sort too. Not until it was pointed out by the director of the Waterways project did the team realise that the fish in the provided

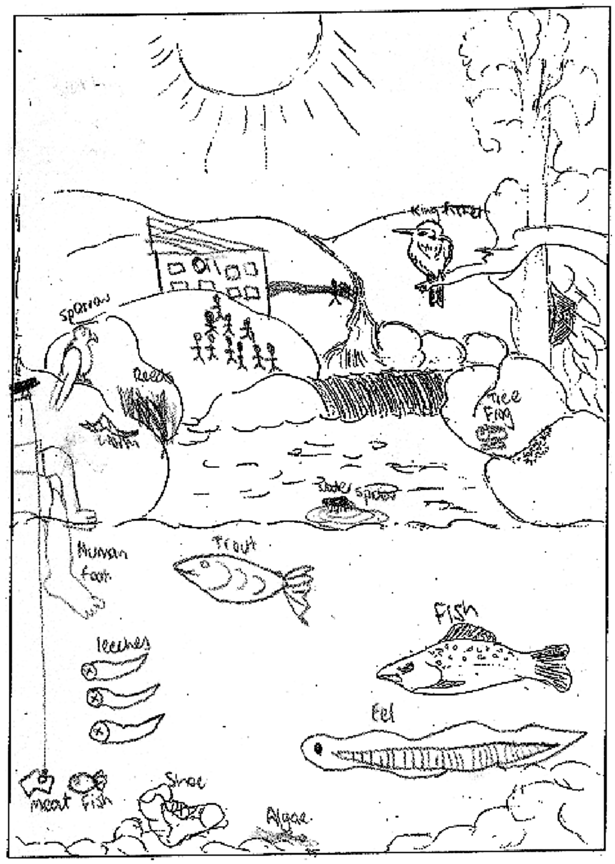

Figure 19.3 Matt's interesting selection of waterways components

drawing outline had fins more typical of sea species than freshwater species. This may have confused some children. Additionally, the interviews revealed that the overall structure of the drawing led some children to conclude that the foreground represented the sea.

- Plants that live in freshwater: many children did, however, include algae, which obviously caught their imagination during the Waterways unit.
- Non-living components: few students mentioned erosion and those who did generally referred to cows trampling the banks. There was little reference to water temperature despite the Waterways focus on the importance of summer shade provided by trees, and elements of the water cycle were addressed in very few students' work.

4. IMPLICATIONS FOR TEACHING

This moment-in-time snapshot of children's learning in a rich ecosystems context revealed the three broad patterns described above. There was an apparent interplay between conceptual and contextual understanding as each child described direct and indirect systems relationships, and each pattern implied a somewhat different immediate learning challenge, with associated potential 'next learning steps'.

4.1 Next learning steps

Tables 19.1–19.3 summarise aspects of children's work that could prompt teachers to provide formative feedback that is manageable in the classroom moment.

Table 19.1 Emergent concept/context relationships and next learning steps

Pattern of concept/context interaction	*Examples*
Some contextual elements identified.	The bird is staring at the fish.
Relationships are implied but not explicit.	The dead leaves have fallen into the water.
Implications for next learning steps	
Both conceptual and contextual understanding may need strengthening. Modelling a range of examples of relationships and discussing the type of relationship shown by each – e.g. feeding, habitat – could help.	

Table 19.2 Direct concept/context relationships and next learning steps

Pattern of concept/context interaction	*Examples*
A wider range of plants and animals can be named.	Alge [sic] gets eaten by macroadnvertebrates [sic].
Simple direct relationships are described.	The trees shade the water.
Implications for next learning steps	
Conceptually, the range of types of relationship could be extended (e.g. not just feeding relationships). Contextual knowledge can be enriched and extended, and exploratory use of interesting new vocabulary (as in the first example) consolidated.	

Table 19.3 Dynamic concept/context relationships and next learning steps

Pattern of concept/context interaction	*Examples*
At least one concept such as a food chain is sufficiently well understood that impacts of changes can be proposed.	The humans can eat the fish so the kingfishers etc. won't have much to eat.
Dynamic relationships where one change influences another are described.	People fishing makes the algae grow more because fish aren't eating it.
Implications for next learning steps	
Conceptually, children have a grasp on the intended learning. However, there may be aspects of the context that need to be revisited: • Check for and challenge misconceptions in the scale of effects (e.g. thinking that one small change will cause widespread pollution). • Encourage children to check the accuracy of the contextual details in their examples.	

The advantage of a broad set of patterns of concept/context interactions such as those shown in these tables is that teachers are supported in knowing the sorts of things to attend to as they quickly check for both conceptual understanding and contextual accuracy – assuming, of course, that they have the necessary knowledge of the ecosystem for the latter critique. Even if they do not, awareness that they can direct children to check for themselves may be sufficient.

4.2 Paying greater attention to contexts in systems thinking

The findings reported here support Assaraf and Orion's (2005) contention that 'naming parts and processes' underpins learning for systems thinking when it provides a firm contextual foundation on which to build. Each new context that is encountered will need to be a specific focus of learning, and will have its own challenges for the accurate transfer of concepts. It may be that teaching children to ask specific questions about how an idea applies in a context could alert them to the aspects to which they will need to pay attention. For example, once they know about food chains, they could think about which animals are herbivores, knowing what role these play and then checking if they are correct.

Nevertheless, it is of particular interest that children's conceptual development was *not necessarily* impeded by a lack of accurate, rich contextual knowledge. Whilst some children did not appear to be ready to move forward until they could name and describe more ecosystem components, others were well able to think more abstractly about relationships, notwithstanding their accurate lack of contextual knowledge.

The findings also challenge the idea that temporal dimensions represent the final stage in a series of progressive developments of systems thinking. Any change in an ecosystem implies a temporal dimension. Something happens, something else follows. Even when children did not join their ideas into coherent chains of consequent actions, it was evident that they were aware of temporal dimensions (as in Leona's description of spilling her drink in the stream). This suggests caution is needed when interpreting children's responses to a task such as the one discussed here. Systems are complex and sometimes contradictory. So, it seems, is children's thinking about them.

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20 Genetic diseases in French secondary school biology textbooks (for students aged 15–18): a study of genetic determinism models

Jérémy Castéra, Catherine Bruguière and Pierre Clément

LIRDHIST, UNIVERSITY CLAUDE BERNARD, LYON 1, FRANCE

jeremy.castera@univ-lyon1.fr

The presentation of genetic diseases in French secondary school biology textbooks was analysed to determine the major conceptions taught in the field of human genetics. References to genetic diseases, and the processes by which they are explained (monogenic and polygenic inheritance, chromosomal anomaly and environmental influence) were studied in recent French textbooks targeted at the four different school levels for students between the ages of 15 and 18. Four different publishers' textbooks were included for each school level. It was found that direct, linear and causal genetic determinism was the interpretative model most often associated with genetic diseases. Nevertheless, environmental influences were addressed more often in recent textbooks than in older ones, and were mainly associated with polygenic models of genetic determinism. The issues surrounding these results are discussed.

1. INTRODUCTION

Recent research in the fields of genetics and molecular biology has emphasised 'the end of genetics for everything' (Atlan 1999) and the increasing importance of epigenetic processes (Morange 2005a, b) in the formation of the phenotype. However, for many years the teaching of genetics has been centred on the determinism of the phenotype by the genotype. For this purpose, simple examples have been chosen, which, by minimising the interaction among genes or between genes and their environment, risked, albeit inadvertently, promoting a hereditarianist ideology (Abrougui and Clément 1997a, b). The methods by which the topic 'biological identity' has been addressed in French textbooks has also supported this hereditarianist concept (Forissier and Clément 2003). Taking into account the results of current research, French curricula have recently changed. Therefore, this is an opportune time to analyse the ways in which human genetics is being addressed in the newly published French school textbooks and to assess whether less deterministic concepts are now being presented.

For this study, we chose to analyse examples related to human pathologies. Not only are these examples most often found in school textbooks, but they also systematically provide an opportunity to reflect on health education. Furthermore, the topic of genetic disease possesses an important emotional dimension, so much so that in France it is the focus of the Telethon, an annual television event accompanied by numerous activities and a fundraising campaign to support genetic disease research. In addition to the critique that the Telethon inspires 'false hope' in the public (Séralini 2003), it has also been criticised for its undeniable effect of strongly associating the idea of genetics with that of disease in the minds of viewers. Newspapers and magazines often employ dramatic, scientifically questionable headlines such as 'the fat gene,' 'the shyness gene,' 'the heredity of intelligence' and 'the crime chromosome' (Clément and Forissier 2001). To what point are school textbooks influenced by such media campaigns?

2. THEORETICAL BACKGROUND

2.1 Didactical background

The idea of conception was a key concept in this study. Giordan and de Vecchi (1987) defined conception as 'a set of explanatory, coordinated ideas and coherent images used by learners when confronted with a problem situation'. From this constructivist perspective, researchers of science didactics became interested in the learners' previously held ideas related to a topic, and whether these previous ideas would allow or inhibit the acquisition of new knowledge related to this topic. These previous ideas, whether more or less organised, more or less coherent, or more or less scientific, are called conceptions in science didactics.

More recently, conceptions have been defined as the results of interactions among scientific knowledge (K), social practices (P) (Martinand 2000) and values (V). As illustrated in Figure 20.1, any conception can be analysed – and will be analysed here – as the interaction among these poles (known as the KVP model: Clément 1998, 2004).

Several research projects have analysed students' conceptions of genetics since the work of Rumelhard (1986). Some (Abrougui 1997; Abrougui and Clément 1997a, b) have examined French and Tunisian school textbooks and serve as references for the starting point of the current work. A textbook that only cites examples of monogenic diseases (i.e. genetic diseases caused by a single mutant gene) inadvertently conveys the message of an implicit hereditarianism, which could be used to justify a certain fatalism with regard to social practices. Pointing out this possible implicit ideology does not mean that we deny the importance of genetic influence on disease, which, in some cases, can be clearly direct (e.g. Duchenne muscular dystrophy).

2.2 Epistemological background

Geneticists today criticise the notion of a 'genetic programme' that suggests that everything is written in the DNA and ignores the epigenetic processes that play a role in every phase of DNA activity, from

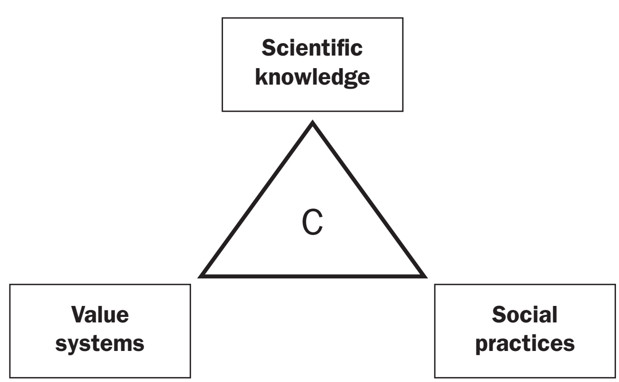

Figure 20.1 Conceptions (C) may be analysed as interactions among the three poles: scientific knowledge, values and social practices (from Clément 2004)

self-repair (Friedberg 2003) to protein synthesis (Stewart 1996; Atlan 1999; Morange 2005a, b). In particular, it is accepted that every human disease is the result of interactions between the genotype and its environment (Chakavarti and Little 2003). However, Forissier and Clément (2003) identified three types of conception taught by French teachers related to the genetic determinism of the phenotype:

1. A simple, linear conception, linking the genotype with the phenotype exclusively by genetic determinism, without any environmental influence.
2. An additive conception, in which the phenotype is partially determined by the environment and partially by the genotype.
3. An interactive conception, where the phenotype results from the interaction between the genotype and its environment, as well as the interaction between the phenotype and its environment.

Some genetic diseases illustrate a simple linear genetic determinism, whilst others clearly demonstrate interactive processes in the development of the pathological phenotype. A genetic disease represents a malfunction or a mutation in one or several genes. But these irregularities do not necessarily occur in the reproductive cells; therefore, they do not always become transmissable. Consequently, a genetic disease is not always hereditary (Séralini 2003).

We can separate genetic diseases into two large categories: monogenic diseases, caused by a mutation in a single gene, and polygenic diseases, where multiple genes play a role in symptom development (Swynghedauw 2000). Our research addressed both monogenic and polygenic diseases, as well as chromosomal anomalies. We grouped all of these pathologies under the heading of genetic anomalies or genetic pathologies.

The monogenic diseases studied in French textbooks are all hereditary. The case is very different for polygenic diseases, where variations in the DNA sequence are necessary but not sufficient to trigger the disease. An interaction with the environment is also required (e.g. diabetes, cancers, etc.). Even for monogenic diseases, an environmental influence is not ruled out. It can play a role in the partial or even total reversibility of the disease. For example, in the case of phenylketonuria, a special diet can completely prevent the occurrence of mental retardation.

In addition, cases of monogenic diseases or chromosomal anomalies are relatively rare. For instance, cystic fibrosis affects only 1 in every 25,000 births and Down's syndrome, 1 in every 750 births. However, current statistics indicate that one American in two and one European in three will develop a cancer during the course of his or her lifetime (Seralini 2003). Furthermore, according to the World Health Organization (WHO), there were 177 million diabetes patients in 2000 and this figure could rise to 300 million by 2025.

3. RESEARCH QUESTIONS

Genetic pathologies are frequently used as examples in chapters on genetics in French secondary school textbooks. However, the choice of one particular example over another can significantly impact on the message to the learner. For this reason, we chose to list genetic disease examples found in chapters on genetics in school textbooks and to explore the way these examples were presented:

- Do they illustrate genetic determinism in the strict sense or rather do they show interactions between the genome and the environment?
- Which types of examples are most recurrent: chromosomal anomalies, monogenic processes or polygenic processes?

- Do differences exist among the school levels and, for a given level, are there differences among the publishers?

In short, what are the conceptions of genetic determinism presented through the examples of genetic diseases or chromosomal anomalies in school textbooks?

4. METHODOLOGY

We analysed 18 biology textbooks, published by four different French publishers, and containing chapters treating human genetics (Table 20.1). As genetics is only taught in the last four years of secondary education (i.e. students aged 15–18), only these school levels were included in the study. In the first two of these four years (*troisième* and *seconde*, for ages 14–16), there is only one biology textbook. However, for the last two years, several textbooks are available according to the students' specialisation: humanities, economy and social studies, or the sciences. Here, we limited our study to textbooks for the scientific section. Additionally, we included the textbook for students pursuing a biology specialisation in their final year (*terminale scientifique specialité biologie*). This specialised textbook is complementary to the *terminale scientifique* textbook: it is only intended for students specialising in biology, whereas the text for *terminale scientifique* is intended for the three scientific disciplines of mathematics, physics/chemistry and biology. The four publishers chosen are among the most widely used in France, but not all of them published texts for every school level. A list of the textbooks included in the study is provided in Table 20.1.

We made an inventory of all of the diseases found in the chapters concerning human genetics. Each disease example was analysed with respect to the text as well as to the images, and was characterised according to the following five criteria: monogenic determinism, polygenic determinism, chromosomal anomalies, the presence of environmental influence, and absence of environmental

Table 20.1 The French biology textbooks analysed

School level	*Age (years)*	*Publisher*	*Publication year*
Troisième	14–15	Bordas	2001
		Hatier	2004
		Nathan	2003
Seconde	15–16	Bordas	2004
		Hatier	2003
		Nathan	2000
		Didier	2000
Première scientifique	16–17	Bordas	2001
		Hatier	2001
		Nathan	2001
		Didier	2001
Terminale scientifique	17–18	Bordas	2002
		Hatier	2002
		Nathan	2002
		Didier	2002
Terminale scientifique spécialité biologie	17–18	Bordas	2002
		Nathan	2002
		Didier	2002

influence. This analysis allowed us to ascertain whether the genetic determinism was chromosomal, monogenic (where the presence of a single defective gene is responsible for the disease) or polygenic (where either multiple genes are responsible for the disease or modulator genes are involved). An environmental influence can also play a role in the emergence or even in the development of a disease. For example, the influence of tobacco could trigger a cancer in an otherwise genetically favourable situation. In other cases, one or more genes are considered solely responsible for the appearance of a disease and there is no environmental influence on the pathology.

Our research method was based on a search of the texts using the names of the anomalies or genetic diseases as keywords. This technique, introduced by Harris (1952), was employed by Abrougui and Clément (1997a) to analyse French and Tunisian textbook content on genetics. However, we modified this technique by deciding not to count the occurrences of a disease name, but rather only to count the number of passages that described a disease. Most often, these passages took up less than one page (1/8 to 1/4 page), although some took as much as one to two pages.

5. RESULTS

5.1 The different diseases presented in the school textbooks

A wide range of genetic diseases appeared in the texts analysed. Given the length of the complete list of the different examples, Figure 20.2 is limited only to diseases cited at least five times in the body of the 18 textbooks.

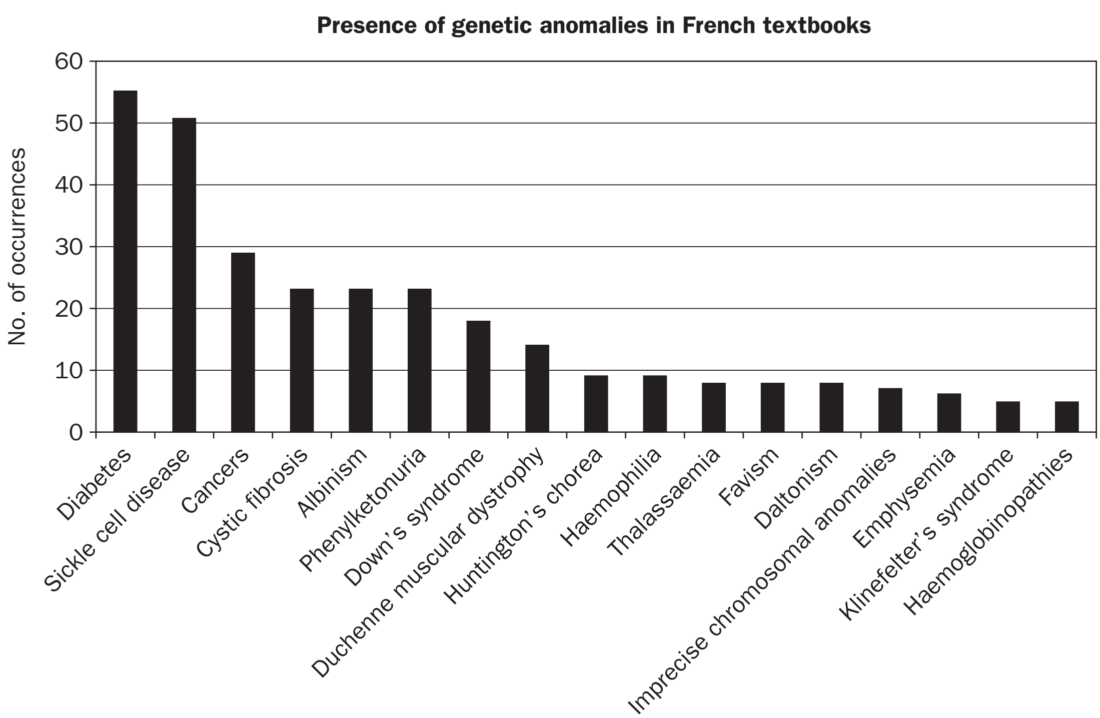

Figure 20.2 Number of occurrences of genetic anomalies in the school textbooks analysed

Diabetes and sickle cell disease were the two most often cited genetic diseases (>50 times, Figure 20.2). The strong presence of diabetes is due to the fact that in the *première scientifique* (ages 16–17) an entire chapter is dedicated to the topic in accordance with the syllabus entitled 'Diabetic phenotypes and glycemic regulation' (BO HS no. 6, 29 August 2002). In this school year, the syllabus mentions sickle cell disease both as an example to illustrate the complexity of the relationships among genes, phenotypes and the environment, and as an example to define the phenotype on various scales.

5.2 Different types of phenotype determinism

The following results considered the diseases that had more than ten occurrences in the chapters on genetics.

The most significant result was the high occurrence rate of examples of monogenic determinism: between 52 and 91 per cent of all examples at each school level. Chromosomal anomaly examples were frequently used in the *troisième* (students aged 14–15), comprising 36 per cent of the examples. At this school level, there were no examples of polygenic determinism. The authors preferred to introduce simple mechanisms first and only later address the more complicated polygenic processes, mainly in the *premièere sscientifique* (students ages 16–17), where the highest number of genetic disease examples was found, with nearly half of the examples showing polygenic determinism mechanisms.

Diabetes, albinism and cancers were the polygenic disease examples most often presented (Table 20.3), despite the fact that in a few cases these diseases were presented as monogenic. For example, with regard to cancer: 'We determined the sequences for the two gene alleles in cancerous cells' (Hatier *seconde* 2003: 216). However, sickle cell disease and phenylketonuria were generally presented as monogenic: 'Phenylketonuria, a disease caused by the mutation of a single gene . . .' (Hatier *première scientifique*: 24). The *première scientifique* Hatier textbook was exceptional in that it presented both diseases as polygenic. For sickle cell disease, it explained that 'modulator genes' are involved, and in the case of phenylketonuria, it stated that 'even in the case of phenotypes considered to be monogenic, the determinism mechanism is far from an absolute . . . in this sense the vast majority of phenotypes are polygenic' (Hatier *première scientifique*: 76). Such distinctions demonstrate an approach closer to actual scientific knowledge.

Table 20.2 Number and percentage of occurrences of genetic anomalies as a function of both school level and type of genetic determinism presented school textbooks analysed

School level	*Genetic determinism*				
	Monogenic	*Polygenic*	*Chromosomal anomaly*	*Total*	*No. of occurrences per school level*
Troisième	14 (64%)	0 (0%)	8 (36%)	100%	22
Seconde	10 (91%)	1 (9%)	0 (0%)	100%	11
Première scientifique	27 (52%)	25 (48%)	0 (0%)	100%	52
Terminale scientifique	12 (57%)	3 (14%)	6 (29%)	100%	21
Terminale scientifique spécialité biologie	10 (71%)	0 (0%)	4 (29%)	100%	14

Table 20.3 Number of occurrences (n>10) of diseases as a function of the genetic mechanism

Genetic determinism mechanism	*Monogenic*	*Polygenic*	*Chromosomal anomaly*
Diabetes	1	11	0
Sickle cell disease	23	3	0
Cancers	6	5	0
Cystic fibrosis	16	0	0
Albinism	8	7	0
Phenylketonuria	9	3	0
Down's syndrome	0	0	19
Duchenne muscular dystrophy	10	0	0

Current scientific and medical knowledge suggests that cancer development is a multi-stage process. A number of mutually exclusive events altering certain genes are effectively necessary for progressive transformation of the descendants of a normal cell into malignant cells. Cancers have a polygenic origin, as their development is due to the accumulation of successive anomalies in different genes over the course of multiple cellular generations (Séralini 2003). The same argument holds for both type 1 and type 2 diabetes, which are also considered to be polygenic.

In the case of sickle cell disease, the presence of modifier genes that regulate the severity of the disease has been acknowledged (Labie and Elion 1996). In most cases of phenylketonuria, it has been difficult to prove the existence of modulator genes. There are, however, cases of brothers having the same genotype for the gene in question, with one brother contracting the disease whilst the other does not (case study included in the textbook for the *première scientifique* published by Hatier).

Environmental influence was rarely addressed in the *troisième* and was included in no more than one-third of genetic disease examples presented in the textbooks for the *seconde*, *premiere scientifique* and *terminale scientifique*. These results demonstrate the predominance of simplistic, causal determinism mechanisms in the French secondary school textbooks studied. However, diseases significantly influenced by environmental factors (e.g. diabetes, cancers) were relatively frequent in textbooks for 15–16- and 16–17-year-old students. The presence of such examples contributes to a less simplistic representation of genetic determinism.

Figure 20.3 shows that the environment was mentioned in the discussion of cancers and diabetes in more than 50 per cent of cases studied. As we have already explained, even with monogenic diseases or chromosomal anomalies, the environment can influence a disease, for example, by rendering it either partially reversible (e.g. by means of an adapted education in the case of Down's syndrome) or completely reversible (e.g. phenylketonuria). Therefore, apart from the two clear exceptions of cystic fibrosis and Duchenne muscular dystrophy, both of which are strongly subject to monogenic determinism, the environment has an effect on almost all diseases.

Down's syndrome is a special case: only one text (Bordas, *terminale scientifique*) made reference to environmental factors capable of influencing the disease by clearly indicating that an adapted education may allow a better social integration of Down's syndrome patients.

5.3 Comparison of textbook publishers

The textbooks for students aged 14–15 presented the same types of example disease, regardless of the publisher: the genetic determinism of the disease was either chromosomal or monogenic.

Table 20.4 Environmental influence in genetic pathology examples

School level	*Troisième*	*Seconde*	*Première scientifique*	*Terminale scientifique*	*Terminale scientifique spécialité biologie*	*Total*
Number of occurrences of genetic disease examples	22	20	144	24	25	235
Number of occurrences of genetic diseases mentioning environmental influence	3	6	49	6	4	68
Percentage mentioning environmental influence	14	30	34	25	16	29

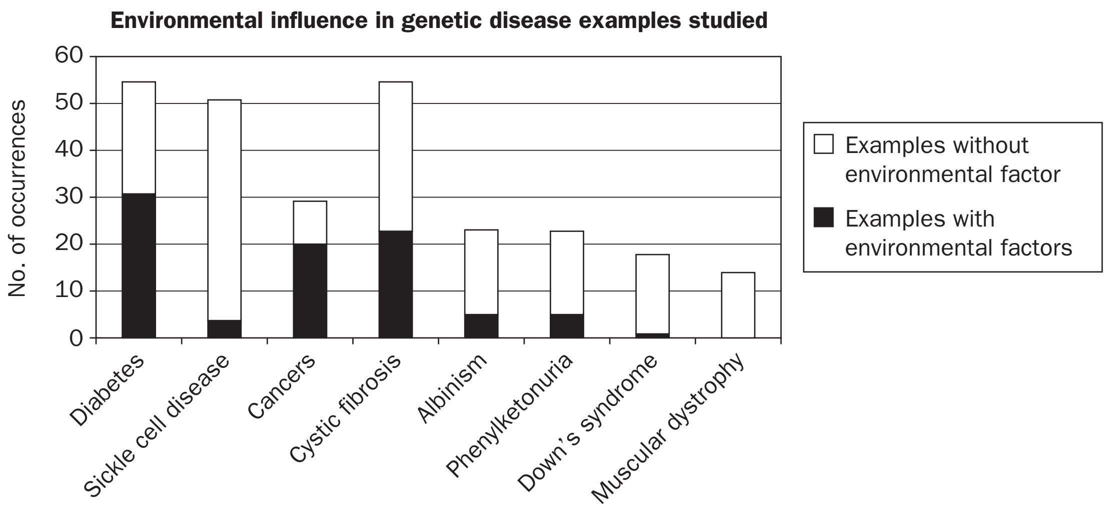

Figure 20.3 Environmental influence in the genetic disease examples presented more than ten times each in the books analysed

The textbooks for students aged 15–16 were also basically the same for all publishers, with the slight exception of the modest inclusion of examples of environmental influence in the publications by Didier and Hatier. The latter was also the only one to address polygenic determinism (with regard to cancer).

In contrast, in *première scientifique* (students ages 16–17), there were important differences among the publishers. The Hatier textbook presented at least twice the number of examples of monogenic determinism as the other texts and roughly half the number of cases including environmental influence.

The textbooks for 17–18-year-old students were very similar, with the exception of a notable lack of cases involving environmental influence in those published by Hatier and a presentation of chromosomal determinism examples found exclusively in the texts by Nathan.

With regard to the biology specialisation textbooks, the publisher Didier did not mention any of the diseases that we chose to study. In general, there was a complete lack of polygenic models in all of the publishers' texts at this school level.

6. DISCUSSION: EVOLUTION OF THE CONCEPTIONS OF GENETIC DETERMINISM IN THE TEXTBOOKS STUDIED

Our results demonstrate that current French secondary school textbooks still focus heavily on the simple, linear determinism model (genotype → phenotype: Forissier and Clément 2003). The frequency of examples demonstrating this model is, however, reduced in comparison with the textbooks published in 1995, which were previously analysed by Forisser and Clément. Thus, polygenic determinism and the interaction between the genome and its environment have a greater presence in textbooks today, especially inthe *première scientifique* (students ages 16–17), where cancer and diabetes are frequently discussed.

In the *troisième* (students aged 14–15), Down's syndrome and Duchenne muscular dystrophy were the pathologies most often cited. The appearance of 'abnormal' traits for Down's syndrome was presented as the result of an anomaly in the number of chromosomes. Discussion of chromosomes and human chromosomal anomalies provided the introduction to genetics. This presentation first defined a gene as a portion of the chromosome, and then as a portion of the DNA (Abrougui and Clément 2005), even though the definition of a 'gene' is currently under debate (Chevassus-Au-Louis 2001). For the other diseases, such as Duchenne muscular dystrophy, the explanation was exclusively monogenic. In general, it was common to read: 'The responsible gene is . . .' and to see chromosome maps where the gene responsible for cystic fibrosis or Duchenne muscular dystrophy was pinpointed. No examples were found to illustrate either polygenic determinism or environmental influence (Table 20.2). Therefore, the genetic model taught to students aged 14–15 corresponds almost totally to a linear, causal model with the unique influence of a single gene or of an extra chromosome.

In the *seconde* (students aged 15–16), a new dimension was added to genetic determinism with the introduction of cancers. The text published by Hatier was the only one to state explicitly that cancers have a 'polygenic origin'. This example of polygenic inheritance remained, however, only one of a small minority found in all of the textbooks for this school level. The other 11 examples for which the determinism mechanism was defined were based solely on monogenic processes (Table 20.5). In contrast, the relationship with the environment was relatively adequately represented, as it appeared in six examples (three in Didier and three in Hatier), most of which referred to cancers. Therefore, a polygenic, environmental model was introduced at this level. However, examples without environmental intervention continued to represent the majority.

The *premiere scientifique* (students aged 16–17) is a pivotal year for French scientific students with regard to the construction of their conceptions about genetic determinism. Genetics was fully developed, including an entire chapter dedicated to the diabetic phenotype, which is strongly linked to a polygenic determinism model. Polygenic determinism represented almost half of the explanations provided for the emergence of genetic diseases. The students were also introduced to the concept of modulator genes, the presence of which are a good indicator of polygenic causality. As in the Seconde, half of the examples of cancers presented a polygenic model. The examples of diabetes, considered as monogenic in the previous year, now had a polygenic causality in 100 per cent of

Table 20.5 Citation frequency of different genetic diseases as a function of school level and publisher

Textbooks	*Monogenic determinism*	*Polygenic determinism*	*Chromosomal anomaly*	*Undefined*	*Environmental influence*
Troisième					
Nathan	5	0	3	0	1
Hatier	4	0	3	0	1
Bordas	5	0	2	0	1
Bordas	1	0	0	1	0
Seconde					
Didier	1	0	0	4	3
Nathan	5	0	0	0	0
Hatier	3	1	0	4	3
Première scientifique					
Bordas	4	7	0	21	14
Hatier	12	8	1	19	8
Didier	5	5	0	31	14
Nathan	6	5	0	20	13
Terminale scientifique					
Bordas	5	0	2	2	3
Hatier	5	1	0	0	0
Didier	4	2	2	0	2
Nathan	0	0	2	1	1
Terminale scientifique spécialité biologie					
Nathan	2	0	2	3	0
Didier	0	0	0	8	0
Bordas	8	0	2	0	4

cases. To a lesser extent, sickle cell disease and phenylketonuria also occasionally appeared as examples of polygenic diseases.

In the textbooks for the *terminale scientifique* (students aged 17–18), the diseases most often cited were sickle cell disease and Down's syndrome, and both were generally associated with simple genetic determinism. Albinism was the only exemplary disease to introduce the notion of polygenic inheritance in phenotype determinism. Sickle cell disease, albinism and Down's syndrome (in a single case) introduced the environmental aspect. The influence of the environment was present in a quarter of examples studied in the texts at this school level.

In the *terminale scientifique spécialité biologie* (students aged 17–18), examples of polygeny and environmental influence are absent in contrast to the *terminale scientifique*. Both implicit and explicit determinism examples were exclusively monogenic and concerned only Duchenne muscular dystrophy, Down's syndrome, cystic fibrosis and sickle cell disease. Environmental factors were rarely mentioned (16–25 per cent of examples) and were introduced by examples involving diabetes, cancers and, in a single case, phenylketonuria.

The textbooks intended for the biology specialisation therefore expressed a stricter form of genetic determinism than the texts for *terminale scientifique*. This can be explained by the fact that the specialised textbook complementary to the standard *terminale scientifique*. textbook; therefore, content is not repeated. On the contrary, the content is rendered more complete with the addition of a historical approach to genetics, beginning with Mendel and ending with DNA sequencing. Hence, it makes sense that the strict genetic determinism model dominates, as this model prevailed throughout the development of the field of genetics, as explained in the introduction to this study.

7. CONCLUSION

In conclusion, two primary trends can be highlighted: there was a strong presence, at all school levels analysed, of a simplistic conception in which the genotype provides the unique explanation for the pathological phenotype. We have shown that this conception represented the majority of genetic pathology examples. Thus, this reductionist model always cites examples such as cystic fibrosis or Duchenne muscular dystrophy, even though the expression of all genetic diseases also depends on environmental influences. Otherwise, how else can we explain that a given genotype can lead to pathologies of varying severity?

The conception of a linear and causal determinism of the phenotype by the genotype could provide support for hunting down and eradicating 'bad' genes in the same sinister vein as that of the eugenics movement at the beginning of the 20th century. This oversimplified hereditarianist conception also promotes fatalism (Abrougui and Clément 1997b; Clément and Forissier 2001): if we are healthy and successful in life, it is because of our good genes and if we are not, how can we overcome our genetic destiny? In addition, this simplistic conception directs medical research towards tracking the unique genetic cause of a given disease. This, in turn, reinforces support for a biomedical model of health and leaves no room for the health promotion model espoused by the WHO. In the WHO model, health is a multi-dimensional concept, and the promotion of health requires the consideration of all of these dimensions, the origins of which are just as psychological, social, economic and environmental as they are biological, if not more so.

Important advancements have been made since publication of the previous curriculum in France (1995) towards a less simplistic presentation of the causes of genetic diseases, no longer limiting them to a single gene. In the new syllabuses, multiple genes, as well as the interaction between the genome and its environment, may be involved. Complex determinism models for diseases (such as cancers or diabetes) help to prevent students' minds from being ingrained with the single, oversimplified conception of genetics, which continues to dominate the human pathology cases presented in the texts. Thus, by analysing the French textbooks published by Bordas and Nathan for the *troisième*, the *première scientifique* and the *terminale scientifique*, Abrougui (1997: 149) observed that 'the idea of environmental determinism of phenotypes is totally absent in French textbooks in the *3ème* and the *1ère* and only presented in the text by *Nathan* for the *terminale S*'. Forissier and Clément (2003) observed by analysis of the same textbooks that a simplistic approach, as well as the concept of genetic programming, were frequently used in the texts to define biological identity. Therefore, the new French syllabuses and the secondary school textbooks that follow them represent an important step towards a less simplistic approach to teaching genetics, even if we have noticed some differences from one publisher to another.

To conclude, we emphasise that our objective is not to rid the genetics curriculum of every determinist approach that demonstrates the existence of the genome and its influence on the phenotype. Simple, linear and causal models are certainly necessary to introduce genetic concepts. However, secondary school textbooks cannot limit themselves to such simple examples and mechanisms. Otherwise, they risk introducing implicit ideologies that go beyond the boundaries of scientific discourse. Such ideologies threaten citizenship values, the teaching of which also represents an essential objective in biology education.

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21 Experienced junior high-school teachers' pedagogical content knowledge in light of a curriculum change in the topic of the cell

Rachel Cohen and Anat Yarden

DEPARTMENT OF SCIENCE TEACHING, WEIZMANN INSTITUTE OF SCIENCE, REHOVOT, ISRAEL

anat.yarden@weizmann.ac.il

The cell is the basic structural and functional unit of every living organism and is central to understanding some of the most important biological phenomena. Here, we examined junior high-school science and technology teachers' pedagogical content knowledge (PCK) with regard to the topic of the cell. Teachers who participated in this study were in three focus groups (n = 59) and one workshop (n = 12). In addition, six experienced teachers were interviewed in the course of this study. Specific tools were developed to capture the teachers' PCK. Data analysis was carried out following a characterisation of the teachers' PCK components following Magnusson *et al.* (1999). The teachers attributed great importance to the cell topic, but had ambivalent feelings towards it, as they viewed it as not tangible and difficult to comprehend for junior high-school students. The junior high-school teachers were found to have no PCK capacity to integrate biological phenomena at the macroscopic level with their cellular explanations. We also found a duality among the teachers with regard to relating macro- and microscopic levels in biology and in chemistry. The research findings reported here may shed some light on the source of students' comprehension difficulties in relating macroscopic phenomena with their cellular explanations.

1. INTRODUCTION

Various international biology education programmes emphasise the importance of teaching and learning the topic of the cell during high school, including the National Science Education Standards (NRC 1996) and the Benchmarks for Science Literacy (AAAS 1993). In Israel, a new curriculum for science and technology studies in junior high school has been published (Israeli Ministry of Education 1996), followed by the development of new learning materials in science and technology for junior high school, and in-service professional development workshops and courses for teachers.

In the new curriculum (Israeli Ministry of Education 1996), the topic of the cell has been classified as obligatory. This requirement is accompanied by a recommendation that content appearing under the cell topic is to be studied 'longitudinally' in conjunction with other study content. Thus, content appearing under the cell topic is to be studied as a central axis for the entire 3 years of junior high school, together with all of the biological topics studied at the macroscopic level. Thus, on the one hand, the cell topic was determined to be an obligatory topic, in contrast to its status as an elective topic in the previous curriculum. On the other hand, no teaching time was allocated to the cell topic and the teachers were requested to integrate it longitudinally with the other biology topics. The new curriculum also calls for a change in the grades in which the cell topic is taught, namely, grades 7–9 (age 12–15 years), whereas previously it was taught only in grade 9. Finally, this new set of guidelines can be considered a change in the context in which this topic is taught and learnt, i.e. together with other biological topics, rather than independently. In other words, the new curriculum calls for a change in teaching of the topic of the cell in junior high school. The recommendation to teach the cell topic longitudinally provides an opportunity to form meaningful relationships between biological phenomena taught at the macroscopic level and their cellular explanations, and to overcome some of the students' reported difficulties (Dreyfus and Jungwirth 1988; Knippels 2002; Verhoeff 2003).

However, the new recommendation to teach the cell topic longitudinally may require recognising the teachers' role in the reform, and changing teachers' conceptions, beliefs and attitudes with regard to the cell topic, as well as with regard to other biological topics in junior high school. Teachers are required to change their teaching approaches and adopt new ways of thinking and behaving in teaching the cell topic together with all of the other biological topics, rather than as an independent topic. Such a change requires the development of appropriate teacher pedagogical content knowledge (PCK).

Magnusson *et al.* (1999) conceptualised PCK as consisting of five components: (1) orientations towards science teaching – knowledge of the purpose and goals for teaching science at a particular grade level; (2) knowledge and beliefs about the science curriculum – mandated goals and objectives and specific curricular programmes and materials that are relevant to teaching the topic; (3) knowledge and beliefs about students' understanding of specific science topics – prerequisite knowledge for learning specific science knowledge, and the abilities and skills that students might need, as well as science concepts or topics that students find difficult to learn; (4) knowledge and beliefs about assessment in science – the dimensions of science learning that are important to assess within a particular unit of study, and methods that can be used for assessment; (5) knowledge and beliefs about instructional strategies for teaching science – teachers' knowledge and beliefs of strategies and topic strategies. Teachers' use of strategies is influenced by beliefs or lack of PCK and content knowledge (Magnusson *et al.* 1999).

Little is known about teachers' content-related beliefs about a specific subject matter, the importance of teaching specific topics or curricular goals, and the relationships of such content-related beliefs to general education beliefs (Van Driel *et al.* 2005). The content knowledge of junior high-school teachers about the cell has been investigated by Douvdevany *et al.* (1997). However, their PCK has not been studied; this was the focus of our study.

Conceptualising PCK and investigating it in practice are not easy tasks, because it is an internal construct, and much of the PCK of practice is tacit. Teachers generally do not use language that includes PCK constructs (Loughran *et al.* 2004). We believe that teachers' PCK should be considered at the start of a change or reform. In view of the fact that teachers' knowledge is tacit and that they should be asked to articulate their own PCK, we created an opportunity for junior high-school teachers to discuss and explicitly explore their PCK with regard to the cell topic. Here, we describe an analysis of junior high-school science and technology teachers' PCK using the five components suggested by Magnusson *et al.* (1999).

2. RESEARCH DESIGN AND METHODOLOGY

2.1 Sample

The data was collected from three different junior high-school science and technology teachers' focus groups (n = 59), a workshop that was conducted within the framework of a teachers' course entitled 'Teaching the cell longitudinally' (n = 12) and interviews with six experienced (20 years on average) teachers. All of the teachers who participated in this study had already taught the cell topic in junior high school and, similar to all of their colleagues in Israel, mostly teach chemistry in grades 7 and 8 in the framework of the science and technology curriculum.

2.2 Tools

2.2.1 Teachers' assessment of authentic students' explanations of biological phenomena

The focus groups, the interviews and the workshop discussions were audiotaped, and the tapes were transcribed and analysed. In the discussions, teachers were asked to comment on a sample of student answers to questions in which they were asked to explain some biological phenomena. The questions dealt with wilting plants on a hot dry day, sprouting of seeds, fertilisation in living organisms and embryonic development following insemination. The teachers were initially provided with a macroscopic-level type of explanation provided by a junior high-school student (i.e. 'Plants need a fertile ground and appropriate weather to survive. Plants dry out without water. Once the heat level exceeds the amount of water the plant gets, it will wilt') and were asked to score the answer. Subsequently, a cellular explanation given by another junior high-school student for the same phenomenon was shown to the teachers (i.e. 'The cell vacuole will lose water to the inner cellular environment and therefore the pressure on the cell wall will be reduced. The plant cell has a vacuole, which presses against the cell wall. This pressure is reduced when there is no water supply and then the plant wilts') and they were asked to score that answer. This task enabled us to probe the teachers' knowledge and beliefs about assessment of the cell topic. The discourse elicited among the teachers following the activity enabled us also to probe the other four PCK components suggested by Magnusson e*t al.* (1999).

2.2.2 Semi-structured interviews

Semi-structured interviews were conducted in order to capture the teachers' opinions on their teaching of the cell topic, the reasons for their practice and what components might influence their opinions and practice with regard to the topic. For example, the teachers were asked to imagine a situation in which they were members of a curriculum committee: Would they recommend teaching the cell topic as an obligatory topic in junior high school (grades 7–9)? The semi-structured interviews enabled us to probe all five of the PCK components suggested by Magnusson *et al.* (1999).

2.2.3 Teachers' tests

Teachers' tests were analysed, where teachers provided them. Analysis of the tests enabled us to probe the teachers' knowledge and beliefs about the cell curriculum and about assessment of the cell topic.

2.2.4 Questionnaire

A questionnaire that attempted to probe the teachers' familiarity with learning materials for the cell topic was distributed to the teachers at the beginning of the workshop. The questionnaire was aimed at probing teachers' orientations towards teaching the cell topic, their knowledge and beliefs about the cell topic curriculum and students' understanding of the cell topic, and instructional strategies for the topic.

2.2.5 Unfamiliar test questions

To examine teachers' conceptions about students' assessment of the cell topic in grades 7–9, we gave them questions about the cell that were not familiar to them (taken from Dreyfus and Jungwirth 1988), as well as additional questions that were developed such that each learning objective presented in the curriculum would be represented in at least one question. The questions were aimed at examining whether the main principles of the cell topic as they are presented in the curriculum appeared in the questions chosen by the teachers for each grade level (Israeli Ministry of Education 1996). We asked the teachers to classify the questions to form a suitable test for each of the grades (7–9) and to eliminate questions that they did not deem suitable for junior high-school level. The analysis of the teachers' responses to the questions enabled us to probe the teachers' knowledge and beliefs about the cell curriculum and about students' understanding of the cell topic, in addition to their knowledge and beliefs about assessment of the cell topic.

2.3 Data analysis

The focus groups' discussions, interviews and relevant parts of the workshop were fully transcribed. Transcripts were read several times in search of recurring categories and ideas according to the stages, as recommended by Shkedi (2003). Various sources were included in this study. The information received from these sources was used for corroboration or refutal. Method gathering and triangulation were used to enhance the validity of the findings.

3. RESULTS

Data collected from teachers' focus groups, the workshop and the individual interviews were used for analysis of junior high-school science and technology teachers' PCK, according to the five components suggested by Magnusson *et al.* (1999).

3.1 Orientations toward teaching the cell topic

All of the teachers who participated in the research stated that the cell topic is an important one and that it should be presented as an obligatory topic within science and technology studies during junior high school. The teachers were asked the following question: If you were a member of the curriculum committee would you recommend the cell topic as an obligatory topic for grades 7–9? All of the teachers unanimously answered that they would recommend that the topic be obligatory. Their justifications were that the cell is a basic component of all biological topics studied, that the topic includes major biological principles and that it is essential for understanding biological phenomena.

Although the teachers had positive orientations toward the cell topic and exhibited a broad consensus about its importance to their students, they appeared to harbour different affective beliefs towards the issue. Some of the teachers referred to the fact that their students, and themselves, found the topic very boring, whilst some teachers declared that the topic was interesting to themselves and their students. Other teachers' stated that that the cell topic is intangible, hard to teach and difficult for the students to grasp. These beliefs may lead teachers to postpone teaching the topic until the last grade of junior high school or to minimise the time allotted to teaching it. The teachers emphasised the importance of teaching cell structure as an essential component for understanding every biological phenomenon, but often did not mention cell function or the relationship between structure and function with regards to the biological phenomenon being discussed.

3.2 Knowledge and beliefs about the cell topic curriculum

We first examined the learning progression with regard to the cell topic in junior high school. We asked the teachers' opinions of the meaning of the curriculum guideline, 'The cell is to be studied longitudinally in conjunction with the other study contents', and how they interpreted it. We then asked them to delineate the objectives of teaching the cell topic in junior high school.

When we asked the teachers who participated in the workshop to explain the meaning of the guideline – to teach the cell topic longitudinally – on a questionnaire that was handed out at the beginning of the workshop, 75 per cent of the teachers (n = 9) did not answer the question. The teachers who did answer this question expressed various interpretations as to its meaning. It seems that the teachers understood that there was a change in the teaching approach to the cell topic, and that the topic should not be studied separately in grade 9, as it had been prior to the new curriculum. However, the new teaching method was only semi-comprehensible to them.

Despite the different interpretations teachers provided for the curriculum's guideline 'The cell is to be studied longitudinally', all of the interviewed teachers agreed with this recommendation, for didactical and practical reasons. The teachers indicated that a gradual teaching of the topic while connecting it to other biological topics can contribute to the implementation of the concept of the cell.

In terms of the objectives of teaching the cell topic in junior high school, the teachers indicated that their students should know that the cell is the structural unit of every living organism, the function of certain cells such as sperm cells and muscle cells, and the biological hierarchy (molecules, cells, tissues, organs, etc.). The teachers stated that their junior high-school students should be familiar with the fact that the cell is the structural unit of every living organism, should be able to recognise cell organelles and should be able to accept the fact that every cell sustains all life characteristics. However, none of the interviewed teachers or those who participated in the workshop spontaneously mentioned that their students should know that processes that occur in multicellular organisms or that every biological phenomenon at the macroscopic level can be explained at the cellular level (a specific learning objective appearing in the curriculum).

The teachers indicated different approaches that enable them to teach the cell topic while relating solely to the microscopic level. The teachers did not consciously refer to the relationships between the various organisational levels and the connections that can be made between the micro- and macroscopic levels. We also found that the teachers were not familiar with all of the educational objectives that they ought to teach or with the majority of the learning materials that were developed in order to realise those objectives. They used materials that they had developed themselves or materials that they had already used before publication of the curriculum.

3.3 Knowledge and beliefs about students' understanding of the cell topic

The teachers who participated in this study declared that some of their students' difficulties originate from typical difficulties of junior high-school students in establishing explanations that require merging various pieces of scientific information. They were familiar with several of the students' difficulties, for example, in understanding the meaning and interpreting the size of living cells and the biological hierarchy. Teachers also knew that students encounter difficulties in understanding the image they see under the microscope, that students usually ignore the fact that living cells are three-dimensional and that they have difficulties in understanding cell structure, as well as cellular processes.

After being exposed to the assessment question, which included students' explanations of phenomena (see section 2), the teachers added that the students have difficulty integrating ideas from the macro- and the microscopic levels.

3.4 Knowledge and beliefs about assessment of the cell topic

To learn about the teachers' conceptions of students' assessment of the cell topic, we asked them what knowledge junior high-school students need to demonstrate in a test given after learning about the cell. The interviewed teachers were requested to bring tests that could be used to demonstrate junior high-school students' knowledge about the cell topic. Analysis of these tests showed that most of the teachers ask their grade 9 students to make a schematic drawing of the cell, recognise cellular organelles and demonstrate an understanding of the differences between an animal cell and a plant cell. Very few of the questions examined the understanding of grade 7 and 8 students about the cell. The teachers ask their junior high-school students simple factual questions require information recall related mainly to cell structure.

The national authority for measurement and evaluation of education in Israel (Meytzav 2005) influenced most of the interviewed teachers' instruction of the topic. The teachers claimed that the external evaluation system assists them in focusing their teaching and assessment. We analysed the teachers' reactions to the students' answers about: wilting plants on a hot dry day, sprouting of seeds, fertilisation of living organisms and embryonic development following insemination. These biological phenomena are taught in junior high school under the framework of the topics of water supply and reproduction (in grades 7 and 8). Most of the teachers estimated the answers given at the macroscopic level with the highest score (almost 90 points). The teachers changed their scores when they were exposed to the students' cellular level answers.

The teachers indicated that questions that require integrating topics from the macro- and microscopic levels in biology are usually only minimally presented to junior high-school students. The teachers stressed that they do not emphasise these relationships in their teaching, and that junior high-school students will find such integrations difficult. The teachers' attitudes caused them to minimise the emphasis on the relationships between the macro- and microscopic levels in grades 7 and 8 in biology. This is probably why the teachers evaluated the macroscopic level answers of the junior high-school students as meeting their level of expectation from their students. Furthermore, most of the teachers could not recall whether the national evaluations included questions about the cell topic. About half of the teachers indicated that the national examinations included questions related to the relationships between macro- and microscopic levels in chemistry but could not recall, or claimed that there are no such questions, in biology.

To examine teachers' conceptions about students' assessment of the cell topic in grades 7–9, we gave the teachers some questions about the cell topic that were not familiar to them (see section 2). We asked the teachers to classify the questions and to use them to design a test on the cell topic for each of the grades (7–9), and to eliminate those that they did not find suitable for junior high-school level. While classifying the questions, the teachers expressed their opinions and perceptions about the cell topic and the difficulties that junior high-school students encounter while learning the topic. The workshop teachers unanimously agreed that 15 of the 34 questions (44 per cent) were appropriate for a certain grade or for junior high-school in general. Forty-seven per cent of those questions were consensually categorised by the teachers as appropriate and suitable for grade 9, 13 per cent for grade 8 and 40 per cent for grade 7. This observation may indicate the differences among various teachers with regard to teaching the cell topic in junior high school. The task resulted in exposing teachers' beliefs about junior high-school students' knowledge and their expectations from their students with regard to the cell topic. The teachers claimed that they ask their junior high school students only recall-type questions, and use fewer questions that require written explanations, as such questions demand a higher cognitive level to answer them. As the junior high-school teachers do not expect their students to form relationships between the macro- and microscopic levels, it is not surprising that they do not help their students form such relationships.

3.5 Knowledge and beliefs about instructional strategies for the cell topic

The interviewed teachers described several of their teaching methods for the cell topic that they use to make the topic more accessible to their students. They noted that they prepare special tools, such as models of the cell, films and other educational tools that can facilitate illustration of the cellular level. The teachers referred to different topics with regard to the cell that were related to the microscopic level, but they rarely referred to a conscious connection of the different organisational levels in biology (the macro- and microscopic levels).

3.6 Teachers' duality with regard to relating macro- and microscopic levels in biology and in chemistry

All of the science and technology teachers who participated in this study, like their colleagues throughout Israel, teach both chemistry and biology in grades 7 and 8 in the framework of the science and technology curriculum. The teachers mentioned that they refer to different cellular aspects that are related to the microscopic level, but minimise their teaching of the relationships between the different biological organisational levels. However, junior high-school teachers emphasise the relationships and integration between the macro- and microscopic levels when they teach chemistry. It is natural for teachers who teach chemistry to require such explanations at the microscopic level (particles) from their grade 7 students.

Presenting questions to the teachers that required explanations of phenomena using cellular processes, and comparing this with what is required from their students in chemistry, resulted in doubts about emphasising the microscopic level while teaching biological phenomena. Comparing teaching strategies used by junior high-school teachers for biology versus chemistry topics forced the teachers to think about their way of teaching the cell topic. Most of the teachers who participated in this research suggested that a lack of awareness may be the cause. Some of them even stated that they do not know how to do this in biology or that they are still influenced by previous guidelines, their habits and by the learning materials. They said that a conceptual change in their thinking is needed.

It seems that there is a duality among the science and technology junior high-school teachers who participated in this study with regard to relating macro- and microscopic levels in biology and chemistry. These teachers were found here to lack the required PCK capacity to integrate biological phenomena at the macroscopic level with their cellular explanations.

4. DISCUSSION

The curriculum guideline 'The cell is to be studied longitudinally in conjunction with other study contents' (Israeli Ministry of Education 1996) can be considered a deep change in the teaching and learning of all biological topics in the framework of the science and technology curriculum in junior high school in Israel. This change obliges teachers to modify their ways of thinking and teaching the topic of the cell, as well as all of the other biology topics in junior high school. Due to the importance of the teachers' role in assimilating the change, their PCK with regard to the cell topic was examined in this study.

Magnusson *et al.* (1999) conceptualised PCK as comprising five intertwined components. Here, we used these five components to analyse junior high-school science and technology teachers' PCK with regard to the topic of the cell. Despite the importance the teachers placed on teaching and learning the cell topic in junior high school, their concerns about their students' comprehension difficulties reduced the time they devoted to teaching the topic in class. The teachers seem to experience conflict between their personal beliefs about the importance of the cell topic and their actual classroom practice. It seems that Israeli junior high-school science and technology teachers' PCK cannot support the required change in the teaching and learning of this topic. Considering our findings, it seems that the teachers who participated in this study have changed their way of teaching the cell topic only superficially (following Coburn 2003), by making minor adjustments: they did not undergo any deep change. Thus, experienced junior high-school science and technology teachers' PCK with regard to the cell topic cannot contribute to the required curriculum change.

There are several factors that may contribute to the establishment of teachers' PCK. Some of these may originate from the teachers themselves (internal factors) and some may stem from the educational system in which they work (external factors). The internal factors can be their professional development in terms of knowledge of the specific subject matter, especially while learning the topic as high-school and university students. All of the teachers learnt about the cell as an independent topic, focusing mainly on the microscopic level. Other internal factors can be the teachers' practical experiences, their habits of teaching the topic, their lack of awareness with regard to the curriculum and their fear of their students' inability to comprehend the topic.

The external factors can be related to the content of the curriculum guideline 'The cell is to be studied longitudinally'. This guideline carries minimal information and can be interpreted in a variety of ways. The teachers are required to change their thoughts and teaching habits, as well as their learning materials, while simultaneously considering the national evaluation system (Meytzav 2005). The teachers claimed that the external national evaluation system assisted them in focusing their teaching. However, most of the teachers could not recall whether the external evaluation included questions about the cell. We found that junior high-school science and technology teachers in Israel emphasise the relationships between the macro- and microscopic levels while teaching chemistry. However, the same teachers form far fewer relationships between biological phenomena at the macroscopic level and the cellular processes involved at the microscopic level. In other words, the teachers are occupied with teaching the cell topic at the microscopic level, and they rarely present the relationships between a macroscopic phenomenon and its cellular explanation. However, it is very natural for the same teachers to require chemical explanations for different chemical phenomena at the macroscopic level and to expect their students to provide explanations at the microscopic level.

Shifting between macro- and microscopic levels in chemistry has been reported previously to be problematic for secondary school students, whereas their teachers were often unaware of the students' learning difficulties in this domain (Van Driel *et al.* 2002). Here, we found that the teachers were aware of junior high-school students' learning difficulties with regard to the cell topic, but they were not aware of their difficulties in connecting macro- and microscopic levels in various biological topics, as previously suggested (Knippels 2002; Verhoeff 2003). The PCK of the teachers who participated in this study was based on minimal emphasis on the relationships between the different organisational levels while teaching biological topics in junior high school. This may explain some of the student difficulties in understanding the cell topic.

Here, we used assessment and evaluation questions as a tool to expose teachers' tacit PCK. We found this tool very useful, as teachers' conversations during their analysis of students' responses can expose teachers' behaviours in certain class situations and the reasons for their actions, without actually being present in their classrooms. As a result of this analysis, we do not claim that the teachers that participated in this study are a homogeneous group possessing only a single PCK pattern. The teachers had intra-mixed PCK patterns, according to Magnusson *et al.*'s (1999) components, with regard to the cell topic.

5. EDUCATIONAL IMPLICATIONS

The characterisation of teachers' PCK with regard to teaching and learning about the cell topic in junior high school can serve as a basis for designing teachers' professional development workshops as well as pre-service training programmes, which may help close the gap between the current teachers' PCK and students' comprehension difficulties, especially in terms of understanding the micro-/macroscopic relationships within living organisms. We have recently harnessed our current understanding of junior high-school science and technology teachers' PCK as a tool for creating a meaningful change among these teachers that will enable them to adopt the idea of teaching the cell topic longitudinally (Cohen and Yarden 2007).

This study shows that there is a wide spectrum of interpretations given by the teachers to the curriculum's recommendation to teach the cell topic 'longitudinally'. We suggest ensuring that the teaching guidelines and objectives of the cell topic are clearly explained to teachers before a meaningful change in their mode of teaching can be expected to take place. In addition, we suggest searching for instructional means that will enable a better understanding of biological phenomena in everyday life. We also believe that a discussion with teachers through assessment items and evaluation test questions is an efficient approach to assisting with and exposing their hidden PCK.

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22 What do biology tests look like in German grammar schools? A descriptive study about task formats and teachers' intentions for surveying different cognitive dimensions

Michael Germ[1] and Ute Harms[2]

[1]DIDAKTIK DER BIOLOGIE, LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN, GERMANY;
[2]LEIBNIZ-INSTITUTE FOR SCIENCE EDUCATION AT KIEL UNIVERSITY, GERMANY

michael.germ@lrz.uni-muenchen.de; harms@ipn.uni-kiel.de

This article reports data from a descriptive study about the current state of testing biological competencies by written tasks in grades 8–10 in German grammar schools ('*Gymnasien*'). Data were collected from two sources: the main focus was on an analysis of a large pool of tasks (600 in total) from biology tests in terms of both the task format and the different cognitive dimensions the tasks were able to test. In addition, a questionnaire was given to the teachers who had utilised the analysed tasks, to acquire statements about their attitude towards their preference or non-preference for specific task formats and their personal intentions for testing different levels of cognitive dimensions. The study revealed that an open-answer format requiring an answer in the form of a short text was preferred and that a very high percentage of tasks were limited to testing only the reproduction of knowledge. Another interesting fact and possible starting point for further investigations was the apparent lack of correlation between the results of the task analysis on the one hand and the teachers' self-reported intentions on the other.

1. INTRODUCTION AND RATIONALE

Particularly with regard to discussions about the results of the recent international students' assessment studies (TIMSS and PISA), the 'culture of tests' is being paid increasing attention in science education research today. As tasks for testing purposes at school are – beyond their traditional functions according to societal and pedagogical objectives – considered a key factor for the quality development of science teaching (Duit *et al.* 2002: 185), aspects concerning the method of testing or evaluating the learning progress have become critical issues for research in science education, especially with respect to the demand for teaching scientific literacy. The Programme for International Student Assessment (PISA) defines scientific literacy as the 'capacity to use scientific knowledge, to identify questions, and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity' (OECD 1999: 60).

As students' learning behaviours are supposed to depend on the quality of the tasks used for assessment, a type of assessment that closely follows the objectives expressed by the above-cited definition of scientific literacy will effectively contribute to the realisation of this theoretical concept (Duit *et al.* 2002: 184–185). Duit *et al.* (2002: 169) stress the importance of creating appropriate instruments for evaluating scientific competencies and capacities that are the essential components of contemporary educational goals in the science subjects. This leads to the need for tasks that require transfer and use of knowledge in various contexts and problem-oriented situations, mainly related to everyday life and to societally relevant issues.

Various suggestions for an examination of the present testing practice in the science subjects are also given by von Davier and Hansen (1998), who argue that tasks to solve problems of everyday life and to transfer acquired knowledge to new situations and applications have become an intentional part of assessment at school. The authors underline the necessity of exploring the nature of tests in German science lessons within the scope of intra-school attempts at quality assurance (von Davier and Hansen 1998: 2). For this purpose, they recommend an analysis of the tasks in tests presently used in German schools. Such an analysis could help draw a picture of how testing and assessing are currently conducted in the science subjects and how categories such as 'retrieving routine knowledge', 'connecting new matter with formerly acquired knowledge structures' or 'transfer of knowledge' are ranked in terms of their importance in the tests (von Davier and Hansen 1998: 21, 24). This empirical basis can then serve as a starting point for selective improvements of the current test practice. Such an investigation becomes especially important in consideration of the recent developments of certain standards for German school education ('*nationale Bildungsstandards*'; see KMK 2005), which include lists of particular competencies the students have to acquire. This focus on the outputs of educational processes emphasises the need for appropriate tasks that adequately agree with the named competencies. It is yet to be considered whether these efforts at improvement and building up of a 'new' test practice or task culture can be realised without profound knowledge about the status quo in schools; otherwise they will resemble searching for the best route to a certain destination on a map whilst one's own starting point is unknown. Due to the present lack of empirically based information about the characteristics of the tasks used in German biology lessons today, it becomes all the more evident that research studies that aim at a detailed description of the present task practice by using various methodological approaches are indispensable.

2. THEORETICAL BACKGROUND

2.1 Current discussion about task culture in science lessons – a short overview

There are various recent trends to develop a 'task culture' for the science subjects in Germany that seem able to contribute decisively to meeting the demands of science education today, aiming at a general body of tasks as well as improvements in terms of shaping certain task characteristics. The following aspects are the focal points of this approach (Häußler and Lind 1998; Kroß and Lind 2000):

1. Improving the integration of tasks in different teaching phases (see also Leisen 2001).
2. Developing tasks that can be solved in different ways.
3. Setting tasks into various contexts.
4. Developing suitable tasks for systematic recapitulation and connection to contents formerly dealt with in class.
5. Designing tasks that cover different cognitive process categories.

Additionally, learning from worked-out examples is discussed as a promising method for fostering an application of knowledge and problem-solving capacity. For detailed presentations and empirical investigations of this strategy, see Kroß and Lind (2000, 2001) and Sandmann *et al.* (2002), among others.

The rare use of tasks that involve the application of acquired knowledge and competencies to deal with certain questions set in definite contexts is often supposed to be a special deficiency in the current task practice of science subjects (Hammann 2006: 85). This aspect has recently drawn particular attention, notably due to the demands for an appropriate assessment according to PISA (see section 1).

2.2 Criteria for a task analysis

Biology tests can consist of different types of tasks, whose systematisation is not uniform in the literature. Some authors merely distinguish between 'tasks with an open-answer format' and 'tasks with a closed-answer format' (e.g. Zöller 1971: 12), whilst others name various numbers of different types of tasks (e.g. Häußler *et al.* 1998: 73 ff.; von Davier and Hansen 1998: 15 ff.; Duit *et al.* 2002: 173 ff.), mostly with regard to the degree of being able to design answers independently. In connection with the variety of different cognitive competencies that are associated with the concept of scientific literacy, the relevance of a broad range of various testing formats has been underlined (Duit *et al.* 2002: 172 ff.).

For the characterisation of the cognitive dimensions that are demanded by a task, miscellaneous categorising systems are cited in the literature. Widely known and thoroughly discussed frameworks for this purpose are the taxonomy by Bloom (1972) and its recent revision by Anderson and Krathwohl (2001). Particularly with regard to scientific literacy, Bybee's (1997) threshold model for levels of scientific literacy is also important in this context.

Bloom (1972) defined six major categories for the cognitive domain, most of them split into subcategories. These are named 'Knowledge', 'Comprehension', 'Application', 'Analysis', 'Synthesis' and 'Evaluation'. This order was assumed to correspond to increasing complexity and abstraction.

3. AIMS OF THE STUDY AND RESEARCH QUESTIONS

The study dealt with in this paper attempted to construct a multifaceted and profound image of how assessing by informal written tests (so called '*Stehgreifaufgaben*') is currently carried out in German biology lessons. Technical restrictions and time limits, as well as the desire to deal with a set of comparable tasks, made the survey focus on grades 8–10 (students aged approximately 13–16 years) in German grammar schools ('*Gymnasien*').

The identification of the cognitive dimensions covered by a task and labelling of its formal type were considered adequate to outline the constitutive elements of the current testing mode as a basis for discussing its appropriateness for teaching and assessing biology.

Specifying the task format was the most obvious aspect for the analysis of tasks mentioned in the literature. In this regard, a broad range of different formal types of tasks are available for biology to assess the variety of scientific performances and competencies. Hence, it was necessary to gain insight into how far the amplitude of this range is actually used in German school practice, i.e. whether certain types are preferred whilst others play only a minor role. These aspects were expressed in research question Q1:

> Q1. Which task formats are used for tests in biology lessons and how often? Are there task formats that are mentioned in literature but not used in German school practice?

Every task type features specific advantages and preferred scopes of application in terms of evaluating certain cognitive processes. Concept maps, for example, seem especially suitable for the diagnosis of comprehension (Duit *et al.* 2002: 181–182). Therefore, for a meaningful interpretation of the results of research question Q1, the background of teachers' intentions in applying their favoured types of task also needed to be analysed. It was important to know whether the use of the detected task formats was guided by mere routine without respecting the different formats' pros and cons or whether their particular advantages and capabilities for specific objectives were clearly seen and reflected upon. This lead to research question Q2:

> Q2. Which arguments are given by teachers to explain a favoured use of definite task formats for their biology tests in contrast to others?

Particularly with regard to the discussion about the spectrum of competencies related to scientific literacy, the investigation of the cognitive process categories covered by the examined tasks have to play a major role in every research effort that tries to evaluate the current state of testing practice in science subjects. Therefore, research question Q3 stated:

> Q3. Which cognitive dimensions are covered by the tasks used for biology tests in practice?

Furthermore, in this context an insight into the intentions of the teachers who utilised the analysed tasks was important: which particular competencies did they focus on in their biology lessons and which cognitive process categories did they therefore intend to give special emphasis to in their biology tests? Based on this information, whether the teachers' aims and intentions were congruent with the results of research question Q3 or whether a possible divergency could be revealed was able to be explored using question Q4:

> Q4. Is there a correlation between the results of the analysis of tasks used for biology tests with regard to the cognitive dimensions on the one hand and the teachers' self-reported intentions on the other hand?

These research questions formed the centre of the empirical study reported in this article. Other less important matters that were dealt with additionally are not referred to in this context.

4. METHOD AND DESIGN

4.1 Sample and methodological approach

To investigate the above research questions, a broad data collection was completed methodologically based on two sources: firstly, the analysis of a sample of tasks used in practice; and secondly, additional data collected using a questionnaire given to the teachers using the tasks.

Overall, 11 biology teachers from three different grammar schools in Munich participated in the data collection. From these data, a pool of 600 single tasks was catalogued for the task analysis.

4.2 Task analysis

As already mentioned in section 2, the analysis of the collected tasks followed two fundamental classification criteria: labelling of the task format and identification of the different cognitive dimensions that are required for dealing with the tasks successfully.

To analyse the task formats, the following types of task were differentiated:

1. Right-or-wrong tasks.
2. Multiple-choice tasks.

3. Rearrangement tasks.
4. Completion tasks (subtypes: cloze test, annotation of figures).
5. Open-answer format requiring the answer in a short text.
6. Open-answer format asking for a concept map.

Each of the alternative categorising systems for defining and arranging the cognitive processes required by a task that were cited in section 2 was considered only partially appropriate as a suitable instrument for analysing the biology tasks according to the aims of the study, each having particular advantages and disadvantages. Finally, a proposal by Häußler *et al.* (1998: 72) was adopted, which also deals with this problem. It refers very closely to Bloom's taxonomy, including the following modifications to produce five subcategories:.

The 'Knowledge' category, which was assumed to be affected by a high percentage of the collected tasks, was divided into two new categories:

1. 'Knowledge of single facts or terminology' (abbreviated to 'Knowledge I').
2. 'Knowledge of concepts, theories and principles' (abbreviated to 'Knowledge II') to facilitate more detailed statements.

These first two levels are limited to the mere reproduction of certain material in basically the same way or form as it was dealt with in the preceding lessons. However, it is emphasised that there is a qualitative difference and also a graduation in demands about whether a certain task only applies to retrieving single facts (e.g. local or temporal issues, names, numerical values or units) or scientific concepts, theories and principles.

3. 'Comprehension' mainly involves the capability not only to reproduce information, but also to reorganise memorised or given material in a certain new way. This category is also affected when a task demands the description or summary of a text, a table or a diagram as well as the translation of a (verbal or non-verbal) message into another form (e.g. formulas, symbolic languages), as it has already been constituted in Bloom's original taxonomy, due to the fact that here a restructuring of information also becomes important.
4. 'Higher cognitive competencies' is a category that integrates Bloom's categories 'Application', 'Analysis' and 'Synthesis', ones that are often not easy to distinguish in the context of science education. A task was also subsumed under this category when it focused on solving new problems or processing and interpreting experimental data (i.e. beyond their mere description or summary).
5. 'Evaluation' means rational judgement, balancing opposite points of view, as well as integrating a scientific issue into a historical, political or societal context.

This framework seemed both adequately manageable and sufficiently detailed for the analysis of the task pool. Due to its closeness to Bloom's traditional framework, it also promised to be appropriate for the target group of biology teachers, for it must be assumed that the most recent developments in the discussion of tasks and demands might not yet necessarily have found sufficient and widespread attention. Cohen's Kappa coefficient was determined as 0.70 for the intercoder reliability.

Figure 22.1 offers concrete examples of tasks from the examined sample to clarify the method of classifying tasks with the chosen categorising system for cognitive dimensions.

Figure 22.1 (opposite) Examples out of the analysed task pool (T1–T8), arranged according to the applied categorising system for cognitive dimensions. Note: each task was assigned to the highest category that it is able to test

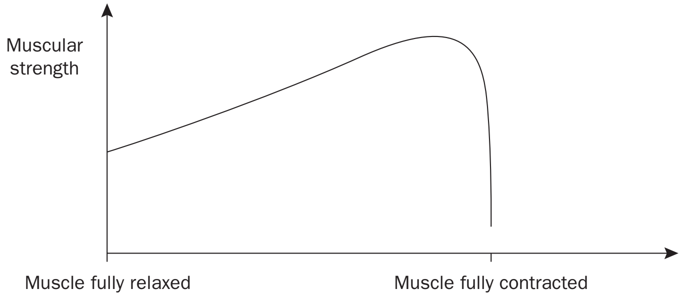
Knowledge of single facts or terminology ('Knowledge 1')
T1. How high is a healthy person's average blood sugar concentration?
T2. Which phylum does *Hydra* belong to in the system of animals?

Knowledge of concepts, theories and principles ('Knowledge II')
T3. Define the concept 'symbiosis'.
T4. Explain the sexual reproduction of the earthworm.

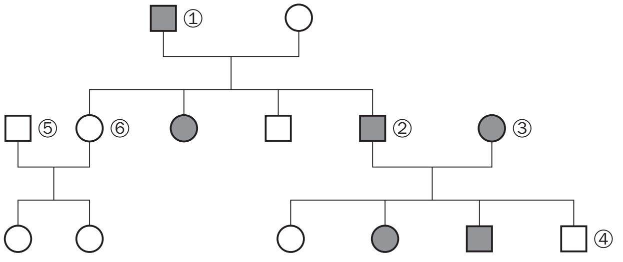
Comprehension
T5. Maltase plays an important role in digestive processes in the small intestine by degrading maltose to glucose.

(a) Represent the function of this enzyme by means of a simple labelled diagram.
(b) Explain the concepts 'substrate specificity' and 'function specificity' relating to the concrete example maltase.

T6. The following diagram shows the dependence of the muscular strength on the degree of contraction. Describe the changes in muscular strength for increasing contraction.



Higher cognitive competences
T7. The following figure presents the genealogical tree of a family, within which the hereditary disease 'brachydactyly' occurs. The family members showing the symptoms (i.e. having shortened phalanges) are hatched



(a) Is the disease caused by a recessive or a dominant allele? Give a reason for your answer.
(b) Determine the genotypes of persons 1, 2, 3 and 4. (Notation: B/b for dominant/recessive allele)
(c) Couple 5 and 6 want to have more children but worry about whether these could suffer from the disease. Comment on this issue.

Evaluation
T8. An old Egyptian papyrus (approx. 1500 BC) delivers the following advice:
'. . . mouldy bread laid on a wound is the strongest remedy for suppurating wounds . . .' Discuss what evidence there is for and against this cure from today's point of view.

4.3 Collecting data using the questionnaire

In the first part of the designed questionnaire, the teachers were asked in two open-answer questions which task formats they preferred for their biology tests and what their reasons were for this preference. In a second step, the participants were asked to rank the different cognitive dimensions in terms of how often they are required in their biology tests using a five-step bipolar rating scale. In order to reduce the necessary instructional comments in the questionnaire, the two categories 'Knowledge I' and 'Knowledge II' (see section 4.2) were integrated to a subsuming category 'Knowledge', thus leading to a total of four different rating items in this context.

5. RESULTS

5.1 Task formats in biology tests

The frequencies of the different formal types of task listed in section 4.2 that could be found in the sample were counted and related to the total of 600 tasks. Table 22.1 shows the data obtained.

An outstanding feature was the predominance of the open-answer format: over 90 per cent of the examined tasks require an answer in the form of a short text. In comparison, all of the other types that were detected were of much less importance: completion tasks, whose different subtypes overall amounted to 5.5 per cent of the sample, were second, whilst multiple-choice and right-or-wrong tasks lagged far behind (2.0 per cent overall). Concept maps were not represented in the sample.

Examination of the questionnaire revealed that the teachers were conspicuously in favour of the conventional open-answer format (11 mentions of this type as the preferred way of formulating tasks). The arguments brought forward in this regard could be classified using three main statements:

1. Open-answer tasks are attributed the highest potential for evaluating the comprehension of the issues being dealt with.
2. The general capacity to verbalise, express and communicate biological matters is regarded an essential objective and therefore relevant to evaluation.
3. Open-answer tasks are able to cover a broad range of different cognitive competencies, ranging from reproduction to transfer.

Table 22.1 Absolute and relative frequencies of the different task formats (formal task types) that were found in the sample

Formal task type	*Absolute frequency*	*Relative frequency (%)*
Open-answer format (giving answers in form of a short text)	551	91.8
Multiple choice tasks	4	0.7
Right-or-wrong tasks	3	0.5
Right-or-wrong tasks combined with writing a text	5	0.8
Completion tasks		
• Cloze test	4	0.7
• Annotation of figures	29	4.8
Rearrangement tasks	3	0.5
Not attributable	1	0.2
Total	600	100

Less emphasis was given to completion tasks that demanded the annotation of figures (eight entries). Typical arguments in favour of this type of task were: 'short and clearly arranged', 'easy to correct' and 'applicable for evaluating anatomical knowledge'.

All other types of task were also considered to be of little significance: there were four entries for multiple-choice tasks (the only reason given being that they are 'easy to correct') and one for cloze tests, which were all bound by additional restrictions such as 'only in exceptional cases' or 'very rarely'; they are apparently not accepted to a large extent.

5.2 Cognitive demands in biology tests

The distribution of the different cognitive categories within the examined pool of 600 tasks is shown in Figure 22.2.

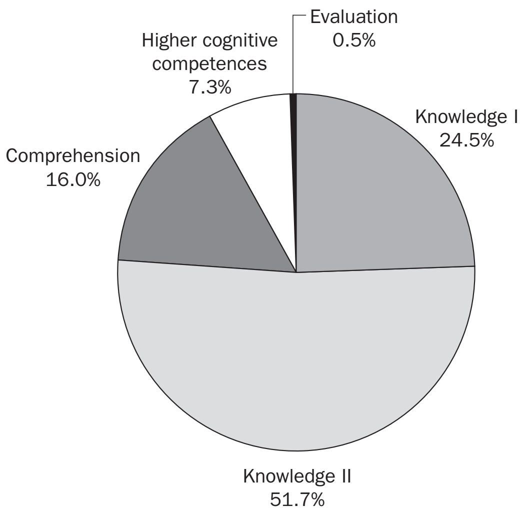


Figure 22.2 Distribution of the different cognitive categories within the examined task pool. Note: each task was assigned to the highest category it was able to test

In this diagram, those tasks that covered more than one cognitive category were assigned to the highest category in each case. Hence, a task allotted to 'Comprehension', for example, covered the category 'Comprehension', but not 'Higher cognitive competencies' or 'Evaluation', whereas it was not noted whether the task also demanded any kind of 'Knowledge' to be dealt with successfully. In this way, the frequencies for the different cognitive categories added up to 100 per cent as they did not overlap, making it possible to carry out correlation analyses (see below).

As Figure 22.2 shows, 76.2 per cent of the analysed tasks were restricted to mere reproduction of knowledge, with the category 'Knowledge of concepts, theories and principles' takes centre stage. There was evidently less focus on 'Comprehension' (16.0 per cent) and 'Higher cognitive competencies' (7.3 per cent), and tasks that demand 'Evaluation' were rarely found in the sample (0.5 per cent). As regards this mode of weighting of the various cognitive categories, no important differences could be perceived among the 11 teachers.

5.3 Correlations between the results of the task analysis and teachers' intentions

Overall, only tendencies with very low correlations or in some cases even no correlations at all could be found between the results of the task analysis and the teachers' self-reported intentions (see Table 22.2), none of them reaching statistical significance.

Table 22.2 Correlations between the results of the task analysis and the teachers' self-reported intentions concerning the cognitive categories 'Knowledge', 'Comprehension', 'Higher cognitive competencies' and 'Evaluation'

Category examined	*Correlation coefficient (r)*
'Knowledge'	0.074
'Comprehension'	–0.258
'Higher cognitive competencies'	0.018
'Evaluation'	–0.443

Tendencies with low correlations could only be detected for the categories 'Comprehension' and 'Evaluation', although both were negatively correlated (r = –0.258 and –0.443). This means that those participants who rated them particularly highly in fact use tasks that cover these categories all the more rarely. In all of the other cases, no correlation between the results of the task analysis and the teachers' self-reported intentions could be found.

6. DISCUSSION AND CONCLUSION

In the sample examined, a general mistrust of the potential of tasks with a closed-answer format as appropriate instruments for evaluation was evident, where even important advantages such as their enhanced objectivity were not considered. The application of completion tasks was obviously limited to particular aspects where they seemed more suited than open-answer tasks (e.g. testing anatomical knowledge). The present lack of concept maps as parts of biology tests can primarily be traced back to the fact that they are still being largely unknown.

Overall, an open-answer format that requires an answer in a short text was preferred and argued for. In this context, particular focus seemed to be on the demand to express and verbalise biological matters. Such a position might be legitimised in view of some particular aspects of current German educational standards (see KMK 2005): for the subject of biology, these describe the field of 'communication' competence, which refers to the capacity to present and discuss scientific matters, cognitions and phenomena adequately. The criteria that define this competence (e.g. comprehensibility, clarity, purposeful arranging and applying certain materials, as well as an adequate use of scientific language) are very closely related to the aspects that are inevitably also required by an open-answer task format.

In view of the analysis of the cognitive dimensions, the current test practice represented by the sample discussed seems only partially able to meet the demands of science education today, particularly with regard to the evaluation of competencies connected to the concept of scientific literacy. The most striking result of this was the heavy emphasis on tasks that did not require any cognitive competencies beyond 'Knowledge', and thus were limited to the mere reproduction of certain matters dealt with in class. This mode of compiling biology tests inevitably leads to the conclusion that German biology lessons currently draw little attention to the application of knowledge, transfer and problem-solving, as well as processes of valuation and judgement. Against this background, it is no wonder that these aspects, which take centre stage in the PISA science tests, represent particular problems for German students (Kattmann 2003: 121; Mayer 2004: 92–93). The results of the task analysis are consistent with the assumption that their main capacities seem to be restricted to describing and defining scientific matters conceptually, and their competencies are limited to dealing with them in a defined content frame (Kattmann 2003: 121). Addressing this issue, especially the inferior status of tasks that focus on higher cognitive competencies, will require attention in the long run. When conveying higher cognitive competencies (e.g. the ability to apply certain knowledge situationally) is mentioned as an important goal of modern science education, it is indispensable that appropriate tasks become a part of the assessment (Duit et al. 2002: 184).

On the other hand, the relevance of knowledge as an educational goal, especially in the science subjects, must not be underrated for several reasons (Bloom 1972: 44 ff.): firstly, a growth of knowledge indicates an overall development of someone's cognition of reality, which is why knowledge also bears a social and cultural relevance as a characteristic for individual maturity. Moreover, knowledge constitutes the necessary basis for all further objectives of the cognitive domain; in other words, higher cognitive competencies can only be accomplished in relation to concrete factual matters. Finally, aspects of the affective dimension (such as interests and attitudes) also develop as a result of increasing knowledge.

Another key result was the apparent lack of correlation between the results of the task analysis and the teachers' self-reported intentions concerning the whole range of cognitive dimensions. Searching for possible reasons for this, in the first place methodological aspects also have to be put into focus, especially the uncontrolled tendencies in the answers in data collected with the questionnaire, for example the tendency towards social acceptance – such methodological deficiencies may have carried particular weight when the teachers have reflected insufficiently on their current test practice and aspects of task culture (e.g. the connection between objectives and adequate assessment tasks) so far. Provided that the teachers have dealt thoroughly with the demands for a contemporary evaluation of science lessons and have clear intentions regarding the mode of testing their students' competencies, then an actual contradiction and therefore critical issue and suitable starting point for further investigations could have been revealed. A first step could, for example, include problem-centred interviews with the teachers involved. Without further results, a main reason for the missing correlation might seem to be in the current lack of a satisfactory assortment of well-commented upon and approved examples of tasks referring to higher cognitive competencies.

Overall, the study seems to have provided a valuable insight into the status quo of task culture and testing practice, pointing out particular indications for further investigations and underlining the clear-cut necessity for biology and science education research in this field.

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23 Motivational and cognitive effects of learning in a natural history museum with differently structured tasks

Matthias Wilde[1] and Detlef Urhahne[2]

[1]UNIVERSITY OF BIELEFELD, BIELEFELD, GERMANY; [2]LUDWIG-MAXIMILIANS-UNIVERSITY MUNICH, GERMANY

matthias.wilde@uni-bielefeld.de

According to Reinmann-Rothmeier and Mandl (2001), learning environments should provide an ideal balance between constructivist and instructive elements. Most interesting for constructivist learning processes is the combination of the cognitive and the motivational domain. In an empirical study with 207 fifth graders of the highest stratification level ('*Gymnasium*'), we evaluated three different approaches to the learning process based on a visit to the Natural History Museum in Berlin: the three approaches were characterised mainly by closed, open and mixed tasks. One objective of our study was to assess learning achievement through the visit and the effect of different treatments. Another goal was to evaluate the motivation of the three treatment groups. We conducted a pre-/post-test study with follow-up measurements. The test assessments consisted of 26 open-ended and closed questions in the cognitive domain and 12 questions subdivided into four subscales for measuring motivation according to self-determination theory. In contrast to our hypotheses based on constructivist theories, open tasks were less successful for gaining knowledge and less intrinsically motivating.

1. INTRODUCTION

In the analysis of learning processes, the question of self-regulation is regarded as a major factor (Reinmann-Rothmeier and Mandl 2001; Reinmann and Mandl 2006). Self-regulation needs to be considered with respect to two dimensions.

The first dimension concerns the real choices of the learner – the possibility of making genuinely different decisions. In different kinds of learning processes, this degree of self-regulation varies considerably. In traditional approaches, 'closed' methods dominate learning and teaching processes. The learners are guided closely. Instruction – the input – is designed to meet exactly the assumed prior knowledge and the assumed cognitive level of the learners, as well as the intended output (Skinner 1968, 1971; Bloom *et al.* 1976; Issing 2002). This 'technological perspective' (Reinmann and Mandl 2006) focuses on predictable outcomes of the learning process. Consequently, in traditional approaches, the real possibilities of self-regulation are very limited. In contrast, constructivist approaches, where our focus is on educational constructivism (Matthews 1998; Gerstenmaier and Mandl 1995), favour more open methods. Ideally, the process is learner-centered (Reinmann-Rothmeier and Mandl 2001; Mandl *et al.* 2002). In an ideal set-up, learners are in an active position, free to construct their own reality in situated environments, work at their own pace and take their own decisions, and are aware of their prior knowledge, their cognitive capacities; they decide their personal aims and know their current status in the learning process (Reinmann-Rothmeier and Mandl 2001). The learning output of this process cannot be predicted with any accuracy (Winn 1992). Teaching approaches that live up to this must be very open indeed. The extent of real choice with these constructivist approaches is almost unlimited. Learning environments meeting these conditions cannot be easily implemented in output-oriented institutions designed for educating large numbers of pupils, e.g. schools. Young pupils especially cannot gain deeper insights into all of those aspects covered by their curriculum that are deemed necessary by society. They cannot be expected to have reasonable personal aims and sufficient awareness of these aims. They cannot be expected to have sufficient meta-cognitive awareness and they can hardly be expected to possess the discipline to act in a goal-oriented way. As all of this affects their status in the learning process, it demands an adjustment of the constructivist approach. For less gifted pupils in particular, the excessive demands can lead to disorientation and poor learning results (Gräsel and Mandl 1993). Because of the unpredictability of the learning outcomes, constructivist approaches have been criticised as inefficient (Reinmann-Rothmeier and Mandl 2001). Therefore, moderate constructivist approaches are preferred by many practical educators, e.g. teachers, and by researchers implementing constructivist approaches, e.g. Vance *et al.* (1995), Lord (1997), Hay and Barab (2001) and Liang and Gabel (2005). According to Reinmann-Rothmeier and Mandl (2001), moderate constructivism is characterised by 'active, social and self-regulated' learning processes in 'situated' learning environments in order to encourage the 'construction' of the learner's own reality. According to this approach, a learning environment should provide an ideal balance between constructivist and instructive elements. If it is too unstructured, the process may be overdemanding (Gräsel and Mandl 1993). If the learning process is too strictly structured, it may lead to inert knowledge (Gräsel 2000; Gruber *et al.* 2000; Gräsel 2006). Self-regulation is one of the most important instruments for the researcher to adjust this balance. The goal is to find a degree of real choice fitting the learner's possibilities and constraints, enabling him or her to build up meaningful constructions.

The second dimension regarding self-regulation may be described as one of Deci and Ryan's (2000) innate psychological needs for competence, autonomy and relatedness. As understood in this study, the perceived self-regulation is very closely related to Deci and Ryan's (1985, 1993, 2000) perceived autonomy. Obviously, the degree of real choice can be one criterion influencing the perceived autonomy. Interestingly, identical possibilities of real choices might lead to very different perceptions of autonomy (Grolnick and Ryan 1987). Hence, the perception of self-regulation is not only caused by real possibilities of choice and control. Rewards and punishments undermine the perceived autonomy, whereas providing choice and acknowledging feelings enhances it (Deci and Ryan 2000). In traditional approaches, the perceived autonomy might not only suffer from the limited choices given to the learners but also from evaluation that is a backbone in most forms of designed instruction. Rewards and punishments, e.g. grades, are usually given. The perceived autonomy in traditional forms of science education is presumably low. In constructivist approaches, real choices are given to the learner. Rewards and punishments are absent. Learners can be expected to feel their need for autonomy satisfied. Moderate constructivist approaches providing a balance between constructivist and instructive elements might benefit from this situation. The learning process might eventually be arranged within a structured framework and at the same time permit minor choices and enhance the learner's acknowledged feelings. The learner's perception could be that of satisfied autonomy.

The quality of intrinsic motivation is closely related to the satisfaction of psychological needs, for example perceived autonomy. The quality of learning processes is related to the quality of motivation (e.g. Gottfried 1985, 1990). Situations decreasing the perceived autonomy were found to lead to suboptimal learning outcomes, e.g. a decrease in creativity, complex problem solving and deep conceptual processing (Deci and Ryan 2000). This combination of the cognitive and the motivational domain is particularly interesting for learning processes (Liang and Gabel 2005; Kang *et al.* 2005; Krombaß and Harms 2006).

We conducted this study in the Natural History Museum of Berlin. This informal setting can enhance the possibilities of implementing different degrees of real or perceived self-regulation. Furthermore, self-regulation is described as one of the major factors affecting learning in a museum (Falk and Dierking 2000; Falk and Storksdieck 2005a, b; Wilde 2007). Depending on the visitor's background, his or her previous experience, interests, etc., a visit to a museum leads to unique experiences with the potential for long-lasting effects (Rennie and Johnston 2004). Rennie and Johnston (2004) have described the impact of museums on people's lives and argue that these changes involve learning. In this study, processes of learning were expected from pupils visiting the Natural History Museum of Berlin.

2. RATIONALE OF THE DESIGN

Recent studies have shown that, for fifth graders at high school, a medium approach between constructivist and instructive elements, in particular between self- and externally regulated learning processes, was most successful regarding the learning achievement of the pupils in an excursion to a natural history museum (Wilde *et al.* 2003; Wilde 2004). Looking for perfectly balanced instructions, in this study our focus was on the tasks themselves. Two treatments of differently structured tasks (closed vs. open) were constructed. The content of the tasks was absolutely identical. The subject of this study was the pupils' motivation and learning achievement caused by the visit to the museum. Additionally, using a third treatment, we investigated whether pupils preferred open or closed tasks.

3. OBJECTIVES

The key objectives of our study were to evaluate the pupils' learning achievements and the motivational consequences of our treatments, and to observe and discuss pupils' choices. According to the theory, our hypotheses were as follows:

1. The visit to the museum would leads to knowledge gains. This would hold true for short-term as well as long-term learning achievement.
2. Open tasks would lead to better learning achievement than closed tasks. In particular, open tasks would lead to better results in the longer term.
3. According to the self-determination theory (Deci and Ryan 1985, 1993, 2000), open tasks contribute more to higher intrinsic motivation than closed tasks. In this theory, the mixed group would show medium motivation.

4. METHOD

4.1 Sample

The study was conducted with 207 fifth graders from Berlin of the highest stratification level ('*Gymnasium*'). Pupils were on average 10.5 years old and 54.4 per cent were girls. In this study, the highest stratification level means that the pupils started the grammar school in grade 5, which is somewhat unusual for Berlin. In the Berlin school system, pupils usually start *Gymnasium* in grade 7. Therefore, the sample consisted of a fairly homogeneous group of high achievers.

4.2 Assessment

The question set for the cognitive domain consisted of closed and open-ended questions; with a total of 26 questions. The closed questions were of a multiple-choice type with one correct and three false answers; for example:

> Where do 'Wintergäste' ['winter guests', i.e. a type of migratory bird that spends the winter in Germany] spend the summer?
>
> (a) In Sudan; (b) in Germany; (c) in Sweden; (d) in Africa.

The response could be right (underlined, 1 point) or wrong (no points). The open-ended questions requested factual and conceptual knowledge (see Anderson *et al.* 2001), e.g. descriptions, comparisons or explanations. For example:

> Compare 'Wintergäste' ['winter guests'] and 'Sommervögel' ['summer birds', i.e. a type of migratory bird staying in Germany during their breeding period in summer and leaving in autumn].

The response could be satisfactory (2 points), partly satisfactory (1 point) and not satisfactory at all (no points). The reliability of the scales was sufficient (Cronbach's α coefficient = 0.65). For measuring intrinsic motivation, we used a modified version of the intrinsic motivation inventory (IMI; Deci and Ryan 2003). Like Krombaß and Harms (2006), we used 12 questions with a 5-point Likert scale with the subscales 'interest/enjoyment' (sample question: The activity in the museum was fun to do), 'perceived competence' (sample question: I was pretty skilled at the activity in the museum), 'perceived choice' (sample question: I believe I had some choice about doing the activity in the museum) and 'pressure/tension' (sample question: I felt pressure while doing the activity in the museum) As an indicator for internal consistency, Cronbach's α coefficient was calculated as: 'interest/enjoyment': α = 0.85, 'perceived competence': α = 0.83, 'perceived choice': α = 0.75 and 'pressure/tension': α = 0.54.

4.3 Design

We carried out a pre-/post-test design with a follow-up test (post-test II) after 4 weeks (Figure 23.1). The questionnaire regarding the learning achievement was included in the pre-test, the post-test and the post-test II, whilst the questionnaire regarding motivation was only included in the post-test. Furthermore, we controlled possible knowledge gains based solely on the pre-test (i.e. without a museum visit) by a control group of pupils (n = 33) following the schedule pre-test/no treatment/post-test/post-test II. This group showed no significant learning gains from pre-test (M = 9.21, SD = 3.30) to post-test [M = 8.09, SD = 3.65; $t(32)$ = 1.68, not significant (NS)] and from pre-test to post-test II (M = 8.00, SD = 3.85; $t(32)$ = 1.82, NS). Therefore, a pre-test effect could be excluded.

4.4 Procedure

All pupils worked on three sections of the museum, each covering a set of three to five displays. We constructed lessons on bird migration (section one), reproductive strategies of birds corresponding to their habitats (section two) and lessons on reproductive strategies of native fishes (section three). During the visit, cognitive load was controlled by questionnaire items (Chandler and Sweller 1991; Paas and van Merrienboer 1994; Kirschner 2002). Pupils worked in groups of three to four children,

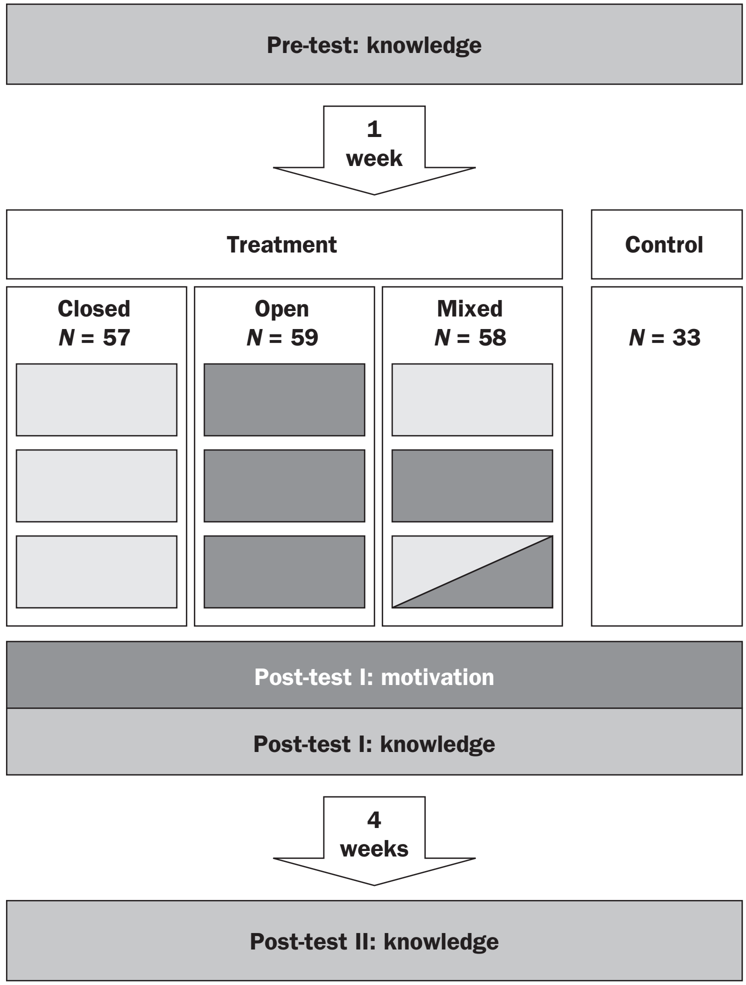

Figure 23.1
Design of the study

a particularly effective size for group work (Lou *et al.* 1996). Furthermore, the time every participant spent at each section was controlled. On average, the time spent at one section was 25 minutes. After finishing every section, pupils went to their meeting point where they worked on a task of medium attractiveness until their working period of 30 minutes was completed. The intention of this task was not to encourage pupils to shorten the time at their original section. The task was to produce an exact drawing of given exhibits, consisting of displays of taxidermic specimens of mammals and birds or of insect models. Each time, after finishing their tasks at their section, the pupils continued this intermediate task.

4.5 Realisation of the treatments

Initially, we created two treatments implementing differently structured tasks (closed vs. open). The closed tasks were created to give the pupils minor opportunities for self-regulation; the open tasks were created to give them more opportunities of self-regulation. At the same time, the contents of both treatments, i.e. the contents of both types of task, were supposed to be identical. This was essential to ensure a meaningful comparison between treatments 1 and 2 for the learning achievement of the pupils. Thus, the opportunities of creating tasks as differently self-regulated as possible were somewhat constrained. Nevertheless, treatments 1 and 2 differed substantially. To create treatment 1, we started from the most instructive point of view. The tasks consisted only of closed questions (multiple-choice answers). For example:

1. What characterises ‘Wintergäste’ [‘winter guests’]?
   (a) ‘Wintergäste’ come from southern Europe.
   (b) ‘Wintergäste’ spend the winter in Germany.
   (c) ‘Wintergäste’ live in Sweden or Finland during the summer.
   (d) ‘Wintergäste’ leave Germany in the autumn, heading north.
2. Why do some small birds, e.g. redpolls (*Acanthis flammea*), migrate to Germany in winter?
   (a) They spend the winter in Germany because here they can hide from predators in scrub, bushes, and gardens.
   (b) They spend the winter in Germany because of the food situation. In winter, they cannot find seeds or fruits in their summer habitat.
   (c) They spend the winter in Germany because in scrub, bushes and gardens there are very good opportunities for nesting.

The responses could only be given by ticking off small boxes. Pupils were restricted to the question and to the possible answers. What they actually needed to do to accomplish these tasks was to recognise the correct alternatives given previously. This does not necessarily imply a low level of cognitive requirement. To recognise a correct answer might involve all sorts of cognitive processes to decipher the relevant information from a display, a text, etc. However, compared with treatment 2, the possibilities of open-minded thinking were constrained.

Treatment 2 consisted of open tasks that were created corresponding to the closed tasks of treatment 1 by maintaining its content. For example:

1. Where is the home country of ‘Wintergäste’ [‘winter guests’]?
2. When and why do ‘Wintergäste’ [‘winter guests’] come to Germany?

To recording the open tasks, an empty space of squared paper was provided on the sheets containing the questions to indicate more possibilities than merely writing a short text, such as sketching, e.g. the mating behaviour of sticklebacks (*Gasterosteus aculeatus*), drawing details of a given exhibit, outlining a map with air routes of certain migratory birds or producing tables/diagrams with explanatory notes. The absence of possible answers in treatment 2 allowed more self-regulation in putting down the response to the task. More importantly, this absence allowed and demanded a much less restrained exploration of the displays and a less controlled thinking about the required reply. Objectively, treatment 2 permitted more self-regulation.

Furthermore, we created a third treatment by combining treatments 1 and 2: given the three sections at the museum, treatment 3 meant passing through a section with closed tasks (from treatment 1), another section with open tasks (from treatment 2) and in a third section the pupils could choose between closed tasks and open tasks. The pupils were not informed about the nature of the tasks themselves. Instead, the work sheets were colour-coded. In this way, their choice was based on the perception of whether the green (closed tasks) or the yellow (open tasks) work sheets were preferable. Thus, we constructed three treatments, one with tasks of closed questions, one with tasks of open-ended questions and a combined treatment.

In this way, we provided differently structured settings: treatment 1 was characterised by instructive elements. In this informal setting for the pupils, this does not necessarily mean a low level of perceived autonomy. Treatment 2 – possibly likewise benefiting from the pupils' perception of autonomy in informal settings – was an approach providing a balance between constructivist and instructive elements. Treatment 3 combined the two treatments and offered a choice between open and closed tasks.

5. RESULTS

Regardless of the treatment, a visit to a museum was expected to increase the pupils' knowledge. The results showed significant learning gains from pre-test ($M = 10.01$, SD = 2.78) to post-test ($M = 16.31$, SD = 4.64; $t(173) = 18.34$, $P<0.001$). The effect size of $d = 1.56$ suggested its relevance. After 4 weeks, this increase in knowledge still existed. As Figure 23.2 shows, the results of post-test II ($M = 13.90$, SD = 4.07) indicated significant learning gains ($t(166) = 12.93$, $P<0.001$). An effect size of $d = 1.12$ revealed a long-lasting learning success. As expected, compared with short-term achievement, the long-term results were reduced. From post-test to post-test II, a significant decrease was measured ($t(166) = 8.21$, $P<0.001$, $d = 0.55$).

The second hypothesis predicted differing results when differing treatments were implemented. Figure 23.3 shows the results depending on the differing tasks. In the pre-test, all treatment groups show a very similar base level. In the post-test, an ANOVA with the dependent variable knowledge and control variable prior knowledge shows no significant differences between treatment groups for learning achievement ($F(2,170) = 1.74$, ns). In contrast to our second hypothesis, pupils with open tasks did not learn more than pupils of other treatment groups. Also in post-test II an ANOVA with the control of prior knowledge reveals no significant differences between the treatments ($F(2,163) = 0.34$, ns). Even in the long term, open tasks did not result in better learning achievement than closed tasks.

In our third hypothesis, motivational differences between the treatments were expected: we expected that open tasks would contribute to higher motivation of the learners. The results of this question are shown in Figure 23.4. An analysis of variance with the four subscales of IMI as dependent

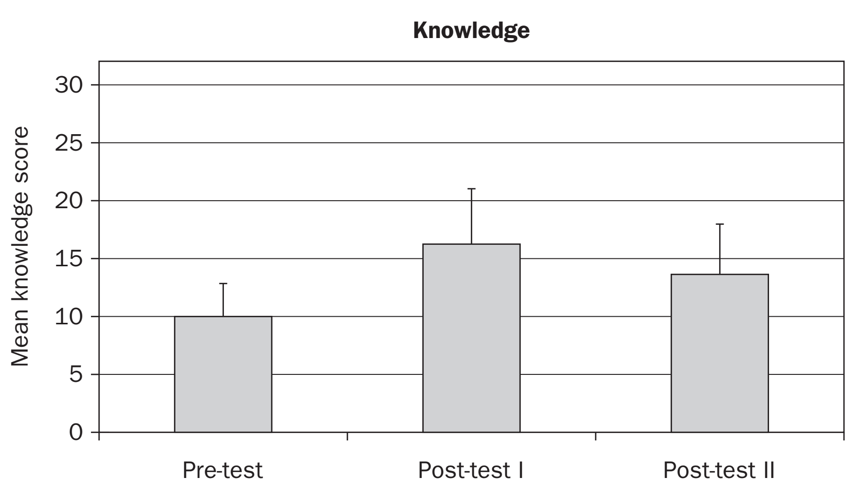

Figure 23.2 Learning achievement of the museum visit ($n = 167$)

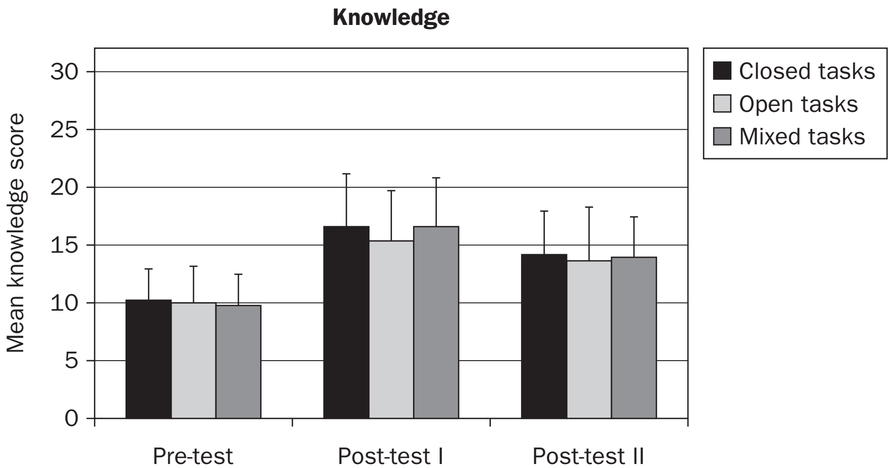

Figure 23.3 Learning achievement of the museum visit subdivided into the treatments open tasks, closed tasks and mixed tasks ($n = 167$)

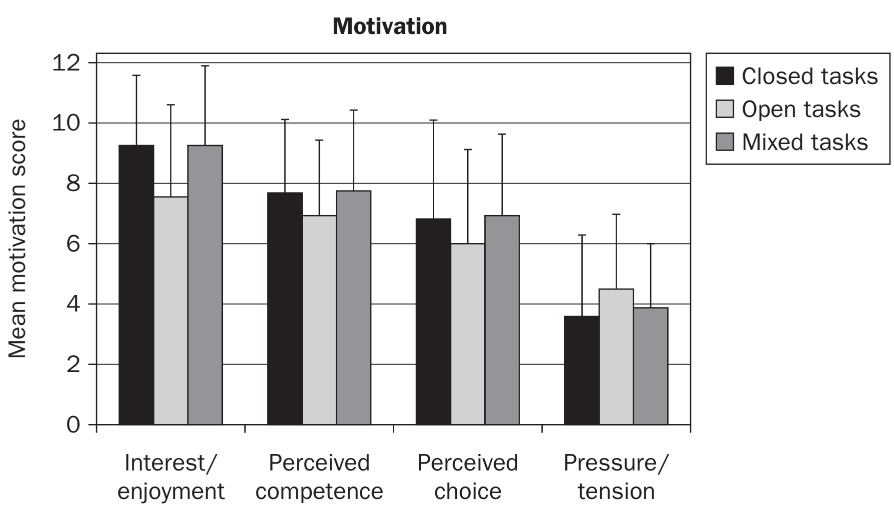

Figure 23.4 Results of the motivational subscales 'interest/ enjoyment', 'perceived competence', 'perceived choice' and 'pressure/ tension' subdivided by treatments open tasks, closed tasks and mixed tasks ($n = 149$)

variables showed significant differences ($F(2,146) = 4.56$, $P<0.01$). Contrary to our hypothesis, a post-hoc Scheffé test suggested that pupils showed more 'interest/enjoyment' with closed tasks than with open tasks. Compared with the mixed treatment, no differences compared with the closed tasks could be found. The differences between the treatments towards 'perceived competence' ($F(2,146) = 2.08$, NS), 'perceived choice' ($F(2,146) = 1.05$, NS) and 'pressure/tension' ($F(2,146) = 2.81$, NS) were not significant.

Nevertheless, the pattern of the results was quite obvious. With regard to the positive predictors, ('interest/enjoyment', 'perceived competence' and 'perceived choice') of intrinsic motivation, open tasks had lowest values, whilst with regard to the negative predictor ('pressure/tension'), open tasks had the highest value. Obviously, open tasks did not contribute to a particularly high intrinsic motivation of the learner.

Treatment 3 requested in the last section a choice between open and closed tasks. Forty-one pupils favoured closed tasks, whereas only 17 chose the open tasks. This outcome corresponded to the results of the intrinsic motivation.

6. DISCUSSION

In agreement with the first hypothesis, the visit to the museum led to short-term and long-term learning gains. The short-term effects were approximately equal to the results of Krombaß and Harms (2006). Even if the decrease from post-test I to post-test II had been statistically significant, the rate of forgetting was low. The long-term learning effect of previous studies could be confirmed (Wilde *et al.* 2003; Wilde 2004). As suggested by Rennie and Johnston (2004), the experiences of the museum visit might have enhanced this preservation of knowledge gains (see also Krombaß and Harms 2006).

Hypotheses 2 and 3 emphasised the benefit of open tasks according to knowledge acquisition and intrinsic motivation. Both domains should have profited from the presumably higher level of real and perceived self-regulation. Assessing cognitive achievement and realising different degrees of real choice is complicated. Principally, there are two alternatives. Self-regulation may vary randomly in the study design. If implemented seriously in this extracurricular setting, this involves the possibility of content-related decisions of the pupils. In this situation, quantitative evaluation of the pupils' cognitive achievement is difficult, because the contents chosen by the pupils are not constant. Alternatively, the study design keeps the potentially acquired content constant. In this design, quantitative evaluation is possible. At the same time, the possibilities for self-regulation are limited. In this study, this dilemma was met by choosing constant contents and limited possibilities of real self-regulation. As reported, the treatment of higher self-regulation was represented by open tasks that were focused towards one display and towards a defined content. The treatment of low self-regulation was realised by tasks of closed questions. The different degree of 'real' self-regulation was due to the more open types of task and the absence of given answers allowing a much less restrained exploration of the exhibits and a much less controlled process of thinking about possible solutions. In treatment 3, the pupils had the opportunity to choose between open and closed tasks. Closed tasks were favoured by a ratio of 41:17.

There are three possible reasons for this behaviour:

1. The choice of treatment 3 was given in the last section. The pupils may simply have been tired of working. Closed tasks meant less writing, possibly less thinking about the tasks and a probably a more familiar working pattern within a given structure. This may explain the pupils' choice.
2. Neglecting the possibility in (1) based on pupils' exhaustion or laziness, real self-regulation might not have been particularly relevant for the perceived self-regulation. Different factors might be crucial for pupils' perceived self-regulation. In their study, Grolnick and Ryan (1987) compared identical learning tasks in controlling and non-controlling conditions. The learning outcomes, in particular interest and perceived pressure of the fifth-grade children, differed substantially. It was not that the real possibilities of the tasks determined the pupils' perception and knowledge acquisition, but rather the controlling or non-controlling circumstances in which the tasks were presented. Possibly, in our study, real self-regulation might have been limited due to unknown circumstances beyond our standardisation.
3. A different explanation stresses the perceived intrinsic motivation. The intrinsic motivation of closed (and mixed) tasks tended to be rather higher than the intrinsic motivation of open tasks. Eventually – even if intended differently – pupils felt more opportunities of choice working on closed tasks. In our reasoning, we assumed that pupils act on all information available, i.e. concerning the closed tasks questions *and* the possible answers. Consequently, pupils working on closed tasks had to recognise true and false answers. In opposition to this reasoning, pupils

might have worked completely differently. By neglecting the previously given answers, pupils could 'upgrade' the required cognitive process to a more demanding task. The decision not to use the suggested answer disregards restraints; it allows an open exploration of the exhibits and open-minded thinking about solutions. If a task is overdemanding or fails to interest the pupils, there is still the option of simply reading and receiving more help by using the previously given answers. From this point of view, closed tasks might have provided choice, which probably affected the perception of self-regulation. This might be an explanation for the pupils' choice in treatment 3. This also might be the reason for the higher motivation of the closed (and mixed) tasks. Eventually, it might explain the at least equal learning success of closed (and mixed) tasks compared with open tasks. If pupils use the given answers merely as an additional help when failing to fulfil the assigned tasks, the cognitive benefit of multiple choice tasks will probably meet the benefit of open tasks. If pupils were really exercising a reasonable amount of metacognitive knowledge for intelligent decisions, when to use the given answers and when to work without this help cannot be decided here. Assuming pupils worked on the closed tasks in that way, a very good balance between constructivist elements and instruction may have come into operation.

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24 The teaching of life sciences in special schools to blind and visually impaired students and its implications for inclusive education in outcomes-based learning environments

William John Fraser[1] and Mbulaheni Obert Maguvhe[2]

[1]FACULTY OF EDUCATION, UNIVERSITY OF PRETORIA, SOUTH AFRICA;
[2]SOUTH AFRICAN NATIONAL COUNCIL FOR THE BLIND, PRETORIA, SOUTH AFRICA

william.fraser@up.ac.za; obert@sancb.org.za

This study reports on the teaching of life sciences (biology) at 9 special schools for blind and visually impaired students in South Africa with specific reference to the development of scientific skills in outcomes-based classrooms. Individual structured interviews were conducted with nine science teachers at special schools (one from each school) and focus group interviews with ten grade 12 students taking a life science at each of the schools. The interviews were video- and audiotaped by sighted observers. The data were transcribed and the results coded and classified for interpretation purposes. The study revealed the students' difficulties in applying scientific skills because of lack of vision, lack of confidence and lack of motivation from teachers. For example, one such skill, namely 'tabulation', remains a problem to most blind students. The blind students were also seldom engaged in practical work and field trips. Practical activities were limited to very simple and elementary exercises that called for few intellectual challenges or advanced problem-solving skills. Also, the students had limited access to computers, encyclopaedias and relevant publications. Teachers did, however, apply cooperative learning strategies in schools where totally blind and partially sighted pupils shared the same learning environment.

1. INTRODUCTION

Inclusive education is gaining momentum globally as a premise to the education of students with special needs in mainstream classroom settings. This paper explains a number of problems pertaining to the teaching of life sciences to blind students and its implications for an inclusive life science education policy. It expresses the views and experiences of both students and teachers who we interacted with during the teacher and focus group interviews. As there are differing types and degrees of visual impairments, this paper pays particular attention to the totally blind, as the authors of this paper consider them to be the most vulnerable individuals in terms of the learning mediation of life sciences in an outcomes-based classroom.

2. RATIONALE AND THEORETICAL BACKGROUND

This paper reports on the outcomes of an investigation based in Jerome Bruner's theory of discovery learning (Carin and Sund 1985; Van Rooyen, and De Beer 2007) and the syntactical structures of the scientific skills reported by Carin and Sund (1985) and Van Aswegen *et al.* (1993). The study was also guided by Spady's (1994) notion of outcomes-based education and Killen's (2000) operationalisation of outcomes-based education for classroom practices.

3. AIMS AND OBJECTIVES OF THE INVESTIGATION

The following research questions were thought appropriate to address the problems highlighted in the above paragraph:

1. How does the lack of visual ability during the learning mediation of biology and other life sciences impact on blind students, life sciences teachers, special schools and outcomes-based education?
2. What are the most appropriate learning mediation strategies and methods for the teaching of the life sciences measured against the outlined national curriculum statements and to what extent do teachers use and apply these strategies and methods in special schools?
3. To what extent do visually impaired students achieve the learning outcomes specified for the life sciences/biology and which variables restrict effective teaching and learning in the life sciences/biology classroom?
4. What adaptations will therefore be required in our traditional classroom practices in support of blind and visually impaired students in inclusive outcomes-based classrooms?

Having taken the problem statement and research questions into consideration, the aim of the investigation became to determine how learning of the life sciences is taught in special schools for blind students and to establish how the lessons learnt from this experience could be implemented to the advantage of blind students in the senior phase (grades 8 and 9) and further education and training band (grades 10–12) in inclusive outcomes-based education settings.

4. VISUAL IMPAIRMENT, TEACHING AND LEARNING

As far back as 1967, Haring and Schiefelbusch (1967) reported on various issues related to the education of visually impaired students. They focused primarily on the importance of vision and the mode of reading, and attempted (in classical positivist style) to illustrate how intelligence manifests itself in blind and visually impaired students compared with the deaf. Their work emphasised the significance of blindness and information processing and also illustrated the maximum utilisation of available sensory data during learning mediation, as well as the translation of visual stimuli.

Freeman (1986: 106) emphasised the importance of visual impairment as a handicap to gifted students as follows:

> In [visually impaired students], conceptual development and abstract thinking seem to be delayed by the absence of visual stimulation or images; cognitive development occurs more slowly, and norms for chronological age groups are invalid.

The significant role of visual stimuli as prerequisites for conceptual development in the teaching of subject content in general, and the life sciences in particular, has been recorded by many authors such as Perkins (1974), Falk (1980), Fraser *et al.* (1996) and Erwin *et al.* (2001).

Wittich and Schuller (1973) argued more than three decades ago that perception remains the foundation of learning. They stressed the fact that without a sufficient conceptual foundation, learning would be severely impaired and thinking would be severely limited. However, it should also be taken into consideration that various developments in technology have significantly contributed, and will continue to do so, towards improving the plight of the visually impaired in the facilitation of learning.

Disabled students, and in particular blind and visually impaired students, require and deserve specific strategies that address their unique learning mediation needs during the teaching of the life sciences. Jurmang (2004: 64) noted:

> The fundamental principles of teaching have not changed, approaches to an individual child must be adapted to take account of that child's special needs. When working with children that have sensory impairment . . . the teacher must understand the significance of all these factors and create a favourable climate for learning.

On the other hand, Paul (2004: 75), with regard to specialist programmes, argued that 'we need to look at introducing specialist programmes of these professionals to create a well trained pool of human resource'.

In instances where specialised education and support systems are not in place, effective advocacy, professional advice and technical assistance will not prevail. Furthermore, the goal of equal participation by blind and visually impaired students and the right to be taught by teachers who fully understand their needs cannot be achieved.

It is generally accepted that, with the loss or absence of vision, the amount of sensory data available to the student is reduced (Haring and Schiefelbusch 1967). It is for this reason that the teaching and learning of the blind and visually impaired must be firmly grounded in a multi-sensory approach (Erwin *et al.,* 2001).

Learning mediation aids such as computers with speech (such as the Job Access With Speech program or JAWS), interfaced speech synthesisers, closed-circuit television, taped materials, reading machines, talking machines, hand-held magnifiers, Braille, talking calculators, sound sonification, auditory analogues of visualisation, instruments with auditory (and not visual) readings, touch- and voice-based interfaces, and touch and large print components have become standard equipment for the teaching of the blind and visually impaired (Collette and Chiappetta 1986; Kumagai 1995; Siekierska *et al.* 2003; Trief and Feeney 2003). Burke (2001: 58) maintains that 'effective access to print is a matter of serious concern to every person who must do significant amounts of reading but who does not see print easily'. As a result, the number of blind students who are likely to learn biology or any other life science subject is severely limited. Maguvhe (2003) argued that blind individuals like any other person, are passionate about access to print, because it fulfils, rewards and satisfies when one is able to get without difficulty what one wants from the vast store of published work, whether instructional, cultural or recreational.

5. ADAPTING THE CURRICULUM FOR BLIND AND VISUALLY IMPAIRED STUDENTS

Any curriculum that is not learner-based and learner-paced will hinder the blind and visually impaired student from learning and actively participating in the learning mediation according to her or his full potential. Teachers are not aware of what should be done to accommodate blind and visually impaired students during the acquisition of scientific skills and/or assessment. As a result, they discourage blind students from taking or considering science-related subjects as curriculum choices.

The following alternative approaches to curriculum adaptation and delivery have been applied to the teaching of blind and visually impaired students: setting a substitute task of similar scope and demand; replacing one impossible or unfriendly task with a task of a different kind; allowing the student to undertake the task at a later date; using another planned task to assess more outcomes or aspects of outcomes than originally intended; giving the student concessions (extra time) to complete the task; using technology, aides or other special arrangements to undertake assessment tasks; using an estimate based on other assessments or work completed by the student (in circumstances where the above provisions are not feasible or reasonable); and considering the format in which the task is presented, e.g. the complexity of graphs, diagrams, tables, illustrations, experiments and cartoons.

6. RESEARCH STRATEGIES APPLIED DURING THE INVESTIGATION

6.1 The research sample

Nine teachers and 45 blind and visually impaired students from nine special schools for blind and visually impaired students in South Africa were interviewed through the use of qualitative inquiry methods. There are 20 schools with sections for blind and visually impaired students in South Africa and a sample of nine schools were drawn from this list. Semi-structured interviews as well as follow-up telephone interviews were used to get responses to various questions. The classroom activities were videotaped. During the interviews, we took notes reflecting the respondents' personal views. Semi-structured interviews helped us to capture the attitudes and opinions of respondents during the course of the investigation. In addition, semi-structured interviews offered us the opportunity to pose follow-up questions for further clarification.

6.2 Data collection and analysis

The fieldwork commenced during the second quarter (April) of the academic year. Each educator interview lasted approximately 40 minutes, followed by focus group interviews involving a group of five students from each of the nine participating schools. The interviews were transcribed, after which each transcription was coded and the responses categorised. The results detail the main findings that emerged from the coding and categorisation of the responses.

7. RESULTS

7.1 Opinions regarding teacher training

The existing view is that education authorities and institutions of higher learning are doing very little to bridge the training gap between regular and special teachers. Most institutions of higher learning have not introduced courses in the facilitation of teaching blind students. This implies that these teachers are inadequately skilled and remain poorly motivated in teaching at special schools. Student or beginner teachers should be placed at inclusive or special schools for the blind to acquire experience on how to teach blind and visually impaired students. Various authors have argued (Spungin 1977; Pauw 1984, 1991; Mani 2000; Mason 2000; Norms and Standards for Educators 2000) that training is necessary for teachers to understand the educational needs of such students. Abner and Lahm (2002: 98) stated: 'To provide high-quality services and instruction, it is vital that certified teachers of students with visual impairments be well versed in the selection and application of current access technology.' They argued further that to benefit from assistive technology,

'. . .students who are visually impaired must have contact with dynamic teachers who have sufficient knowledge and skills in the use of technology'.

7.2 Perceptions of blind students learning science subjects

It has often been argued that teachers' negative perceptions of blind and visually impaired students stem from factors such as the teachers' lack of confidence and ability to teach these children. As a result, teachers with pessimistic attitudes and experiences will encourage negative attitudes in these students. Higgins and Ballard (2000) argued, with regard to negative attitudes, that what individuals like to think of as their attitudes, values and actions are in fact public rule systems or codes that define all possible modes of thought and action.

7.3 Prejudices towards the teaching of blind and visually impaired students

We found that unnecessary demands, unfamiliar surroundings, an inflexible curriculum and inflexible assessment standards are prejudicial factors resulting in the ineffective learning of students with visual impairment. Authors such as Mani (2000), Van Huijgevoort (2002) and Charles and Yewpick Lee (2003) support this notion. According to Van Huijgevoort (2002: 60), 'People are limited not only by physical barriers, but by the attitudes of others.' This author also argued that 'Stigmatization is an important factor in a person becoming. . .isolated.' Prejudices may put blind students at risk of isolation, possessing few friends and inadequate social skills.

7.4 The unique needs of blind and visually impaired students

Blind and visually impaired students, like any other disabled student, have unique needs. Although it is difficult to meet and satisfy these needs during the teaching and learning of biology, special and inclusive schools should do whatever is possible to meet them in order to reasonably accommodate its students. Depending on the degree of blindness, some blind and visually impaired students need computer devices with display magnification software.

7.5 Observations and practical work

Blind students battle with observations during the teaching of life sciences due to the fact that observational activities are less meaningful and less motivating to them. Jurmang (2004: 65) advised: 'Activities in the process need to be meaningful and motivating.' The students become totally excluded from the acquisition of valuable information when they do not receive explanations and interpretations from teachers and fellow students.

Based on sound evidence, we found that, currently, very few blind students study physiology up to grade 12. Access to the learning of biology is limited. This supports the argument that the learning of biology depends on one's visual ability, thus making it difficult for blind students to access information through visual observations. The First Working Session on the National Working Group on Curriculum Adaptation (2003: 16) stated:

> Observing is a good means for gathering information. Traditionally 'observing' has meant that students watch what the educator is doing and then copy or model the same. A learner-centred approach to observation would require that students are expected to analyse their observation . . .

Lack of visual ability deprives blind students of the enjoyment and the advantage of observation. Borg (1987) indicated that observational processes are essential in enabling individuals to collect direct information. This means that blind students are deprived of opportunities to study specific aspects because they cannot observe. This deprivation causes blind students to be less competitive during biology lessons. Blind students will only be able to be competitive when they are fully exposed to all biology phenomena. Nagel and Stobbs (2003: 47) argued that:

> . . . benchmarking against the regular curriculum is extremely important because we've got to foot it with this competitive world that we live in. Like it, or not. And if you want a job you have to compete, you have to be there, you have to develop skills and talents. Part of this is having the ability to know and to deal with others, and to live in the real world. You have to learn to take the knocks and have the ability to deal with prejudices.

What became evident in the investigation was the large amount of time and effort teachers were spending with their students in the biology and life science classrooms. It appeared that the pastoral role of the teacher, as defined by the Norms and Standards for Teachers (2000), predominantly exceeded the teaching of biology and life sciences to these students.

8. DISCUSSION AND CONCLUSIONS

The variables highlighted above restrict effective teaching and learning in the life sciences/biology classroom. Overall, only a small number of blind students take science-related subjects up to grade 12. One could attribute this problem to the following factors.

8.1 Lack of experience and expertise in teaching blind and visually impaired students

Most teachers working at schools for the blind and visually impaired received a general education training qualification. They lack ideas to adapt the curriculum to accommodate blind and visually impaired students in a life sciences environment. This implies that they will not encourage students to take a difficult subject if they cannot teach it properly. Sapon-Shevin (1996: 35) maintains that 'if children who are "different" in any way are routinely. . .excluded, this is not a productive learning environment. Wouldn't improvements in classroom climate have a salutary effect on all students?'

8.2 Competences for facilitating learning

Teachers do not possess the relevant competencies to teach life sciences to blind and visually impaired students; hence, they do not want to expose their weaknesses. The following examples were taken from the interviews asking how teachers dealt with the teaching of similarities and differences in the science classroom. One respondent (R1) stated:

> When you work with blind learners, use concrete things [MS.2] to show them similarities and differences and avoid abstract things like light and darkness, black and white, beautiful and ugly [MS.3].
>
> It is believed that 'persons with visual impairments have been one of the most difficult populations to accommodate. . .' (Butler *et al.* 2002: 166). These authors then argued that for the trend to be reduced, it is '. . .imperative that barriers. . . be resolved'.

Another respondent (R2) stated:

> Experience has taught me over the years that deep stuff does not work [MS.3] well with blind learners when you talk about similarities and differences. Say you want to teach them

> about black and white, refer to the colour black to a coal and the colour white to an ice cube [MS.2].

Basically, biology concepts indicating similarities and differences are used. For example, during an activity that we observed concerning respiration and photosynthesis, the teacher indicated similarities and differences. The respondent (R4) explained as follows:

> Basically biology concepts [MS.5] indicating similarities and differences are used. For example when one is mediating learning about respiration and photosynthesis, there are similarities and differences there. What one should always bear in mind is to inculcate and introduce to learners ordinary [MS.5] and exceptional features [MS.6] of parts, organisms, processes, etc.

In addition, teachers relied on description and explanation of aspects to blind students. Another respondent replied:

> Yes, although I don't fully agree with that statement – look, the traditional approach was about the teacher giving all the information to the learner and the teacher being the only source of knowledge so we seldom apply that. Somewhere, somehow we do apply that. Maybe you find that they have got nothing, no background, they don't have any concept of the subject that you might be delivering, but now we are approaching the outcomes-based one; that one is where the teacher becomes the facilitator. . .

We also discovered that most teachers relied on concepts used in everyday life. Examples given above and the following argument bear testimony to this point. One respondent (R6) stated:

> Concepts [MS.2] such as similarities and differences are used in everyday life [MS.7]. What I do, I reinforce it by making use of both concrete [MS.2] and abstract examples [MS.8].

Certain advantages of creating opportunities for blind students to distinguish between similarities and differences were mentioned. If similarities and differences can be observed tactually, students have immediate access to information. In addition, students' ability to describe and explain is enhanced.

8.3 Curriculum

In the past, special schools used to offer their own curriculum (comprising pre-vocational training, commercial subjects, religious subjects, languages and social sciences subjects). Teachers, therefore, find it difficult to offer a curriculum nationally prescribed by the Department of Education. Blind students seem to cope better in physiology than other life science subjects. This is so because, although there are drawings, there are also good models that the blind can feel tactually. In addition, physiology seems to present fewer problems in terms of adaptation because it comprises more theory than practice.

8.4 Access to sources of information

Braille books, recorded tapes, friends, teachers, magazines, the Internet, experts, the environment, radio and television are the preferred methods for accessing information by blind students and their teachers at South African schools.

Regrettably, most schools use outdated and worn-out books without diagrams, relief maps or other methods of presenting information tactually. When orders are placed with printing presses, books arrive some months or a year later, when they are no longer required. In other instances, printing presses do not produce them because it is not cost-effective to do so due to the small numbers of orders placed by schools. Computers could be a solution, but those who are in charge of them are not computer-literate and they tend to use them for personal use. When students borrow books from libraries, the huge demand for such resources only allows students to keep them for a few months. When they return them, it means they have no sources to refer to or to obtain information from. In the past, special schools used to have Braille specialists whose tasks among others included producing Braille books. Such posts have at the present been terminated, with the implication that in-house Braille production is no longer done – at the expense of students. This implies that, without the assistance of sighted people, blind students cannot benefit from these facilities. Such factors block hinder blind and visually impaired students from obtaining information in unfamiliar and complex settings.

9. RECOMMENDATIONS FOR CLASSROOM TEACHING IN INCLUSIVE SETTINGS

9.1 Development of strong and reliable partnerships in educational development

As there is a need to provide life science subjects to blind and visually impaired students as well as other disadvantaged children, the department of education, private foundations, parents and communities should become partners in educational development by providing personnel, training, equipment, technical assistance, and so on. This type of partnership is crucial for eradicating disparities in education because schools for the blind and in particular teachers will benefit in many ways including, but not limited to, learning from experts, sharing experiences and exchanging constructive ideas. Furthermore, partners in educational development will help upgrade the services rendered to blind and visually impaired students, as well as promoting the well-being of the clients they are serving.

9.2 Development and application of new learning mediation approaches

Sapon-Shevin (1996) argued that teachers whose teaching repertoires are limited to front-of-the classroom, lecture-style instruction will need to explore more interactive, engaging ways of teaching. Sapon-Shevin (1996: 36) also argued that teachers should '. . .seek to find new ways to use those talents and skills so that all students can benefit from highly specialised teaching strategies and adaptations'. Therefore, it is imperative that professionals working with blind (and visually impaired) students should be introduced to new learning mediation approaches, such as collaborative learning, cooperative teaching, peer tutoring and other innovative scheduling and planning activities, because this would yield better outcomes in the teaching and learning mediation of life sciences.

9.3 Analysis of blind and visually impaired students' needs and potential areas of success

In order for blind students to perform better in science-related subjects, we recommend an analysis of students' needs for a myriad of reasons. This should be done on a regular basis in order to determine students' strengths and weaknesses based on the learning mediation demands, and on all of the activities and tasks the student could do successfully and well. Success always positively enhances a student's self-image and motivation.

Based on this, we therefore continue to recommend that education should be delivered in a way that suits and meets blind students' learning mediation needs. Higgins and Ballard (2000) support this argument by stating that when teachers teach these students with similar expectations to those held for others of their age, and teach them with recognition of and in responsive to their particular communication and related needs, blind students use their blindness as part of ordinary human experience. Adaptations in certain instances could, as Friend and Bursuck (1999) viewed them, include bypassing a student's learning needs by allowing or giving the student room to employ compensatory learning strategies, making a modification in the classroom environment or teaching organisation, and instructing a student in basic or independent learning skills.

Teachers should know and understand that, to blind students, perception and sensory awareness are requirements for effective biology learning. Erwin *et al.* (2001) emphasised that teaching science to students with visual impairments must be firmly grounded in a multi-sensory approach if students are to receive positive benefits, such as activities related to tactile and auditory interactions, and therefore ample opportunity to manipulate equipment and materials must be provided.

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6

Health education and biology education

25 Portuguese primary school teachers' conceptions of and obstacles to sex education in the classroom

Zélia Anastácio[1], Graça Carvalho[1] and Pierre Clément[2]

[1]INSTITUTE FOR CHILD STUDIES, UNIVERSITY OF MINHO, PORTUGAL; [2]LIRDHIST, UNIVERSITY CLAUDE BERNARD – LYON 1, FRANCE

zeliaf@iec.uminho.pt; graca@iec.uminho.pt; Pierre.clement@univ-lyon1.fr

This research aimed to identify primary school teachers' conceptions of and obstacles to teaching sex education, in particular, teachers' opinions and perceptions of the difficulties, fears and supports, and the contextual factors that influence their conceptions. The research starting point was the construction and validation of a questionnaire. This method was applied to a sample of 486 primary school teachers from a northern region of Portugal. A database was constructed and statistical tests were applied. The results suggested that: teachers are not in favour of sex education in primary schools; the most difficult area to teach is the expression of sexuality; the most difficult topics to approach are related to sexual pleasure; teachers preferred the participation of parents, health professionals and psychologists; the reactions and thoughts of parents and the conservative community were their strongest fears; teachers considered that colleagues, the school director and the school group president supported them; the expressed needs for teacher training were scientific knowledge to help them to respond easily to children's unpredictable questions and to prepare them to develop an awareness of values. The factors that reflected the strongest influence on teachers' conceptions were: academic qualifications, gender, training courses, religious practice, time of career, area of work and whether they have children.

1. INTRODUCTION

In Portugal, the implementation of sex education has been a difficult process. The main obstacle is essentially rooted in its social origins. Since 1984, several laws (e.g. Law no. 3/84) have been published to promote this educative area, but until now only a few sporadic studies have been carried out in a small number of Portuguese schools (Vaz *et al.* 1996), although laws say that the state must guarantee teacher training in this subject.

Between 1995 and 1998, an experimental project was developed in five national schools, including both primary and secondary schools. As a consequence, the report on this project led to new laws (Law no.120/99; Government Decree no. 259/2000) where a compulsory approach to 'sexual health promotion and human sexuality' from primary school level was reinforced. In 2000, the Ministry of Education also published the book *Sex Education in the School Environment – Guidelines* (CCPES *et al.* 2000) as a result of the report. In this document, the goals, knowledge and appropriate strategies for teaching sex education at different school levels were presented. However, although these legal and school-based documents have been produced, the majority of Portuguese teachers still do not teach sex education.

Our close contact with primary school teachers in their two-year complementary academic formation course (equivalent to a Licentiate's degree or 'licence') and during training courses at university has given us a general picture of the primary school situation as far as sex education is concerned.

With this in mind, we decided to investigate the cause of primary school teachers' resistance to undertaking sex education. Our hypothesis was that teachers have low scientific and pedagogical knowledge in this area and that other factors, including social factors, as well as their convictions, beliefs and ideologies (Clément 1994; De Vecchi and Giordan 2002) and their background (Kehily 2002; Oshi and Nakalema 2005) can interact with their knowledge in the construction of their conceptions.

Conceptions are generally deeply rooted and may influence the learning process or the integration of new scientific knowledge. A conception is based on a set of mental images and models that exists in a student's mind before the learning experience and that actively participates throughout the process of knowledge construction (De Vecchi and Giordan 2002). If conceptions are not considered in the teaching–learning process, they tend to persist and become stronger with time.

The modified model of didactical transposition (Clément 1998, 2004), when applied to sex education, shows that teachers' conceptions (C) are a product of the interaction between their scientific knowledge (K) on this theme, their system of values (V) including opinions, political ideologies and religious beliefs, and their social and pedagogical practices (P) concerning religious practices and school approaches.

Social representations reflect the system of values and can be obstacles to the acquisition or mobilisation of scientific knowledge (Clément 1998). Obstacles can be from several origins: epistemological, didactical, psychological and social (Clément 2003). In terms of sex education in Portugal, we established the different types of obstacle as follows:

1. *Epistemological obstacles* correspond to conceptions constructed from everyday life (familiar situations, opinions and beliefs) that are in opposition to scientific interpretations (Bachelard 1938; Clément 1998, 2003). Religion, by attributing the connotation of sin towards sexuality and pleasure, can be an obstacle to the biological and psychological interpretation of sexuality. Traditional gender roles (e.g. male/female, father/mother) can also be assumed to be 'natural', resulting in an epistemological obstacle to the understanding of the socio-cultural dimension (Clément 2001).
2. *Didactical obstacles* are related to the interference of previous learning in the construction of conceptions, and are influenced by the teacher or by documents such as textbooks or school posters (Clément 2001, 2003; Carvalho 2003). The majority of Portuguese textbooks present sexual and reproductive functions in a minor way compared with other human functions, as this topic shows up at the end of the chapter, relevant concepts are missing and scientific errors can even be found (Teixeira 1999; Alves *et al.* 2007a, b).
3. *Psychological obstacles* are related to personal reasons that lead individuals in learning situations to reject new scientific conceptions (Carvalho 2003). This kind of obstacle results from an individual's personality (Clément 2001) and his or her sexual preferences (Kehily 2002). When talking with primary school teachers, some recognised their own sexuality as an important obstacle in undertaking sex education in school. This has been reinforced by a qualitative study analysing the relationships between teachers' sexual preferences and their pedagogical practices about sex education (Kehily 2002: 229, 230), indicating that 'their approaches to teaching and

learning have been shaped by their past experiences as pupils and as gendered sexual objects' and that 'experience is translated into pedagogic practice in complex and unexpected ways'.

4. *Social obstacles* are associated with political aspects and the teachers' planning of the didactical situation (Clément 2003). In Portugal, until the revolution of April 1974, sex-related issues could not be discussed openly and schools for boys and girls were separated. Even after the revolution, the Catholic Church and some parental associations lobbied for the revocation of law no. 3/84, which guarantees sex education as a fundamental component of education rights. The government itself still considers sex education a potential area of social conflict between institutions and conservative social groups.

Being aware of the obligatory topic of sex education in Portuguese primary schools and that teachers avoid teaching it, in this work we aimed to identify teachers' conceptions and the obstacles to the implementation of sex education. Our general research question was why this subject is not taught. To get an answer to this question, we defined our main goal as identifying primary school teachers' perceptions about the obstacles that prevent them from teaching sex education.

Our specific goals were:

- To determine teachers' levels of agreement with sex education in primary schools.
- To identify the subject areas in which teachers have the most difficulties.
- To determine teachers' opinions about different participants in children's sex education.
- To identify teachers' fears and perceptions of support in problematic situations related to approaches to sexuality.
- To determine teachers' agreement with specific training courses concerning sex education.
- To identify teachers' contextual factors (individual and socio-cultural) that can interact with their professional practice of sex education.

2. METHODOLOGY

We constructed and applied a questionnaire to identify teachers' perceptions about school sex education and the obstacles in implementing it. The questionnaire was based on: (1) a literature review related to sex education and health promotion to define questions about areas of knowledge within sex education, specific topics, participants and community involvement (Vaz *et al.* 1996; CCPES *et al.* 2000) and a values system, such as religion, religious practice and political tendencies, which can interact with pedagogical practice (Clément 1998; Teixeira 1999; Kehily 2002; Walker *et al.* 2003); (2) a previous study, which identified primary school children's most frequent questions in this area (Anastácio and Carvalho 2002); and (3) on our close contact with primary school teachers, which provided us with information about their perceptions and feelings related to fears, delicate situations, support and training needs in sex education.

The questionnaire was validated in a pilot test with 30 primary school teachers and minor changes were introduced. The internal consistency and reliability of the scales were tested using Cronbach's α coefficient at a value of α>0.72 for all variables.

Of the full questionnaire's dependent variables (presented in Likert scales), we used the following in the present study:

1. Agreement with sex education at the various school levels.
2. Difficulties in the four areas of knowledge in sex education (expressions of sexuality, body growth, reproductive and sexual health, and interpersonal relationships).
3. Feelings about approaching sexuality-specific topics.

4. Participants in children's sex education.
5. Fears in dealing with sex education.
6. Support that teachers regard as available in case of difficulties.
7. Teachers' training needs.

The factors we analysed were gender, training courses, having children, age, time of career, academic qualifications, marital status, area of residence, area of work, religion, religious practice and political tendencies.

The sample included 486 primary school teachers from six Educative Area Centres of a northern region of Portugal. A database was constructed using SPSS software and statistical analysis was carried out: descriptive statistics and inferential analysis were carried out using a *t*-test and non-parametric tests such as Kruskal–Wallis (to analyse the set of groups) and Mann–Whitney (to compare pairs of groups).

3. RESULTS

The individual and socio-cultural factors of the sample of 486 primary school teachers were: 426 (87.7 per cent) females and 58 (11.9 per cent) males (two did not answer the gender question), with mean respective ages of 43.4 and 41.6 years and mean respective durations of career to date of 21.4 and 18.3 school years. The majority were married (72.1 per cent of females and 70.7 per cent of males), lived in urban areas (64.0 and 59.6 per cent), had children (80.6 and 75.4 per cent) and had undergone no specific continuous training courses (88.8 and 82.5 per cent). The majority were Catholic: 97.3 per cent females and 88.9 per cent males; however, only 51.6 and 44.2 per cent, respectively, considered their religious practice to be moderate.

3.1 Agreement with sex education at different school levels

In general, primary school teachers were more in favour of sex education in secondary and elementary schools than in primary and nursery schools (Figure 25.1). The factors that seemed to affect this conception were:

- *Academic qualification*: teachers with lower qualifications were significantly less in favour than those with complementary formation for nursery schools (P=0.015) and those with a licence for elementary school (P=0.015).
- *Continuous training courses*: those who had undertaken such courses were more in favour of sex education in primary schools (P=0.051) and at university (P=0.011) than those who had not.
- *Political tendency*: left-wing teachers agreed significantly more with teaching approaches to sexuality in nursery (P=0.024) and primary schools (P=0.006) than those with right-wing tendencies.

3.2 Difficulties in the four areas of knowledge in sex education

The area that teachers expressed most difficulty with was 'expressions of sexuality', whilst the easiest was 'interpersonal relationships' (Figure 25.2). The most influential factors in these perceptions of difficulty seemed to be:

- *Gender*: females registered significantly more difficulties than males in the areas of 'body growth' (P=0.028) and 'expressions of sexuality' (P=0.001).

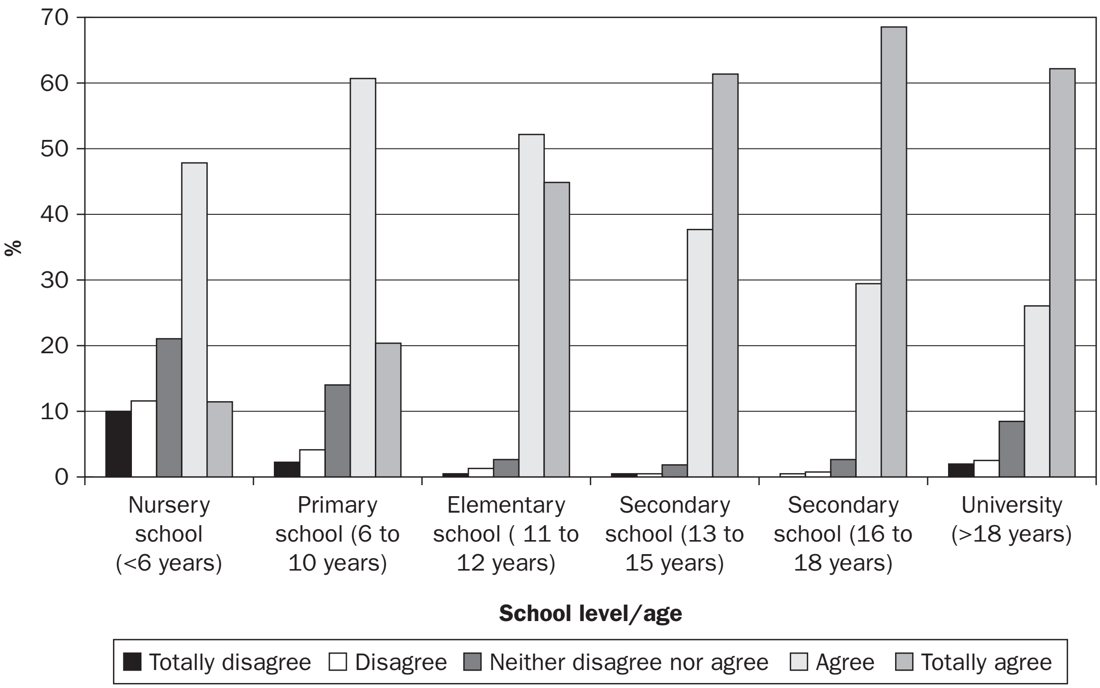

Figure 25.1 Agreement with sex education at different school levels

- *Age*: the group below 30 years of age differed from the group aged 36–40 years in the areas of 'body growth', 'expressions of sexuality' and 'reproductive and sexual health' (P=0.045 for all) and also from the group aged 46–50 years in 'expressions of sexuality' (P=0.015).
- *Training courses (especially sporadic courses)*: teachers who undertook these revealed significantly fewer difficulties than those who did not, and this could be found in all areas: ('expressions of sexuality' and 'interpersonal relationships', P<0.0001; 'body growth', P=0.002; 'reproductive and sexual health', P=0.025).
- *Having children*: teachers who were parents expressed more difficulties than those who were not, also in all areas, with the mean differences statistically significant for 'body growth' (P=0.042), 'interpersonal relationships' (P=0.019) and 'reproductive and sexual health' (P=0.002) and near to the significance level for 'expressions of sexuality' (P=0.051).

3.3 Feelings about approaching sexuality-specific topics

The teachers' most constraining topics were 'eroticism', 'pornography' and 'sexual intercourse', whilst the least embarrassing ones were 'body differences', affectionate relationships' and 'gender roles' (Figure 25.3).

The most interesting factors in teachers' feelings about these topics were:

- *Gender*: there were significant differences between females and males in the topics of 'localisation of the pleasure organs' (P=0.040), 'sexuality as pleasure' (P=0.011), 'eroticism' (P=0.001) and 'intercourse' (P<0.0001), with females revealing more difficulties.
- *Having children*: teachers who were parents had significantly more difficulties in approaching the topics of 'sexuality for reproduction' (P=0.002), 'affectionate relationships' (P=0.004), 'eroticism'

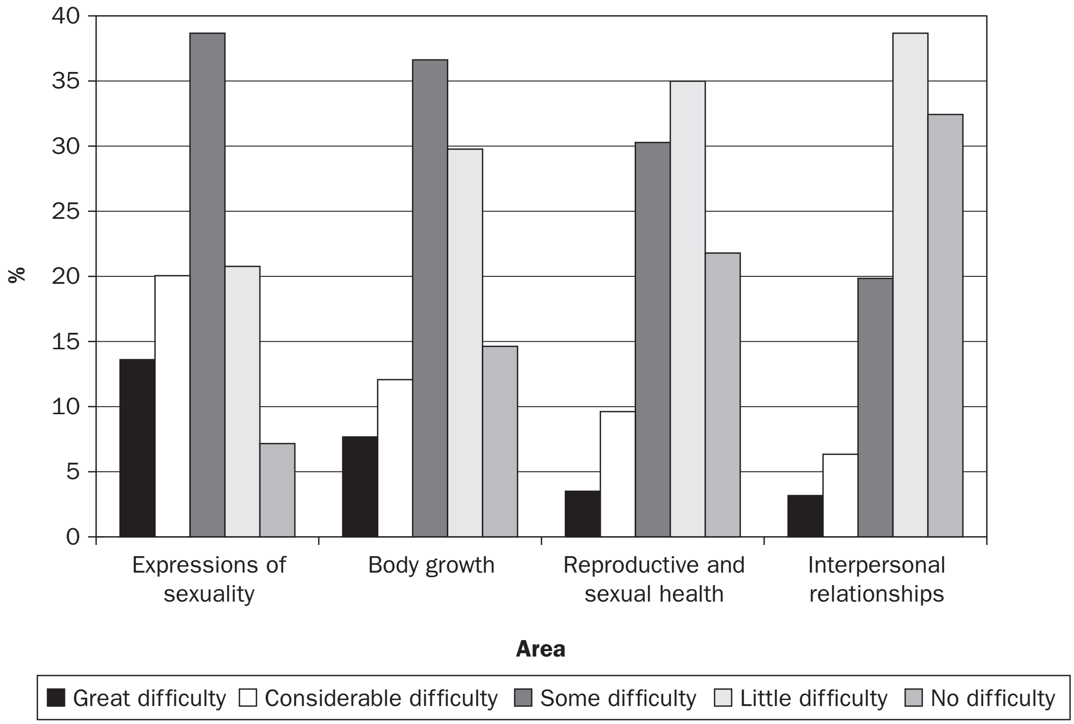

Figure 25.2 Difficulties in the four areas of knowledge in sex education

(*P*=0.047), 'homosexuality' (*P*=0.002), 'exhibitionism' (*P*=0.001), 'sexual abuse' (*P*=0.041) and 'intercourse' (*P*=0.006).

- *Area of work*: teachers in urban areas had fewer difficulties dealing with the topics of 'affectionate relationships' compared with those working in suburban (*P*<0.0001) or rural (*P*=0.036) areas, 'pornography' compared with those from rural areas (*P*=0.024) and 'sexual identity' compared with those from suburban areas (*P*=0.036).
- *Religious practice*: teachers who considered themselves as very religious in terms of their religious practice were significantly more at ease than those who were moderately religious in their approach towards the topics of 'sexuality as reproduction' (*P*=0.024) and 'body differences' (*P*=0.006), whilst those who did not actively practice religion were significantly more at ease than the moderately religious teachers in their approach to 'sexuality as pleasure' (*P*=0.042) and 'homosexuality' (*P*=0.030).
- *Training courses*: teachers who had undertaken training courses were significantly more at ease in the majority of topics (Table 25.1).

3.4 Participants in children's sex education

In the opinions of primary school teachers, the main participants in children's sex education should be parents, health professionals and psychologists. They put themselves in fourth position in this process (Figure 25.4).

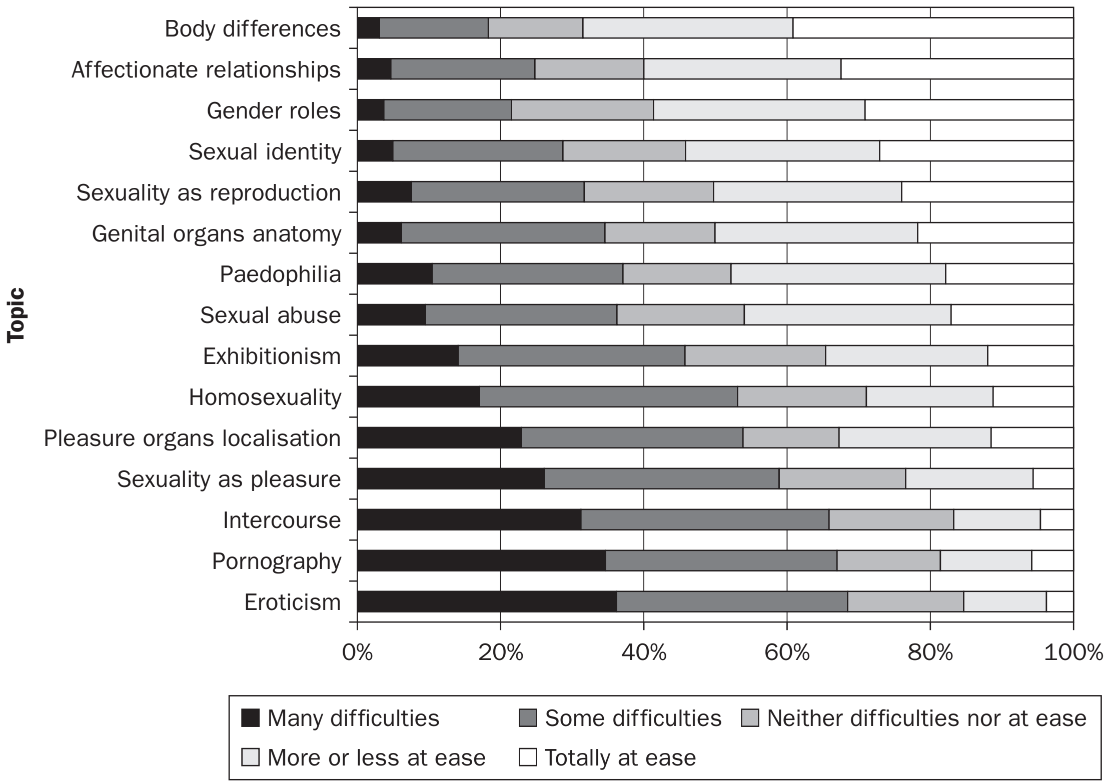

Figure 25.3 Feelings about approaching sexuality-specific topics

This conception seemed to be influenced essentially by:

- *Age*: younger teachers were the most favourable to their own participation, differing significantly from the 46–50-year-olds (P=0.015); the older teachers were most in favour of psychologists' participation, which differed from the opinion of the younger teachers (P=0.030).
- *Academic qualifications*: those teachers with fewer qualifications were significantly less in favour of teachers' participation than those who had a licence (P=0.015) or complementary formation (P=0.030), and those who had complementary formation were more in favour of the involvement of a social auxiliary than those who had *Curso de Estudos Superiores Especializados* (a previous version of the complementary academic formation) (P<0.0001) or a licence (P=0.015).
- *Marital status*: divorced teachers were more in favour of the participation of health professionals than single teachers (P=0.030) and of psychologists than either single (P<0.0001) or married (P=0.012) teachers;
- *Continuous training courses*: those who undertook such courses were more in favour of the involvement of teachers (P=0.006).
- *Area of work*: those working in rural areas were more in favour of their own participation than those working in urban areas (P=0.006).

Table 25.1 Feelings about approaching sexuality-specific topics in relation to training courses

	n	*Mean*	*n*	*Mean*	*t-test*	
	Yes		*No*		*t*	*P*
Continuous training courses						
Anatomy of genital organs	55	3.71	414	3.25	2.54	0.011
Localisation of pleasure organs	55	3.20	408	2.60	3.12	0.002
Sex for reproduction	55	3.75	413	3.29	2.48	0.014
Sex for pleasure	54	2.81	413	2.39	2.41	0.016
Homosexuality	52	3.08	410	2.65	2.31	0.021
Exhibitionism	53	3.19	407	2.82	2.03	0.043
Paedophilia	53	3.55	412	3.13	2.24	0.026
Sexual abuse	53	3.64	412	3.10	2.96	0.003
Intercourse	51	2.61	412	2.20	2.38	0.018
Sexual identity	35	4.06	329	3.42	2.91	0.004
Sporadic training courses						
Anatomy of genital organs	143	3.50	314	3.23	2.16	0.031
Sex for reproduction	144	3.53	312	3.25	2.22	0.027
Sex for pleasure	143	2.61	312	2.35	2.14	0.033
Affectionate relationships	143	3.86	311	3.51	2.92	0.004
Paedophilia	142	3.39	311	3.09	2.25	0.025
Sexual abuse	141	3.38	312	3.08	2.34	0.020
Intercourse	141	2.42	310	2.17	2.14	0.033

n, Number of individuals.

3.5 Fears in dealing with sex education

Teachers' fears were essentially concerned with parents' thoughts and reactions as well as those of the conservative community in which they lived. However, they revealed that they were less afraid of the reactions of social auxiliaries, the school group president and the school director (Figure 25.5).

The most influential factors on teachers' fears seemed to be:

- *Gender*: there were significant differences between females and males – with females having more fears than males – about 'parents' reactions' (P=0.011), 'parents' thoughts' (P=0.049), 'pupils' thoughts' (P=0.039) and 'other people's thoughts' (P=0.045).
- *Training courses*: there were significant differences for the question 'not at ease' indicating that teachers who did either continuous (P=0.007) or sporadic (P=0.004) training courses were more at ease.
- *Area of work*: teachers working in rural areas had significantly more fears than those working in suburban areas in terms of 'parents' reactions' (P=0.006), more than those working in urban areas for 'other people's thoughts' (P=0.021) and more than the other two groups with regard to the 'conservative community' (P<0.0001).
- *Religious practice*: teachers who described their religious practice as moderate had significantly more fears than those who described their religious practice as very religious in terms of 'juridical consequences' (P=0.030) and more than those who did not practice religion for the 'not at ease' question (P=0.012).

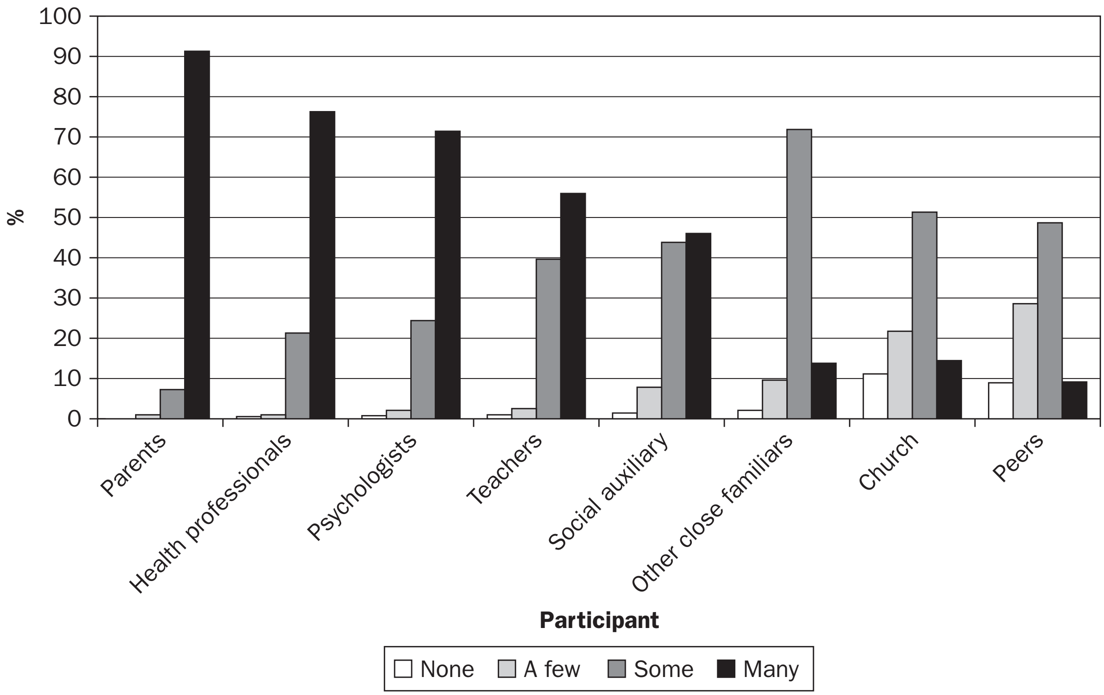

Figure 25.4 Participants in child sex education

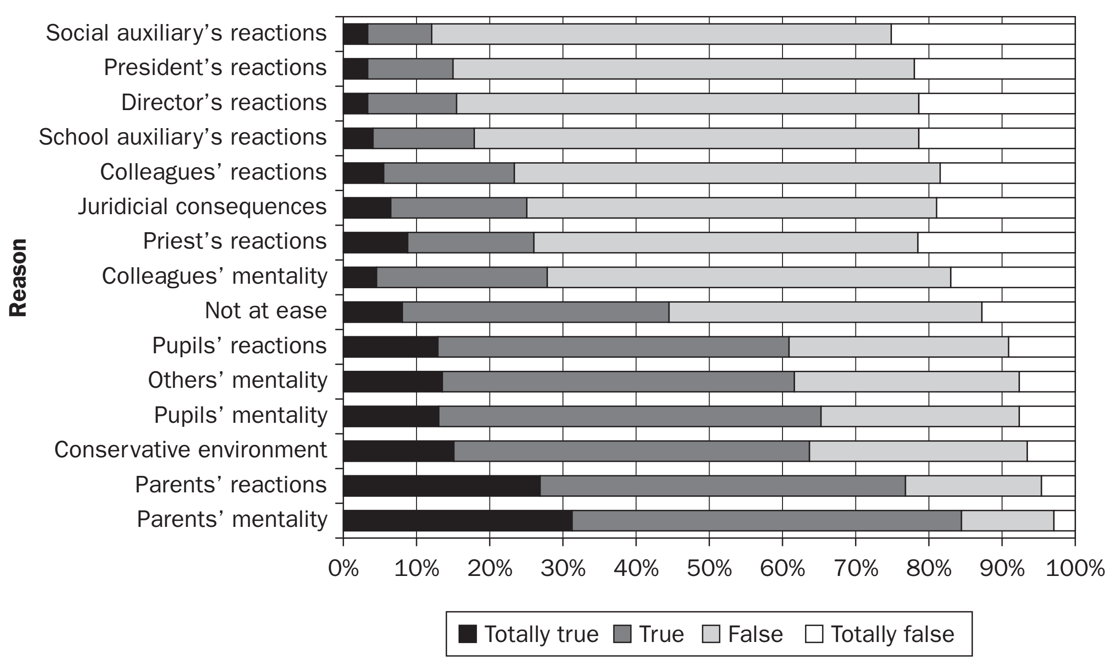

Figure 25.5 Fears in dealing with sex education

3.6 Support that teachers consider available in case of difficulties

In critical sex education situations, teachers felt that that they could get support from their colleagues, the school director and the school group president. In contrast, they were not confident of support from either the priest or the legal system (Figure 25.6).

Their perceptions of support were influenced by:

- *Sporadic training courses*: we found that teachers who had attended these felt significantly more supported by parents (P=0.002) and psychologists (P=0.006), as well as by social auxiliaries (P=0.013), than those who did not.
- *Religion and religious practice*: these were the strongest factors affecting their perceptions of support (Table 25.2). 'Support' was the dependent variable where religion revealed more influence, indicating that teachers with no religion considered that there were fewer types of support available compared with the Catholic teachers. Moreover, religious but non-practising teachers gave significantly less importance to the majority of types of support than did those teachers who described their religious practice as moderate.

3.7 Teachers' perceptions of training needs

With regard to specific training needs, primary school teachers agreed that training should 'give them scientific knowledge' (A), 'prepare them to respond naturally to children's unpredictable questions'

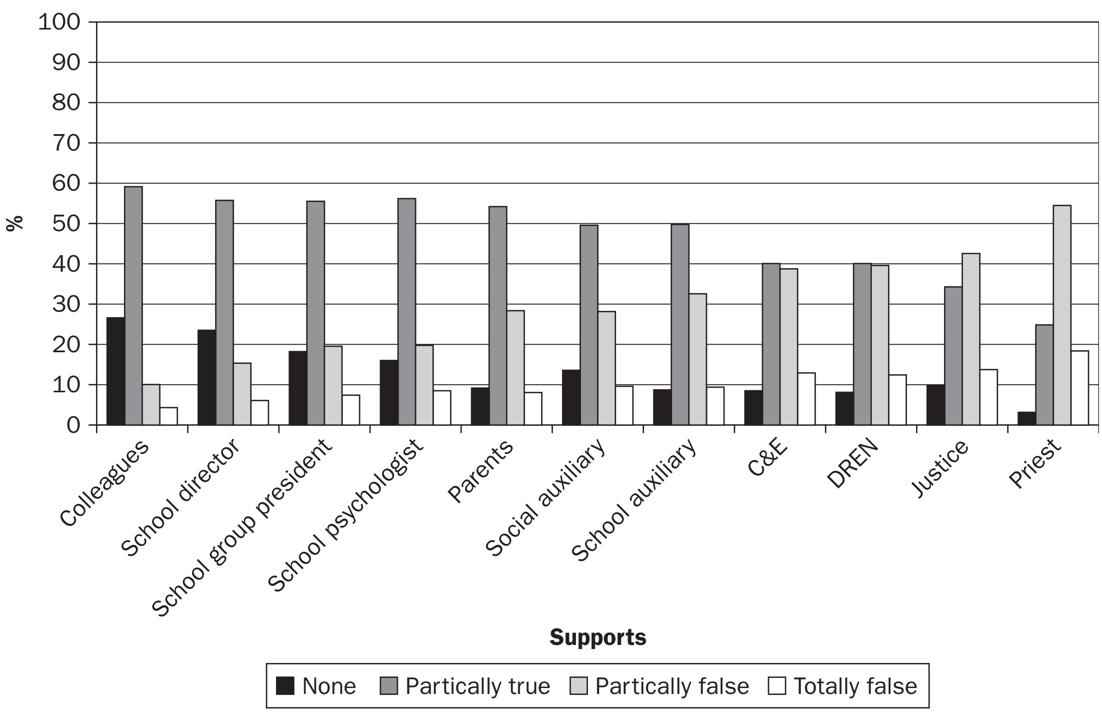

Figure 25.6 Support in case of difficulties related to sex education. CAE, Educative Area Centre; DREN, Northern Education Regional Department

Table 25.2 Supports influenced by religion and religious practice

	n	*Median*	*R>*	*R<*	*U-test*	*P*
Religion						
Colleagues	450	2	None	Catholic	7.00	0.027
School auxiliary	436	2	None	Catholic	7.96	0.018
Priest	418	3	None	Catholic	9.23	0.015
School psychologist	431	2	None	Catholic	15.01	<0.0001
Social auxiliary	432	2	None	Catholic	10.28	0.012
DREN	425	3	None	Catholic	11.87	0.018
				Other		0.024
CAE	425	3	None	Catholic	11.59	0.021
				Other		0.024
Religious practice						
Colleagues	449	2	Non-practising	Moderate	8.12	0.036
School auxiliary	436	2	Non-practising	Moderate	10.56	0.006
School psychologist	431	2	Non-practising	Moderate	16.46	<0.0001
				Low		<0.0001
Social auxiliary	432	2	Non-practising	Moderate	12.52	0.006
				Low		0.024
DREN	424	3	Non-practising	Moderate	11.69	0.006
				Low		0.018
CAE	424	3	Non-practising	Moderate	11.15	0.006
				Low		0.018

n, number of individuals; R>, higher rank; R<, lower rank; CAE, Educative Area Centre; DREN, Northern Education Regional Department.

(G), 'prepare them in the development of an awareness of values' (J) and 'help them to identify and solve sexual abuses' (L). On the other hand, teachers were not very interested in learning new information about the reproductive system (I) as is shown in Figure 25.7.

The more influential factors in teachers' perceptions of training needs were:

- *Gender*: generally females had higher average levels of agreement than males.
- *Continuous training courses*: teachers who had already undertaken this type of training were more in favour of this type of specific training than those who had not.
- *Marital status*: divorced teachers were more in favour of this type of specific training than married or widowed teachers.
- *Area of work*: those who worked in rural areas were significantly more in favour of 'training for all teachers' than those who worked in urban areas, whilst teachers working in suburban areas were more in favour of 'stimulation for self-training' than the other groups.
- *Religious practice*: we only found significant differences between those teachers who described their religious practice as very religious and those who described it as moderately in the question about developing an awareness of values. All significant results are presented in the Table 25.3.

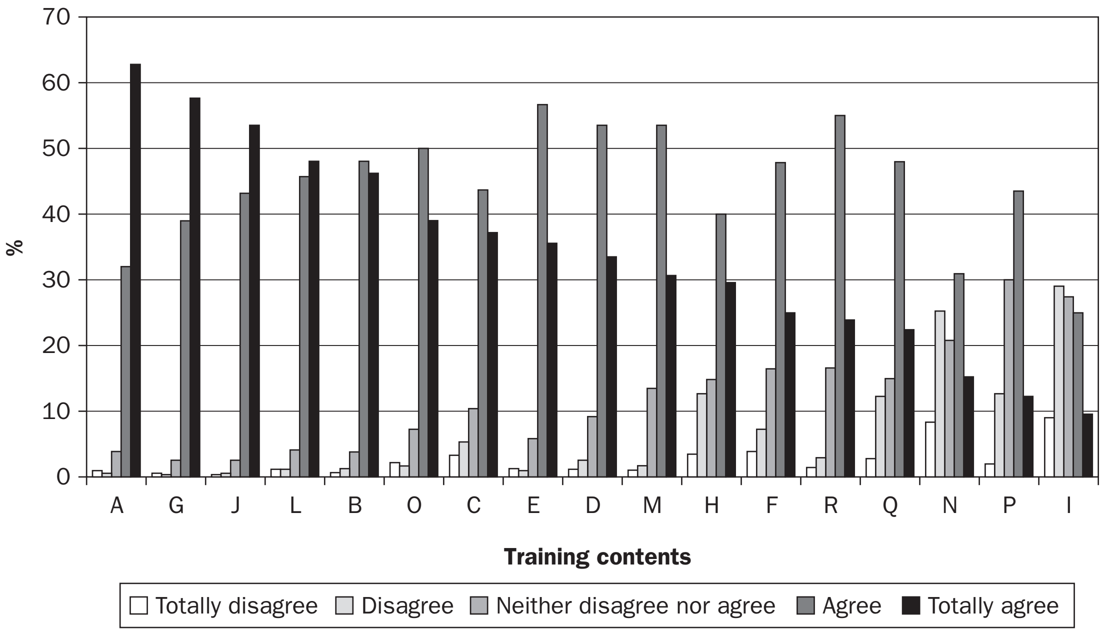

Figure 25.7 Teachers' perceptions of training needs in sex education. A, To provide scientific knowledge; B, to be able to carry out sex education projects simultaneously in school; C, to enable sex education to be carried out by all teachers; D, to specify all contents to be approached at each school level; E, to present the specific objectives for each school level; F, to include pedagogical methodologies testing; G, to prepare them to respond naturally to children's unpredictable questions; H, as a back-up when teaching topics concerning affectionate relationships; I, as a back-up when teaching the reproductive system; J, to prepare them to develop values awareness; L, to help them identify and solve problems of sexual abuse; M, to help them develop projects in sex education; N, to be carried out only by those who want to participate in sex education in school; O, to teach them to deal with parents about this theme; P, to plan some sex education projects in school; Q, to stimulate them for self-training; R, to cover legislation concerning sex education. (Note: questions were asked in alphabetical order in the questionnaire)

4. DISCUSSION

Our data suggest that primary school teachers are not favourably disposed to sex education in primary schools and nurseries. In their opinion, sex education should be taught in secondary schools. Thus, they see sex education as a task for others, not themselves. The expression of this opinion may be a subtle way of avoiding undertaking sex education in their pedagogical practices. It is easier to say that sex education is a topic that should be taught later than to have to address the barriers, myths and misconceptions that are obstacles to the teaching of this subject.

As teachers who had undertaken specific training courses were more in favour of sex education in primary schools, we suggest that these teachers had already begun to remove some of the obstacles. However, as teachers with a licence were more in favour than those with lower academic qualifications, this provides further evidence for the importance of appropriate training in order to change the conceptions of teachers about sex education.

Table 25.3 Significant influences on teachers' perceptions of training needs

	n	*Mean*	*n*	*mean*	*t-test*	
Gender	*Female*		*Male*		*t*	*P*
To fall back on in topics on affection	410	3.83	57	3.51	2.08	0.038
Only for those who want to participate in sex education	411	3.24	56	2.82	2.43	0.015
To stimulate teachers for self-training	407	3.78	57	3.49	1.97	0.049
Continuous training courses	*Yes*		*No*		*t*	*P*
To prepare teachers to respond to children's unpredictable questions	55	4.76	416	4.50	3.70	<0.001
To fall back on in topics on reproductive organs	55	3.27	406	2.92	2.15	0.032
To aim towards elaboration of projects in sex education	54	4.43	410	4.07	3.27	0.001
To stimulate teachers for self-training	55	4.13	408	3.69	2.98	0.003
To learn about legislation concerning sex education	55	4.18	408	3.94	2.04	0.042
Marital status	*n*	*Median*	*R>*	*R<*	*U-test*	*P*
Simultaneous with project development	464	4	Divorced	Married	9.80	0.042
To prepare teachers to respond to children's unpredictable questions	470	5	Divorced	Widower	8.07	0.042
To fall back on in topics on affection	465	4	Divorced	Widower Married	12.50	0.018 0.048
To prepare teachers in the development of values awareness	466	5	Divorced	Married Single	11.54	0.006 0.048
Area of work	*n*	*Median*	*R>*	*R<*	*U-test*	*P*
To be done by all teachers	445	4	Rural	Urban	7.14	0.018
To stimulate teachers for self-training	444	4	Suburban Suburban	Rural Urban	9.17	0.015 0.027
Religious practice	*n*	*Median*	*R>*	*R<*	*U-test*	*P*
To prepare teachers in the development of values awareness	456	5	Strong	Moderate	8.81	0.018

With regard to the four content areas of sex education (body growth: body changes, menarche, sexual response and genital organs; expressions of sexuality: sexual behaviour, petting, intercourse and the use of common language compared with scientific language; interpersonal relationships: familiar relationships, friendly relationships, values of help and respect and sexual abuse; and sexual and reproductive health: body hygiene, fertilisation, pregnancy, contraception and sexual disease prevention), teachers expressed more difficulties in the area of the expression of sexuality, whereas they had fewer difficulties in interpersonal relationships.

These findings tended to be confirmed in terms of the teachers' 'feelings about approaching sexuality-specific topics', where intercourse was one of the most difficult topics followed by eroticism and pornography. In contrast, 'affectionate relationships' was one of the easiest topics, and was included in the easiest area of content – interpersonal relationships. In addition, individual factors such as age, academic qualifications and training courses revealed that younger teachers, those with better qualifications and teachers who had attended specific training courses expressed fewer difficulties in these two variables. This may be associated with previous opinions concerning agreement with sex education in primary school, and reinforces the idea of better training to construct positive conceptions of sex education. However, it must be acknowledged that previous conceptions can be obstacles to the mobilisation of new scientific knowledge (Clément 1998).

It is therefore necessary to consider other contextual factors, such as areas of work and the integration of religious groups. Teachers working in rural areas had more difficulties than the others. This can be explained by the fact that rural areas are smaller, so people know each other, and the primary school teacher is assumed to be an important person in this type of conservative community. In addition, in the northern region of Portugal where this research was undertaken, the Catholic religion is a strong factor, particularly in the rural community. In these circumstances, teachers are afraid of disappointing or of affecting their social image. Even this has not happened, they avoid the process, perhaps due to personality reasons that form the relationship between psychological and social obstacles.

When analysing the opinions about participants in children's sex education, the data suggested a greater agreement with the participation of parents, followed by health professionals (physicians and nurses) and psychologists. This is another way of transferring the responsibility for sex education to others (as above for secondary school teaching). Teachers assume that parents have the primary responsibility for children's sex education. Another factor is that teachers are at school all week; if a problem occurs, they cannot avoid it. However, if health professionals or psychologists participate, they only go to school sporadically and therefore do not have problems with parents or the community.

Surprisingly, teachers working in rural areas were most in favour of their own participation in the teaching of sex education. This seems to be a paradox, and needs to be clarified in future research, but may due to the higher qualifications of teachers compared with parents in the rural community and to teachers' increased confidence in themselves.

We found that teachers who had children had more difficulties than teachers with no children in all content areas and all sexuality-specific topics. One question that emerged from three dependent variables was: Why are pupils' parents the preferred participants to teach sex education if teachers who are parents are also those having the most difficulties? A brief explanation may be linked to effective relationships at home and the difficulties of approaching sexuality in this context (Moore and Rosenthal 1995). Another possibility is that sex education is seen as a 'hot potato' to be passed to others and avoided oneself. We also need to bear in mind that those teachers without children were the younger ones, often single, and those having higher academic qualifications. The association among all of these factors may explain this finding.

The analysis of the fears of undertaking sex education reinforced the false image of parents, as parents' reactions and thoughts were the strongest fears of teachers, rather than people in school such as colleagues, the school director and the school group president.

The area of work again indicated that teachers in rural areas had more fears as well as more difficulties, whilst again those who had done training courses had fewer fears, as well as fewer difficulties.

Another important factor appeared to be gender: females were more fearful of parents' and pupils' reactions and thoughts and of other people' reactions than were males, and they also had more difficulties. We should remember that females formed the majority of our sample (and generally of the teaching population) and for females, society is more restrictive in terms of sexuality. This may be stronger than the idea that females are mothers, so they have a richer experience and are in a privileged position to teach human reproduction (Teixeira 1999).

Comparing the perceptions of support and fears, it was interesting to confirm that teachers felt basically supported by their colleagues, school director and school group president, but not by their priest. The major support factors coincided with the lowest fears. These results were clear cut and validated our method. 'Support' was the dependent variable where the factors of religion and religious practice affected the majority of questions. The Catholic teachers felt they could count on several supports, including the priest, significantly more than the teachers without religion. Those who did not practise religion considered the support of several factors to be significantly less than those who described their religious practice as moderate. Perhaps they did not need this support as they were more confident in their pedagogical practice and freer from social rules or obstacles.

Teachers agreed that training should provide them with scientific knowledge to help them respond naturally to children's unpredictable questions, to help them develop an awareness of values, and to identify and solve problems of sexual abuse. The training content in which teachers were less interested was the reproductive system and the biological component. They wanted new scientific knowledge in areas where they did not feel prepared to teach the subject. However, we believe this lack of training is not only concerned with lack of scientific knowledge. The contents are expressed in school programmes and if the teachers feel prepared in terms of scientific knowledge in other topics, they also should be prepared to teach sexuality. In comparison, they were not very interested in the reproductive system, a subject that requires precise scientific knowledge. Rather, they wanted to feel able to respond to children's questions about sexuality, because these often occur in classrooms and teachers feel embarrassed; they want to be able to avoid these emotions.

The only question that was affected by religious practice was the preparation for developing an awareness of values, where those teachers who described themselves as very religious had the highest mean, and this was significantly different compared with those who described their religious practice as moderate. In our view, teachers preferred training courses on affection and values, so that when implementing this approach they can say they teach sex education, whilst avoiding the biological content. If we accept this in the development of sex education training programmes, then the teaching of sex education is likely to continue in the same way as before. Oshi and Nakalema (2005: 102), reporting on similar research in Nigeria, suggested that training should replace misbelief by correct knowledge and should serve 'to motivate teachers and to train them on how to handle social and cultural issues while carrying out sex education curriculum'.

One interesting finding from our sample was that teachers who undertook training courses had significantly higher scores than those who had not in several topics including the reproductive system. Perhaps this training was effective in being able to change conceptions. In our opinion, a effective training course should: (1) consider teachers' perceptions of training needs and respond to them; (2) consider pupils' needs and prepare teachers to deal with them; (3) include contents of all four areas outlined and in all specific topics, in order to make it easier to approach the more difficult areas or topics; and (4) use several methodologies that can be applied in a classroom context to reduce teachers' constraints with trainer support.

5. CONCLUSIONS

In summary, the most influential factors on primary school teachers' conceptions and obstacles in dealing with sex education in the classroom were: gender (males reported fewer difficulties than females); age (younger teachers generally expressed fewer difficulties than older ones); training courses (teachers who undertook these courses were more comfortable than teachers who did not); area of work (teachers working in rural areas expressed more difficulties than those working in urban areas in all topics); having children (teachers with children revealed more difficulties than those without); and religious practice (non-practising teachers had fewer difficulties and fears and needed less support). We believe that an efficient way of changing the conceptions and obstacles to sex education is specific training for teachers in sex education, first considering the need to motivate teachers and then tackling teachers' perceived difficulties in responding to the real needs of pupils.

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26 Biology and health education: is reproductive biology a real chance for sex education?

Penelope Papadopoulou, Anna Kartsoglou and Kyriacos Athanasiou

DEPARTMENT OF PRIMARY EDUCATION, ARISTOTLE UNIVERSITY OF THESSALONIKI, GREECE

popipap@eled.auth.gr

The study described in this paper aimed to investigate the frame in which sex education takes place in secondary schools in Greece. The study included: (1) interviewing the key person responsible in the local authority, for health education in secondary schools; (2) studying the teachers' views, and (3) examining biology textbooks. The participants of our study were one teacher responsible for health education and three secondary science teachers. Participants were interviewed individually and the interviews were analysed using the method of constant comparison. Biology textbooks for the 7th (age 12) and 9th year (age 15) of compulsory schooling, and especially units on human reproduction, were analysed with a checklist. The results provided evidence that biology lessons are the only real chance for sex education in secondary education, as sex education programmes are rare. However, the biology textbooks' coverage of human reproduction and sex education issues is poor; topics on sexual identity and intercourse are not included. Also, there is no focus on equal opportunities issues. The teachers' interviews revealed the difficulties of teaching sex education in biology lessons on human reproduction and confirmed the obstacles and complications concerning sex education that have been described in previous studies.

1. INTRODUCTION

Today, it is essential for people to view health as a positive aspect of well-being and not simply as the absence of illness or disease. Interest in the goals of health enhancement and problem prevention also includes the area of sexual health as a major, positive part of personal health and healthy living.

It is widely accepted that sex education is a crucial issue. However, there still exists widespread disagreement as to what its aims should be, how they should be realised and indeed whether sex education should be taught in schools at all (Reiss 1995). In the light of this perceived importance, the need emerges to look at the ways in which compulsory schooling gives pupils the opportunity to be informed about sex education.

1.1 Issues related to sex education and biology teaching

1.1.1 Attitudes of teachers

Sexuality is a contested and problematic area of social life around which anxieties accrue. Teachers are not set apart from these beliefs and anxieties. Teachers' attitudes are crucial to the success of any curriculum (Kirby 2002). Thus, given the importance of sex education, the classroom teacher should be an important focus of research (Scribner 2000). According to Wenzlaff (1998), teachers' characteristics, attitudes, conceptions of the self, and intellectual and interpersonal dispositions can influence both the explicit and the hidden curriculum in the classroom.

Teachers were perceived as credible and trustworthy sources of information about sexual health and were high on young people's list of preferred sources of information (Rosenthal and Smith 1995, Eisenberg *et al.* 1997, McKay *et al.* 1998).

Furthermore, teachers' knowledge (Veiga *et al.* 2006) and understanding is not the only factor that determines how teachers feel about teaching a particular topic (Cohen *et al.* 2003). Factors that contribute to the willingness of a teacher to implement the curriculum also include their perception of the importance of teaching the curriculum, their intention to teach the curriculum and their level of comfort with the curriculum's subject (Levenson-Gingiss and Hamilton 1989; Hamilton and Levenson-Gingiss 1993).

Teachers frequently used the word 'difficult' when talking about the practice of sex education, referring to the subject per se, as well as specific topics of the subject (Buston *et al.* 2001; Milton 2003). Certainly, the results of previous studies suggest that the topics that are least likely to be covered are those that are considered most sensitive or controversial, such as masturbation, abortion, homosexuality, diversity, fantasy and sexual dysfunction (Forrest and Silverman 1989; Johnson Moore and Rienzo 2000; Cohen *et al.* 2003; Price *et al.* 2003). Also, these results emphasise that there appears to be a disparity between the importance teachers assign to teaching particular sexual health topics and their own knowledge about it and their comfort in teaching these topics.

Teachers interviewed in English schools expressed concern about the possibility of adverse publicity with respect to sex education and also saw dissenting parents as a potential threat (Lewis and Knijn 2001). According to Sieg (2003), sex education has the potential to bring educators into conflict with parents, schools and even the law. It is not surprising then that the majority of teachers might opt to stick to the biological aspects of sex, sexuality and reproduction, and to avoid uncomfortable topics.

1.1.2 Qualities of teachers

Surveys have indicated that sex education programmes can produce positive outcomes, which are significantly influenced by the teacher's own philosophy and commitment to the programme objectives (De Gaston *et al.* 1994). Well-qualified teachers are seen today as an important prerequisite for effective school-based sex education programmes. Comfort, humour, contact with pupils, flexibility and acceptance of others' ideas and opinions, as well as the creation of an atmosphere of trust, seem to be important attributes for teaching sex education (Milton *et al.* 2001; Hilton 2003; Buston and Wight 2004). These qualities are similar to those recommended in the literature in the 1970s and 1980s (Milton *et al.* 2001).

1.1.3 Sex education in biology classes

Although health education is interdisciplinary, many topics and themes in health education are addressed as part of biology curricula and teachers of subjects such as biology have an important role in teaching about health (Turner *et al.* 1999). Tunnicliffe and Reiss (1999) argue that, for young pupils, the potential for science activities are adequate to fulfil some of the wider aims of education, specifically those that traditionally fall under the banner of 'sex education'. By the end of secondary school, many sex education programmes expect pupils to have covered topics such as growth, physical development including changes at puberty, keeping safe, reproduction including human conception and fetal development (Reiss 1993). Topics such as puberty, menstruation, pregnancy, childbirth and contraception are components of biology syllabi of compulsory education, and biology teachers are expected to teach them to pupils of this age. It is expected that biology classes will discuss many of the topics mentioned above, but biology deals with a lot of other issues. Scholer (2002) claims that the average biology teacher can adequately illustrate the process of reproduction and the risks of unprotected sex, whilst also acknowledging the non-reproductive aspects of sexuality. However, Dutch biology teachers felt that the emotional side of sexual relationships was too diverse for biology teaching, as science teaching has long been criticised for being too mechanistic (Lewis and Knijn 2001).

1.1.4 Curricula and textbooks

Biology textbooks, unlike sexuality textbooks, traditionally present a mechanical approach to sexuality, with strong implications that sexuality is strictly for reproductive purposes. This approach denies the social and emotional aspects of sexuality (Reiss 1998). Additionally, the focus on equal opportunities issues, an essential quality of sex education curricula and textbooks, encourages students to examine the roles played by men and women in society. Many textbook editors place the chapter or chapters on sexuality at the very back of the book, implying that sexuality is something that should be hidden. It also suggests that sexuality is the last topic to be presented in the course, with a high probability that it will not be fully discussed (Scholer 2002).

1.2 Aims and research questions

Our study's main aim was to describe the frame in which sex education takes place in Greek secondary schools. We focused on the following research questions:

- Where in the curriculum does sex education take place in secondary education? In biology classes or during particular health education/sex education projects?
- What are teachers' views of teaching sex education topics as part of the biology syllabus?
- What are teachers' understandings of the views that pupils aged 12–15 years have about human reproduction and sex education topics?
- What are teachers' opinions about the other factors that affect sex education teaching?
- Given that most biology teachers rely on textbooks, what is the coverage of reproductive biology and sex education topics provided in biology textbooks?
- Is there a focus on equal opportunities issues in the sex education topics provided in biology textbooks?

2. METHODS, PARTICIPANTS AND DATA SOURCES

In order to investigate whether sex education is delivered in secondary schools, a teacher responsible for all health education programmes in a large urban educational authority, namely the East Thessaloniki area, participated in our study. She was interviewed individually. The conversation was free, although it started with a group of prepared questions. The aim of the interview was to secure the maximum amount of information about sex education in secondary schools.

Biology textbooks (Kastorinis *et al.* 1997; Andriotis *et al.* 1999) for the 7th and 9th year of compulsory schooling, especially the units about human reproduction, were analysed using a checklist of 14 questions, based on that developed by Reiss (1998). The checklist contained the four major categories of anatomy, puberty, contraception and sexual identity/intercourse. According to Reiss (1998), these categories were identified as covering the major areas of sex education that deal with human sexuality. The questions are presented in Table 26. 3. In the analyses, the focus was mainly on equal opportunities issues, an essential quality of sex education curricula and textbooks, in order to encourage students to examine the roles played by men and women in society. The findings of biology textbooks were compared with those of sex education teaching packages (Gotzamanis and Papathanasiou 2000; Merakou *et al.* 2000). The sex education teaching packages contained a variety of materials, but for the purposes of this study we analysed only those parts that contained information texts.

In the study of teachers' views, the participants were three in-service secondary school teachers, one man and two women, who were teaching biology in public junior high schools. They each had teaching experience of more than 15 years. Their scientific backgrounds were: a bachelor's degree in biology for the two women and in physics for the man. None of them had received any official training in sex education.

The interview schedule was prepared after analysing the interview of the Health Education Advisor in order to use the information garnered and focus the questions. The schedule covered topics such as the content and delivery of human reproductive biology, teachers' views about the perceived barriers and obstacles to teaching sex education in biology classes, pupils' attitudes and finally teachers' views about the educational material and textbooks.

The participants were interviewed individually. The analysis of the interviews was performed following selected analytic principles of grounded theory (Strauss and Corbin 1998). One methodological element of grounded theory we used was that of 'constant comparison': the findings were compared with each other, across respondents and against the current literature and results from related studies (Strauss and Corbin, 1998). The process ended when theoretical saturation – the point at which no new categories emerged from the data – was reached (Strauss 1987)

3. FINDINGS

3.1 Sex education in the health education frame

In Greek secondary schools, health education is optional. These projects are essentially extra-curricular, developed outside the obligatory curriculum and during students' leisure time. Health education is part of the curriculum only in particular vocational schools. Optional means that health education is taught only when a group of pupils and their teachers decide to engage with issues related to health education. These groups are not formed in every school and it is not necessary for all of the pupils and the teachers of a particular school to be involved in such a group. Teachers from all backgrounds can be involved with these projects.

The topics of the sex education projects in were:

- I care about my body
- Puberty – my life is changing
- Pregnancy – contraception – abortion
- AIDS
- Sexually transmitted diseases
- Personal relationships, based on love
- Gender relationships – AIDS
- Gender relationships

- Gender relationships – sex education
- Sex education
- Sex education – gender relationships – prenatal screening
- Young people and sex education
- Gender equality and sexually safe behaviour
- Personality empowerment with sexually safe behaviour
- Pupils' personality empowerment with a focus on sex education

The Health Education Advisor confirmed that the chances of sex education in the context of health education are disappointingly restricted. The number sex education projects was extremely small. This assertion was based on the fact that, in this urban district, there are 176 secondary schools of all types (junior high schools, high schools and vocational schools). Health education projects that focused on sex education in these schools during the last 6 years are presented in Table 26.1. As can be seen in the table, only a very few sex education projects were implemented in Junior High Schools, which are the last years of Greek compulsory schooling. For example in 2004–2005, only one of the five sex education projects was implemented at a Junior High School. The same teachers in the same schools are committed to teaching sex education and they usually received an official special training to teach the subject. In these schools, problems and obstacles with parents and the school Head Teachers are very rare.

3.2 Textbooks

Analysis of the textbooks using the checklist (Tables 26.2 and 26.3) revealed the poor coverage of the topic. Of the four main categories, only anatomy and puberty were represented in Year 7 and intercourse/sexual identity in Year 9. It was not possible to find elements that focused on equal opportunities, which was one of the main research interests of this study.

The comparison with sex education teaching packages (Tables 26.2 and 26.3), as expected, revealed a many differences in the coverage, variety of topics and the focus on equal opportunities. All of the main categories of the checklist were presented in both teaching packages.

Topics about anatomy, puberty, menstruation and human reproduction were presented in biology textbooks (Table 26.2). Such topics are expected components of biology syllabuses for pupils aged 11–16 years but the coverage, in this case, was extremely restricted – ten pages from a total of 214 pages for Year 7, and nine pages from a total of 199 pages for Year 9. Year 7 biology textbooks

Table 26.1 Sex education in the secondary schools in this study: total number of health education (HE) projects and sex education (SE) projects

School year	*Total number of HE projects*	*Total number of SE projects*	*Total number of schools involved in sex education*	*Number of SE projects in Junior High Schools*	*Total number of teachers involved in SE projects*
2000–2001	65	3	3	0	5
2001–2002	90	5	4	3	8
2002–2003	104	1	1	0	2
2003–2004	99	5	4	1	9
2004–2005	91	5	5	1	7
2005–2006	96	4	4	1	6

Table 26.2 Topics related to sex education presented in biology textbooks and sex education packs

Biology for the 1st Grade of Junior High School (7th year of compulsory schooling – age 12)	*Biology for the 3rd Grade of Junior High School (9th year of compulsory schooling – age 15)*
Reproduction in human beings (part of a unit about: Reproduction in living organisms):	**Reproduction in human beings** (part of a unit about: Reproduction and Genetics):
Male reproductive system	Definitions
Female reproductive system	The creation of a child
Menstruation	*In vitro* fertilisation
Conception – Development of the fetus – Delivery	Delivery
Pregnancy and health behaviour	Contraception
Adolescence: the start of a new life	
Sex Education Pack (for 11–14 years old)	*Sex Education Pack (for 15–18 years old)*

Puberty and adolescence
• Sexuality in adolescence
  • Masturbation
  • Homosexuality
  • Sexual violence behaviour
Male reproductive system
Female reproductive system
Conception, reproduction and fertility
The end of the age of fertility
Contraception and young people
Sexually transmitted diseases
	Sex education and health
	• Taking care of our bodies
	• Conception, reproduction and fertility
	• Puberty
	• Adolescence
	• Intercourse
	• Sexuality today
	• Pregnancy
	• Delivery/labour
	• Problems with fertility
	• Menopause in women and in men
	What to take care about in intercourse
	• Contraception and young people
	• Sexually transmitted diseases
	• The whole truth about AIDS
	Medical care
	• Women
	• Men
	• Abortion
	My sexuality
	• Culture and sexuality
	• Norms of sexual behaviour
	• Sex roles and gender
	The 'first time'
	• The necessity for sexual activity
	• Masturbation
	• First intercourse
	Other topics of sexuality
	• Sexual abuse
	• Sexual deviations
	• Homosexuality

Table 26.3 Criteria for analysing textbooks and sex education teaching packages with a focus on equal opportunity issues

Topic	*Checklist*	*Biology textbook, 7th year (12 pages)*	*Biology textbook, 9th year (9 pages)*	*Sex Education pack (11–14 years)*	*Sex Education pack (15–18 years)*
Anatomy	Are external female sexual organs shown/described?	No	No anatomy topics	Yes	Yes
	Are external male sexual organs shown/described?	Yes	No anatomy topics	Yes	Yes
	Is there a description of the variation in age concerning the beginning of menstruation?	No	No	Yes	Yes
Puberty	What images about menstruation are given?	Physiological approach	None	Physiological + personal approach	Physiological + personal approach
	Is masturbation in women discussed?	No	No	Yes	Yes
	Is masturbation in men discussed?	No	No	Yes	Yes
Contraception	Are the attitudes of different religious groups towards contraception addressed?	No	No	No	No
	Whose responsibility does contraception seem to be?	No	Both	Both	Mainly woman
Sexual identity and intercourse	Are lesbian and gay issues addressed?	No	No	Yes	Yes
	Is intercourse assumed to be heterosexual?	No	No	Generally	Generally
	Is sexual activity equated with penetrative intercourse?	Yes	Yes	Yes	Yes
	Is non-penetrative sex considered?	No	No	No	No

Table 26.3 *Continued*

Topic	*Checklist*	*Biology textbook, 7th year (12 pages)*	*Biology textbook, 9th year (9 pages)*	*Sex Education pack (11–14 years)*	*Sex Education pack (15–18 years)*
	Is non-penetrative sex considered?	No	No	No	No
	Do diagrams/texts portray a variety of positions for sexual intercourse?	No	No	No	No
	Is orgasm described in more detail for one sex than for the other?	No	No	Few details for both sexes	Yes, mainly for males
	Are issues of sexual harassment and rape presented?	No	No	Yes	yes

presented puberty by using images and sets of questions in order to provoke debate about psychological and societal aspects. The two textbooks were complementary to each other as they did not have any common topics except for fertilisation issues, which was covered by both text books.

3.3 Biology teachers' views

Biology teachers' interviews completed the picture, as they revealed the difficulties of teaching sex education in biology lessons. Although their perspectives varied, some key themes emerged from their accounts:

3.3.1 Teachers' understanding of pupils' attitudes

This section includes teachers' accounts of pupils' curiosity and interest, pupils' in-class behaviour and pupils' reactions to all these.

All of the teachers reported that children exhibited a lot of interest and curiosity during the biology classes in which they studied human reproduction.

'It was the first time in my career I had the feeling that pupils were so interested about the lesson, they were perfectly willing to discuss, to ask. . .' (Teacher 2, female). In everyday language, they were asking questions all the time and about everything, such as the possibility of a pregnancy at their age, about contraception, sexually transmitted diseases, the proper age for being sexually active, masturbation and homosexual relations, if intercourse is painful and about intercourse positions.

The younger pupils (Year 7) were much more interested than their elders. Also, the girls were reported to be more mature and participatory than the boys. 'Boys sometimes boasted about knowing everything, you know, all these typical jokes . . . and implications' (Teacher 1, female). Sometimes, there were strong reactions such as sounds of disgust, signs of shock and nervous laughter: 'They start laughing, while opening their books' (Teacher 1) or 'they laughed a lot, when someone asked something' (Teacher 1). Once or two twice, one boy strongly refused to take part in the discussion: 'It was a boy, older than his schoolmates, who took his chair and turned it to the opposite wall and without looking at me he asked me "What are all these things you are talking about?"' (Teacher 1).

Teachers felt that these lessons were sometimes difficult for some of the children, mainly boys, who in their schoolmates' eyes did not have the stereotypical behaviour of this age.

'The older ones, those of the 3rd grade, scorn their timid schoolmates . . . They are trying to prove their masculinity, and they are sarcastic to the shy pupils when they try to ask some questions' (Teacher 1).

According to the teachers, the strongest reactions were presented when the pupils realised that their text book's coverage was brief and that after two or three teaching hours they had to pass on to the next topic. 'Always they want more, they need more . . . Children always want more and more and it was obvious that they were disappointed. When I decided to come to an end, they protested vigorously' (Teacher 2).

3.3.2 Teachers' attitudes

This section includes teachers' accounts of discomfort and anxiety, but also accounts of good communication, pleasure, jokes and empathy.

The female teachers were similar in their responses towards their pupils' attitude in the classroom. They believed that they have to understand their pupils and to react sometimes seriously, sometimes firmly and sometimes lightly or by laughing. However, this depends on the existing relationships with their pupils. 'You have to put yourself in their position, ask them to speak freely, to understand them; sometimes you have to be serious and sometimes you need to laugh with them. I believe all this is necessary . . .' (Teacher 1). 'We are asking children not to laugh when we are talking about sexuality. How is it possible? It is not possible for adults and we ask children to do so?' (Teacher 2).

However, they also recorded a different attitude, which was uneasy and competitive: 'I said to them, "I know you are waiting for me in the corner" and they all laughed. They told me: "We shall see how you cope with our questions, we will be hard on you." They were waiting for me in the corner but I was ready too. I said: "Be serious, now, we are talking scientifically"' (Teacher 3, male).

Finally, the teachers believed that their attitude in the classroom depended on their beliefs about sexuality and that all of the difficulties were due to this.

3.3.3 Adults connected to the school

This section mainly contains accounts of the difficulties with the Head Teachers of their schools, and the parents and the other teachers.

The adults were not very positive about the teaching of sex education, even when the subject was covered so briefly and restricted to human biology units. The heads of the schools, usually older teachers, were reported to be unconcerned in the best cases or fearful and wanting to control everything in the worst cases, even the teaching materials were produced with official supervision. 'How can I know what this is?' (Reference to a videotape about AIDS prevention.) 'I have to check it, to see for myself' (Teacher 1).

The teachers' colleagues were also reported to be reluctant to teach these topics: '. . . I heard one of my colleagues saying, "I make light of this topic if possible . . ."' (Teacher 3). 'A female teacher, a very religious person, refused to teach human reproduction. She announced to her pupils that they would discuss the topic later. One of our colleagues offered her help, to teach the units instead of her. But the Head of the school did not give his permission' (Teacher 2).

The situation was not the same with the parents; however, parents' opinions were in opposition to those of the teachers: parents preferred the teachers to be the first and main source of information for their children, whilst teachers preferred the opposite.

3.3.4 Teaching

This section includes accounts about the in-class processes and techniques used by the teachers, as well as their views about the insufficient educational materials in their schools.

Teachers valued the developmental approach (Carter 2001) of the biology textbook for Year 7, the coverage of contraception in the Year 9 textbook, the fact that there were many images and diagrams and that the units were not at the end of the book. However, in their opinion, there were many gaps and deficiencies.

The teachers stated that they would like to have more resources, especially audiovisual ones, available in their schools.

4. DISCUSSION AND EDUCATIONAL IMPLICATIONS

Access to effective, broad-based sexual health education is an important contributing factor to the health and well-being of the young. School-based programmes are an essential avenue for providing sexual health education to young people. The significance of sex education remains high in countries like Greece, where, although no high rates of sexually transmitted diseases or teenage pregnancies are reported, there are reports of other sexual health problems, such as the highest rate of abortion in the EU and the lowest use of contraceptive pills (Athanasiou 2000).

In discussing the findings of this study, it is important to recognise first that the only substantial chance of sex education in Greek secondary schools is through biology courses. This is not only the case in Greece but is also common in other European countries (Reiss 1995; Hodžić 2003). We base our conclusions on the fact that health education is not mandatory in either primary or secondary education. Additionally, our findings indicate that few health education projects deal with sex education issues. Sex education is a theme that only a very small number of pupils and teachers are working on, and the numbers are even smaller for compulsory schooling.

Considering the significance of formal education and given that biology is the only real chance for sex education, the quality of teaching human reproduction topics is extremely significant. As it was revealed by analysis of the textbooks, the coverage is poor, as only two of the four major areas of sex education were presented, and even these were sometimes very limited. Some people believe that biology classes discuss many of the topics of sex education, but this is often no longer the case because of time constraints. Sex education is not a major priority for the biology curriculum (Scholer 2002).

According to Reiss (1998):

> It is unrealistic to expect biology/science textbooks to provide a second-wave feminist critique of sexual relationships, a complete personal, social and health education programme for sexual health or a full postmodernist deconstruction of sexual identity. Nevertheless, it is realistic to expect such books to help young people manage their transition from childhood through adolescence to adulthood.

Our results reveal that even the last expectation is not realistic because of the poor content about the main issues of sex education and the lack of points of view about equal opportunities. Our findings also fit well with Reiss's (1998) statement that:

> The biology textbooks, unlike sexuality textbooks, traditionally present a mechanical approach to sexuality, with strong implications that sexuality is strictly for reproductive purposes. This construction of sexuality denies the social and emotional aspects . . .

Our investigation concerning teachers' views and attitudes about teaching human reproduction units in biology classes revealed obstacles and complications related to sex education previously described by other researchers (Biddle and Forrest 1997; Buston *et al.* 2001; Lewis and Knijn 2001; Hilton 2003; Milton 2003).

On the other hand, teachers reported the great interest and curiosity pupils have about all aspects of human sexuality. This interest is the main motivation of the teachers in their effort to deliver sex education, grasping the opportunity of human reproduction in the curriculum to do so. In our opinion, the biggest problem is that these teachers do not have special training to teach this subject and they lack the necessary time.

Given the gravity of sex health problems worldwide and the significance of sex education for individuals and societies, it is not possible to leave sex education up to the teachers' willingness. There appears to be a need to look more carefully at the ways in which teacher education courses prepare biology/science teachers to teach aspects of health, even if biology instruction, and particularly human reproduction units, do not manage to confront all of the needs and complications presented in individual countries. Teachers' pre-service and in-service training on sex education is also critical.

It is an urgent necessity for sex education not to be optional and extracurricular, but to be included in the curriculum of compulsory education and in the pupils' timetable. Time is needed, more than one school year, for a developmental approach to sex education in which pupils learn the fundamentals of sexual health in elementary school and, as they are growing, build on this foundation and learn about additional and more complex topics (Cohen *et al.* 2003).

School-based sex education should receive a high priority for several reasons but importantly for the reason that it encourages young people to become wise, sexually healthy adults. Opposition to sex education appears to be escalating in many countries and this is also the situation in Greece. Whilst such disapproval is not new, it is important that academics and educators recognise the connections between local, national and global neo-conservative agendas, in an attempt to shift the discourse and prepare an intelligent and coherent response (Eyre 2005).

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7

Social, cultural and gender issues in biology education

27 Therapeutic cloning? Discourse genres, ethical issues and students' perceptions

Marta Federico-Agraso and

María Pilar Jiménez-Aleixandre

UNIVERSIDADE DE SANTIAGO DE COMPOSTELA, SPAIN

maragra@usc.es

This paper is part of a study on decision-making about human cloning. The objectives were: (1) to analyse the discourse in scientific and newspaper articles about the first nuclear transfer (NT) in humans reported by Hwang *et al.* (2004), with a focus on rhetoric; and (2) to examine the comprehension of university students about this research, as filtered by newspapers. The study was framed within discourse analysis and socio-scientific issues in science learning. The context was the controversy around the first reported human NT, later exposed as a hoax. The methods involved analysing: (1) six reports, both academic and journalistic; and (2) the written reports of university students with and without a biology background about one of them. The results showed features of the rhetoric in the papers, as the reduction of uncertainty or the emphasis on therapeutic applications; attention was given to terms such as 'cloning' versus 'nuclear transfer', 'therapy' versus 'basic research'. Analysis of the students' reports also showed the difficulties encountered, even by those with a biology background experienced in acknowledging a range of ethical issues involved and in perceiving rhetoric. Implications for biology education and critical thinking are discussed.

1. INTRODUCTION

This paper is part of a study purporting to document epistemic practices and processes of construction and the use of biology concepts related to decision-making about human cloning. The context was the impact on the media of the first reported nuclear transfer (NT) in humans (Hwang *et al.* 2004), which, whilst our study was in progress, took on a new dimension after November 2005 when Hwang faced problems related to oocyte donation. In December 2005, Hwang's papers were exposed as a fabrication and in January 2006 they were retracted by *Science*.

On 12 February 2004, whilst we were designing a teaching sequence about cloning, a paper by Hwang *et al.* (2004) was published online and received wide coverage in the media. In addition to the original paper, we collected articles published in Spanish journals with the objectives of (1) comparing the discourse in texts about the same topic written in scientific articles and in newspapers and, from these, comparing articles written by journalists and by scientists; and (2) examining the comprehension and attitudes of university students about this research, filtered by the journalistic reports. We could not have anticipated the fabrication of the results, which expanded the paper's ethical implications beyond our initial scope.

The study is part of a project about scientific competencies, which seeks to assess the capacity to draw appropriate conclusions from evidence and to criticise claims made by others on the basis of evidence, paying attention to the reading and writing of scientific texts. Scientific literacy involves literacy (Norris and Phillips 2003) that includes understanding journalistic science reports. Our goals in this study were:

1. To analyse the discourse genre in scientific and newspaper articles about the first nuclear transfer in humans, focusing on content and rhetoric.
2. To explore the capacity of university students to identify the main issues of this research as reported in the media, including the ethical implications.

2. READING, WRITING AND EVALUATING SCIENTIFIC TEXTS: RATIONALE AND OBJECTIVES

Our rationale was drawn from two different aspects: first, studies about writing and reading scientific texts and the role of language in science learning; and secondly, studies about students' argumentation and decision-making in socio-scientific issues.

Language is instrumental in the construction of meanings. Norris and Phillips (2003) advocated the centrality of reading and writing for the learning of science, where reading is understood as inferring meaning from texts, for instance journalistic reports.

Our approach to the analysis of texts was framed within a perspective that considered writing science not as reporting but as constructing scientific facts (Myers 1990) and scientific writing as a social practice (Bazerman 1988). This focus on discourse does not indicate an attack on the relevance of science (Myers 1990) but rather an exploration of the features of texts that have rhetorical significance. Texts were viewed as part of the social processes involved in the production of scientific knowledge, of the negotiations of the place and value of a claim.

Myers' (1990) focus was on 'writing biology', on the narrative devices conveying certain meanings and making it difficult to imagine alternative interpretations, rather than on 'writing about biology', interpreted as reporting on entities already existing, rather than constructed – among others – through the process of writing. Halliday and Martin (1993) argued that the difficulties that students and lay people experience with the language of science lie more with the grammar than with the vocabulary. Because the language of science sets apart those who understand it from those who do not, it may alienate students and other people from science; therefore, Halliday and Martin (1993: 21) advocated a shift towards more democratic forms of discourse, constructing 'a world that is recognisable to all those who live in it'.

These perspectives are grounded in Bakhtin's (1986) notions of communication as a social phenomenon and speech genre defined as types of utterance related to particular spheres of communication through thematic content, linguistic style and compositional structure. Halliday and Martin (1993) developed tools to analyse the compositional structure of scientific texts, for instance the subjective intrusions of the author through intensification or evaluation, here analysed as rhetoric.

A second frame for this study was discourse and argumentation analysis. We sought to combine discourse analysis both of scientific and newspaper articles and of students' written reports. Journalistic and scientific reports differ, the first being the product of discourse transformations.

The goals of the project framing the study included assessing the development of the capacities of drawing conclusions and criticising claims, which rely on an understanding of the scientific texts, written or spoken. Scientific literacy should enable students to read science journalistic reports as required in the task. We consider scientific literacy as a requirement for critical thinking, which empowers students to build their own discourse, to participate in social decisions and to uncover the rhetoric in texts.

The study was concerned with a scientific issue with strong social implications. Socio-scientific issues have received increasing attention (e.g. Kolstø 2001). Argumentation in them requires a robust understanding of the content involved, together with consideration of ethical, economic and social dimensions. Relating conclusions to evidence in them requires an articulation of scientific and social dimensions, as for instance in ecology concepts and values hierarchy (Jiménez and Pereiro 2002). Socio-scientific issues are controversial, as it is difficult to assess the relative weights of positive and negative outcomes, and evaluations with support in evidence, which constitute epistemic practices.

The objectives were developed into these questions:

1. Which similarities and differences are found in the discourse genres of (i) the scientific papers, (ii) the journalistic reports written by scientists, (ii) the journalistic reports written by journalists? Do they differ in terms of thematic content and rhetoric?
2. Are the students able to identify the main issues in a journalistic report? Do they perceive the rhetoric? Are there differences among students with and without a biology background?

3. METHODS AND DATA SOURCES

3.1 Participants, tasks and samples

For objective one, we selected: two academic papers from *Science*, the original paper of Hwang (2004) and a summary of it by Vogel in the same journal on February 13, when it was published on line; four journalists' reports from Spanish newspapers also published on 13 February, two written by leading Spanish scientists in the field and two by journalists specialising in science. Table 27.1 gives the details of the papers, which will be subsequently referred to by their first authors.

Table 27.1 Articles analysed (Spanish titles translated)

Author(s)	*Journal/newspaper*	*Title*	*Authors' profile*
Hwang *et al.*	*Science*, 303, 1669–74; March 2004	'Evidence of a pluripotent human embryonic stem cell line derived from a cloned blastocyst'	Scientist, Seoul National University (Korea)
Vogel	*Science*, 303, 937–8; 13 February 2004	'Human cloning. Scientists take step toward therapeutic cloning'	Science staff Raya and Izpisúa
	El País, 13 February 2004, p. 30	'One step toward regenerative medicine'	Scientists, Salk Institute, San Diego (born in Spain)
B. Soria	*El País*, 13 February 2004, 30	'Therapeutic cloning is possible'	Scientist, Elche University (Spain)
Sampedro	*El País*, 13 February 2004, p. 29	'The key to success'	Journalist specialising in science
Jáuregui and Boto	*El Mundo*, 13 February 2004 (front page, continued on pp. 34–5	'First proven cloning of human embryos opens a new age for science'	Journalists specialised in science and health

For objective two, four groups of university students (*n* = 83) two with (*n* = 40) and two without (N = 43) a biology background were selected. The task was part of the activities in their science education course and was as follows: the journalistic report by Soria was distributed to the students and they were asked (i) to summarise it and (ii) to write two or more reasons for and against this type of research.

3.2 Methods

Two dimensions were chosen as the focus for the analysis of discourse genre:

- *Thematic content*: as the topic was the same for all of the journalists' reports, as well as Vogel's commentary on Hwang's reported findings, the analysis could illuminate the options about what to omit and what to highlight.
- *Rhetoric*: these categories of intensification, emphasis on certainty/uncertainty, emphasis on therapies and appeal to authority, discussed in the next section, were identified as the result of interaction with the data.

Both authors of this study performed the analysis independently, and differences were discussed until a consensus was reached. For objective two, the written answers of the students were read and a list of categories was produced. The categories were then modified and the data were subjected to a revised analysis.

4. DISCOURSE GENRES IN SCIENTIFIC AND NEWSPAPER ARTICLES

Although it is now known that the results of the Hwang papers were fraudulent, the journalists' reports were written at the time of its publication when the reported findings were considered reliable. Our analysis did not have the objective of discussing the fabrication, but rather identifying features of the rhetoric, to trace the processes of discourse transformations from scientific to popular articles.

4.1 Thematic content

In order to analyse the thematic content, we took the paragraph as the unit of analysis. Each paragraph was summarised using one or more labels, such as 'therapeutic cloning' and 'parthenogenesis not excluded', keeping as close as possible to the authors' words. These labels were then grouped under common categories, for instance these two were grouped under 'main content' and 'uncertainty' (see Table 27.2).

In five of the nine themes, there were more similarities than differences. These themes were (1) main content label ('therapeutic cloning': 5; 'regenerative medicine': 1; these are labels that others find problematic, as discussed below); (2) findings; (3) therapeutic applications: the emphasis on therapies is discussed together with rhetoric; (4) technical processes; and (5) low efficiency.

In the other four themes, the papers diverged. One of them, previous obstacles, did not have the same rhetorical significance as the other three. The others are further discussed below in connection with rhetoric.

4.1.1 Uncertainty/certainty

Hwang and Vogel stated that, because both the nucleus and the enucleated egg came from the same woman, the parthenogenetic origin could not be excluded. Contrary to expectations about this, whilst the scientists did not.

Table 27.2 Summary of content in the papers analysed

Content	*Category and number of papers*
1. Main content label	Therapeutic cloning, 5: H, V, BS, S, J
	Regenerative medicine, 1: R
2. Findings	Nuclear transfer in humans, 6
	Derivation of human embryonic stem cell lines, 6
3. Therapeutic applications	Transplant without rejection, 5: H, R, BS, S, J
	Tissue repair/reprogramming, 3: H, V, BS
	Long time to therapies, 1: R
4. Technical processes	Nuclear transfer process, 6
	Ovule enucleation, 5: H, V, BS, S, J
	Egg number, 4: H, V, S, J
	Same donor for cumulus cell and nucleus, 3: H, V, J
5. Low efficiency	Low efficiency, 5: H, V, R, BS, S
6. Previous obstacles	Problems with primates' mitotic spindle, 3: H, V, BS
7. Uncertainty/Certainty	Parthenogenetic origin not excluded, 4: H, V, S, J
8. Ethical concerns	
	Risk of reproductive cloning, 5: H, V, R, S, J
	Objections to using human eggs/embryos, 5: V, R, BS, S, J
	Donation procedures, 2: H, V
9. Regulations	Regulation of human nuclear transfer, 5: V, R, BS, S, J
	Call to allow the prcedure in Spain, 4: R, BS, S, J

H (Hwang), V (Vogel), R (Raya), BS (B. Soria), S (Sampedro), J (Jáuregui).

4.1.2 Ethical concerns

Three ethical concerns were mentioned: the first, mentioned in five papers, was the risk of rogue scientists performing reproductive cloning; the second, in all papers except that of Hwang, was ethical objections to using human embryos or eggs; the third, only in the *Science* papers, was the character of the donations, that they should be voluntary and without financial payment. It was the question of donors, with a payment of US$1400 to each, and the affiliation of two of them to Hwang's laboratory that first cast doubts about the trustworthiness of his results.

4.1.3 Regulations

All authors except Hwang mentioned these. The journalists' reports discussed the need for new Spanish regulations, allowing this research. Regulation was entwined with ethical positions.

The analysis of the rhetoric deployed in the papers added new dimensions to this analysis.

4.2 Rhetoric

Rhetoric can be defined as persuasive discourse. For its analysis, both authors read the texts independently and identified instances of rhetoric, assigning them to categories. Subsequently, the categories – products of interaction with the data – were discussed and modified and the texts subjected to a revised analysis. This cycle was repeated yielding the categories presented in Table 27.3.

We considered the following: indicators of emphasis intensifiers, such as adjectives (undeniable, elegant) or adverbs (never, gently); the use of highly charged terms (madness, rogue scientists); analogies ('traffic of female cells could arise, leading unavoidably to thinking about traffic of organs');

Table 27.3 Categories for the analysis of rhetoric (emphasis added)

Category	*Examples*
Emphasis on certainty and reliability	'. . . they would not induce the *least* immunological rejection' (S) '. . . an *undeniable* scientific reality.' (J) '. . . transplants that the patient would *never* reject.' (J)
Emphasis on originality, sophistication and relevance	'. . . and *gently* squeezed out the genetic material.' (V) '. . . shows in an *elegant* way. . .' (BS) '. . . opens a *new age* for science.' (J) '. . . a *new, less aggressive* method.' (J)
Emphasis on therapies	'. . . could be transplanted without immune rejection to treat *degenerative disorders* such as *diabetes*, *osteoarthritis*, and *Parkinson's disease*.' (H) '. . . to turn them into the cells *our patients* need.' (BS) '. . . their *only objective* is to *cure* disease. . . (J)
Emphasis on ethical concerns	'Involves creating human pre-embryos bound *only* to be disposed of. . .' (R) '. . . [they] consider that a 14 day embryo is a *human being*.' (S) '. . . a *trafficking* of female cells could arise.' (J) '. . . creating babies would be *madness*.' (J)
Appealing to authority	*I. Wilmut*: '. . .the team that cloned *Dolly*.' (V) International Society of *Bioethics* (BS) *R. Lanza*: from Advanced Cell Technology (S) A. Rios, *Chair* of Biology in the University (J)

H (Hwang), V (Vogel), R (Raya), BS (B. Soria), S (Sampedro), J (Jáuregui).

and metaphors ('The winning horse in the race of human cloning'). Another dimension of rhetoric that was explored, in addition to mentions, was omissions (e.g. 'cloning' rather than 'human cloning').

4.2.1 Emphasis on certainty and reliability

The analysis of content pointed to differences about the possible parthenogenetic origin, which was omitted in some papers. There were other references to certainty, with stronger emphasis from the two journalists, as illustrated in the excerpts below (emphasis added):

> [The protocol] constitutes the recipe allowing any *other expert l*aboratory in the world to clone a human embryo.
>
> (Sampedro)

> Therapeutic cloning is no more a mere hypothesis, being now an *undeniable* scientific reality.
>
> (Jáuregui)

A second group of references dealt with the transition from this research to therapeutic applications:

> [The transplanted tissues] would not induce the *least* immunological rejection.
>
> (Sampedro)

> . . . transplants that the patient would *never* reject.
>
> (Jáuregui)

The emphasis on certainty in the sentences written by the journalists contrasted with quotations from experts or scientists, where these assurances were toned down:

> All the experts pointed out yesterday that these clinical applications would take several years to arrive.
>
> (Sampedro)

> As Hwang points out 'As these cells carry the nuclear genome of the same person it can be expected that they wouldn't produce immune rejection.'
>
> (Jáuregui)

Table 27.4 represents the process of discourse transformations about immune rejection from the *Science* paper to Hwang's reported statement as quoted by Jáuregui, to this latter author's sentence: 'it is proposed' is transformed into 'it can be expected' and finally into 'never'. The result is a reduction of the tentativeness.

In summary, the comparison of papers in terms of certainty/uncertainty produces a picture of diminishing tentativeness, which can be represented as:

> Science: H, V → Scientists in newspapers: R, BS → Journalists: S, J

4.2.2 Emphasis on originality, sophistication, relevance

There were not great differences among the papers, except for that of Hwang, where these dimensions could be implied, but not stated:

> In a work that observers call both *remarkable* and inevitable. . .
>
> (Vogel)

> First proved cloning of human embryos opens a *new age* for science.
>
> (Jáuregui)

4.2.3 Emphasis on therapies

With regard to the terms or labels used for this research, all papers agreed on either 'therapeutic cloning' or 'regenerative medicine'. Although the authors treated these terms as unproblematic, they

Table 27.4 Discourse transformations about immune rejection (emphasis added)

Original paper by Hwang	*Reported statement of Hwang*	*Sentence from Jáuregui*
'. . .these cells would carry the nuclear genome of the patient; therefore *it is proposed* that after direct cell differentiation, the cells could be transplanted without immune rejection.'	'. . .as these cells carry the nuclear genome of the same person i*t can be expected* that they wouldn't produce immune rejection.'	'. . . theoretically would allow obtaining all types of human tissues for transplants that the patient would *never* reject.'

are far from being so: Magnus and Cho (2005) discussed what they called the therapeutic misconception, or lack of recognition, of the large gap between research and therapy, including the distance of years between research and its potential clinical benefits. They pointed out that 'the language used to describe the research can reinforce the therapeutic misconception misleading donors and subjects into believing that research is therapy' (Magnus and Cho 2005: 1748). For them, the accurate term is 'human embryonic stem cell research' rather than 'therapeutic cloning', because there is currently no such thing as the latter. They extended their critique to terms such as 'cell therapy' and 'patients'.

Only in the report by Soria was there a hint about the inaccuracy of the terminology: 'the *so-called* therapeutic cloning'. However, his orientation appeared to be different from that Magnus and Cho (2005), because in a previous article he proposes 'nuclear transfer therapy' to avoid the negative connotations of 'cloning'. A similar reason may have led Raya to avoid any reference to human 'cloning', using instead 'regenerative medicine'. However, in line with Magnus and Cho's argument, there is currently no 'medicine'. With regard to the emphasis on therapies, there were no differences among the four papers written by the scientists (see also Table 27.3):

> When applied in a therapeutic setting, these cells would carry the nuclear genome of the *patient*.
>
> (Hwang)

> . . . promise for replacing cells damaged by *diseases* such as *Parkinson's*.
>
> (Vogel)

> . . . to differentiate in the type of cells that the *patient* needs.
>
> (Raya)

> . . . to turn them into the cells *our patients* need.
>
> (B. Soria)

In the journalists' articles, the emphasis on therapies was even stronger:

> [Quoting Lanza] is an important *medical* milestone. . .offering hope to millions of *patients* from a long list of *diseases*.
>
> (Sampedro)

> They [Hwang *et al.*] claim that their *only objectiv*e is to *cure disease*.
>
> (Jáuregui)

The emphasis on therapy could be interpreted as a narrative device that, as Myers (1990) points out, conveys certain meanings, here of goals related only to healing, and makes it difficult to think of alternative objectives such as money, prestige or a Nobel prize. As Magnus and Cho (2005) indicate, making the case one of 'therapy' may mislead donors into involving themselves in procedures that, as is the case with ovarian stimulation, are not devoid of risk.

4.2.4 Emphasis on ethical concerns

Three ethical implications were prominent in the papers. All except Soria mentioned concerns about reproductive cloning, peaking with the use of highly charged terms in the newspaper articles:

> Donors *voluntarily* donated oocytes and cumulus cells (including DNA) for therapeutic cloning research and its applications *only*, not for *reproductive cloning*; and there was *no financial payment*.
>
> (Hwang)

> . . . agree that cloning *to produce a human child* should be banned.
>
> (Vogel)

> . . . banning any experiment leading to attempting *human reproductive cloning*.
>
> (Raya)

> . . . creating *babies* would be *madness*
>
> (Jáuregui, repeated three times)

A transition could be observed from technical terminology ('reproductive cloning') in Hwang, omitting any explicit mention of human reproductive cloning, to emotionally charged sentences including 'babies' and 'madness'. Ethical concerns about using human embryos and eggs were omitted only by Hwang:

> . . . *human* embryos would be *deliberately* created and then *destroyed* to derive stem cells.
>
> (Vogel)

> . . . creating *human* pre-embryos bound *only to be disposed of*. . .
>
> (Raya)

The donation procedures were explicit only in the *Science* papers, although in Jáuregui there was an implicit reference. One quote in Hwang related to this is given above.

> . . . [the women donors] were *not compensated*, and were informed that they would *not personally benefit* from the research.
>
> (Vogel)

> . . . a *trafficking* of female cells could arise. . .
>
> (Jáuregui)

Magnus and Cho (2005) criticised the consent process in Hwang, because it revealed little attention to the procedure's risks, pointing to the problematic nature of altruistic donation, which would need to rule out all potential coercion. It should be noted that Magnus and Cho's paper was published in June 2005, when there were no hints about ethical breaches by Hwang. Subsequent disclosures proved that the donations were not unpaid and that a conflict of interest existed at least for two junior researchers. Except for the mention in Jáuregui, this was treated as unproblematic in the papers.

4.2.5 Appealing to authority

Appealing to authority involves mention of scientists, journals, institutions or iconic exemplars (e.g. Dolly the sheep) to support the relevance of the work; some were explicit and others implicit, such as when Soria mentions that the term ‘nuclovule’ was coined by the president of the International Society of Bioethics (SIBI). It could be said that this was prominent in all papers except that of Hwang, although the inclusion as an author of Cibelli, previously affiliated with Advanced Cell Technology, a leading enterprise in the field, could be interpreted as a move in this direction. Some examples are given in Table 27.3. It is worth noting the mention of SIBI because, although referring to a technical term, it can be interpreted as a suggestion of support from bioethics experts. The official statements of SIBI about this research call for caution.

After exploring the features of the rhetoric in the papers, we next turned our attention to how a sample of university students understood one of them.

5. HOW STUDENTS PERCEIVE ‘THERAPEUTIC CLONING’

The article by Soria was chosen as representing a middle level between the *Science* papers and the articles written by journalists. There were only small differences among the ideas identified by students with and without a biology background (see Table 27.5). The process of nuclear transfer was mentioned with the higher frequency. In two cases, the number of mentions from biology students was approximately double that those from non-biologists: problems with the mitotic spindle and cell lines capable of differentiation. Another study by us (Jiménez-Aleixandre and Federico-Agraso 2007) discusses differences in the length and degree of elaboration: the summaries from the students without a biology background were longer and reproduced in more verbatim sentences.

The reasons for and against research about nuclear transfer in humans offered by the students require more space than is available in this paper and are discussed in Jiménez-Aleixandre and Federico-Agraso (2007). The reasons offered in support of this research showed more similarities among students with and without a biology background than the reasons against it. The higher frequency was for medical applications. Although there was greater diversity in the reasons against,

Table 27.5 Ideas identified by students in B. Soria’s article

Ideas identified	*Primary (n = 43)*	*Primary (%)*	*Biology (n = 40)*	*Biology (%)*
Technical process				
Nuclear transfer	36	84	34	85
Enucleation	31	72	30	75
Development to blastocyst	17	39	16	40
Previous obstacles to nuclear transfer				
Problems for nuclear transfer in primates	23	53	24	60
Problems with mitotic spindle	6	14	11	27
Subcloning	20	46	14	35
Results				
Stem cell genetically identical to donor	1	49	18	45
Cell line capable of differentiation	8	19	17	42
Potential applications				
Reprogramming adult cells	28	65	29	72
Nuclear transfer therapy	10	23	9	22
Call for regulation in Spain	9	21	11	27

Primary, Primary Teachers’ Certificate; Biology, biology education.

most of them are grounded in ethical concerns. None of the students mentioned the long time required before clinical application (omitted by Soria) and they did not seem to perceive any bias in the paper's emphasis on therapy.

6. DISCUSSION: RHETORIC, ETHICS AND CRITICAL THINKING

The analysis of scientific and newspaper articles about human nuclear transfer uncovered a many similarities in their thematic content and some features that, in our opinion, have rhetorical significance:

6.1 Uncertainty

There was decreasing uncertainty from the *Science* papers to the journalistic reports by scientists to the reports by journalists, shown both by the content and the emphasis. The scientists writing in newspapers omitted the possible parthenogenetic origin of the embryonic stem cell lines; transplantation without rejection was presented by one of the journalists as inexorable. Current epistemological perspectives advocate the need to include tentativeness and uncertainty as dimensions inherent to scientific work, but it seems that the way that scientific new is reported in the media does little to promote this.

6.2 The therapeutic misconception

Magnus and Cho (2005) noted the effect of language in confusing what, at this stage, is basic research with therapies that may take decades to be implemented. Talking about 'human embryonic stem cell research', as they propose, is not the same as 'therapeutic cloning'. In a press conference, Hwang claimed that they had produced a 'construction' not an 'embryo'. All of the papers analysed emphasised therapy. In his proposal for argumentation analysis, Walton (1996: 26) distinguished explicit from implicit commitments (sides) of participants as: 'a *light side*, a set of propositions known, or in view, to all the participants, and a *dark side*, a set of propositions not known to, or visible to, some or all of the participants. This dark side represents the implicit commitments' (author's emphasis).

Even when in agreement about the interest in nuclear transfer research and about its potential clinical applications, it seems necessary to acknowledge the full range of issues involved in order to promote a rational debate, rather than keeping some issues 'in the dark'. Participation in social decisions requires an informed opinion. In order to develop critical thinking in the students, the presentation of controversial issues should be as balanced as possible.

6.3 Ethical concerns

With regard to the risks of reproductive cloning, there was a transition from technical terms in Hwang, which omits mentions of 'human' reproductive cloning, to others that were emotionally charged in the newspapers as 'human babies'. All but Hwang mentioned concerns about the use of human embryos or eggs. However, the issue of the female donors was mentioned only in the *Science* papers, and implicitly in one of the journalists' articles, whilst the risks of hormone stimulation or the problematic nature of altruistic donation were absent. The weak position of many women in scientific research hierarchies should also be noted, as this creates a situation where coercion can be possible. In summary, we explored how a sample of university students interpreted nuclear transfer research as reported in one journalistic report. The students were able to summarise the content of the paper, identifying its main ideas, and there were only small differences between those with and without a biology background.

The current development of this work is the exploration of the use of evidence about this issue in high schools. There is great interest in the introduction of real controversial dilemmas in the biology classroom, but this poses new challenges, one being the identification of appropriate sources of information and another the preparation of students so that they can perceive rhetoric in the texts and the author's intrusions, promoting the development of critical reading. The identification of the social and ethical dimensions in issues as cloning is not facilitated by rhetoric in the texts, minimising or omitting some of these issues. We suggest the usefulness of designing activities requiring the analysis of scientific and media texts, and the examination of how they construct entities such as 'nuclear transfer therapy' and how the authors negotiate the value of their claims (Myers 1990) in the scientific community. This could help students to understand some of the social practices involved in the construction of scientific knowledge.

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28 Teachers' perceptions of scientific research and teachers' roles in teaching about controversial socio-scientific issues

Laurence Simonneaux and Jean Simonneaux

ECOLE NATIONALE DE FORMATION AGRONOMIQUE, TOULOUSE, FRANCE

Laurence.simonneaux@educagri.fr

In this study, teachers were asked about their opinions of scientists. Most of the teachers consulted (teaching science, technology and economics in the agricultural field in France) had positive opinions of scientists. They considered that scientific research is beneficial to society. All of the teachers considered that scientific research produces provisional truth. Seventy per cent believed that scientific research produces risks and 85 per cent that it produces uncertainties; 66 per cent considered that research depends on the moral values of the scientists. They believed that personal motivations affect the outcome of research, such as satisfying financial backers (81 per cent). They argued that controversial socio-scientific issues (SSIs) must be taught. Before training, teachers adopted a 'neutral impartiality' position (Kelly 1986). Following training, they envisaged a wider range of possible positions. Most of them then accepted the idea of 'committed impartiality'. They then brought into question the existence of absolute, objective and neutral knowledge after thinking about the stakes and controversies related to some SSIs and the interdiscursive analysis of contradictory discourses, but also because they realised that their colleagues had different points of view.

1. BACKGROUND, AIMS AND FRAMEWORK

One of the goals of science education is to help students develop their understanding of how society and science are mutually dependent. In science education, the notion of 'socio-scientific issues' (SSIs) has been introduced as a way of describing social dilemmas impinging on scientific fields. These are issues on which people have different opinions and which have implications in one or more of the following fields: biology, sociology, ethics, politics, economics and/or the environment. Socio-biological issues, in particular, are controversial as they involve a lot of uncertainty.

The educational challenge is to enable students to develop informed opinions on these issues, to be capable of making choices with respect to preventive measures and the intelligent use of new technologies, and, in particular, to be able to debate such issues.

Since the 1960s, research on science education has shown that the effect the teacher has on students' results is even greater than that of the curricula, textbooks or teaching strategies used (Welch 1969). This study is an attempt to describe the position held by teachers of science, technology and economics in the agricultural field when teaching these issues.

A survey of a sample of 183 teachers from different disciplines about their teaching intentions revealed that, a priori, teachers were not against dealing with social problems related to the development of technosciences, but this did not mean that they were prepared to change their epistemology and their practice (Albe and Simonneaux 2002). This article is an attempt to describe the positions adopted by a sample of 55 teachers of science, technology and economics in the agricultural field when teaching these issues.

1.1 The nature of science and the interdependence of society and science

The consensus on the nature of science is as follows: some scientific knowledge is relatively stable whilst other knowledge is more provisional and is likely to change according to new results or because previous results have been reinterpreted. Science is based on evidence and scientists use their creativity to obtain and interpret this evidence. Two kinds of science therefore exist: one kind is characterised by a stable consensus within the scientific community, and the other kind, the frontier science, is the one whose results are discussed in the scientific community.

Initially defined as a discourse on science, contemporary epistemology has widened its scope. Contemporary epistemology is seen as a crossroads discipline, grouping together research in linguistics, sociology and history. It is henceforth concerned with the scientific process rather than just the products of scientific research. Science is thus a social practice marked by conflict, tension and projects in social, economic and political contexts. The sociology of science thus feeds into epistemology. Epistemology then analyses the conditions under which scientific discourse is produced. This discourse is always under construction; consequently, epistemology is always historical. We have taken a moderate 'relativistic' position; in other words, we believe that there is no a priori structure for these technosciences and that they are a social product. We do not subscribe to a radical relativism that postulates that science is only one symbolic product among others. Science (the technosciences) thus includes social, ethical, economic and political constraints that make up the society in which the science is produced and which in turn acts on that society. As has been shown by Desautels and Larochelle (2003: 10), scientists:

> . . . thus get involved in reality performation, to use the term invented by Callon (1999). In so doing, they may or may not decide to communicate with human beings and other 'actants' (living or otherwise), locally and globally. Thus, a common world, with or without electromagnetic waves, with or without nuclear radiation, with or without the unconsciousness, with or without an intellectual quotient, with or without social classes, with or without antibiotics, with or without genes, with or without clones, with or without smart cards, etc. is not the same common world.

What is at stake in debates on technosciences is 'a whole approach based on a loop dynamic between research and the evolution of society' (Jollivet and Mounolou 2005: 46). Technosciences bring into question value systems and practices and even the symbolic foundations of society. They should thus be grasped in their 'controversial' social and scientific dimensions.

Knowledge of the nature of science affects the analysis of SSIs. In order to be able to deal with this type of issue, students have to know how to recognise and interpret data, to understand how different social factors can have different effects and to understand that stakeholders often have diverging opinions (Sadler *et al.* 2004). We wanted to determine: How did our sample teachers perceive the nature of science? What were the teachers' views on the interactions between science and society? Which factors affect scientific research? Does scientific research have an impact on society? If so, what kind of impact?

1.2 Teachers' roles in teaching about controversial issues

Oulton *et al.* (2004) argued that controversial issues can occur for a number of reasons:

- Groups within society hold differing views about them.
- Groups base their views on different sets of information or they interpret the same information in different ways.
- The interpretations may occur because of the different ways that individuals or groups understand or 'see' the world (i.e. their world view).
- Differing world views can occur because the individuals adhere to different value systems.
- Controversial issues cannot always be resolved by recourse to reason, logic or experimental.
- Controversial issues may be resolved as more information becomes available.

One difficult problem is that of the neutrality of teachers leading the debates. Kelly (1986), one of the first researchers who considered using debates for classroom study of controversial issues, postulated four positions that teachers might adopt: exclusive neutrality, exclusive partiality, neutral impartiality and committed impartiality.

Those in favour of exclusive neutrality believe that teachers should not broach controversial themes and that scientific discoveries are value-free truths. They subscribe to a positivistic approach that has been widely criticised. There are two main arguments against their position: first, teachers always convey values, if only through the examples they choose; secondly, the task assigned to schools in a democratic society is to train citizens who are capable of debating controversial scientific issues, which means that the school must stay in touch with real life.

Exclusive partiality is characterised by the deliberate intention to bring students to adopt a specific point of view on a controversial issue. In this case, teachers ignore contradictory positions or brush them aside as insignificant. They believe that their mission is to provide students with intellectual certainties.

Those in favour of neutral impartiality believe that students should debate controversial issues as part of their education to become citizens and that teachers should remain neutral and not reveal their points of view. For some supporters of this position, teachers should remain silent and neutral so as to maintain their authority and should not reveal their uncertainty or ignorance, whilst others believe that they should remain neutral in order not to influence students' argumentation. This position, which is nevertheless quite appealing, has been criticised. It is important that students have the opportunity of comparing their points of view with those of a 'role-model' adult such as the teacher. Moreover, as we have said previously, teachers always convey their values, albeit unconsciously, and neutrality is an illusion.

Concerning the final position, an apparently paradoxical position of committed impartiality, teachers give their points of view while encouraging analysis of competing points of view on the controversial issues. This is the position recommended by Kelly. However many authors continue to recommend that teachers remain neutral (Henderson and Lally 1988, Reiss 1993). Nevertheless, Oulton *et al.* (2004) defend the idea that teachers should explain their points of view while teaching so that students become aware of the danger of teachers developing possibly biased arguments. We wanted to determine how the teachers in our sample population perceived their role in the teaching of controversial SSIs.

2. METHODS

Teachers should be trained to include controversial SSIs in the classroom and to transform information conveyed by mass media into teaching opportunities (Sadler *et al.* 2004). To do this, they should be trained in socio-epistemology; in other words, about the interaction between the construction of science and society, on the implications of scientific developments, in the analysis of the students' representation-knowledge system, in the construction of suitable teaching strategies and in the particular role that they play in these strategies.

Teachers tend to describe science in an uncontroversial way. During their training, they should be encouraged to abandon the idea of science as objective and neutral in order to promote the understanding that scientific research yields facts that are provisional and that are influenced by the scientists' values.

The method used was a survey of a sample of 55 teachers at agricultural training schools in France. They responded to a closed questionnaire on the nature of science and the relationships between science, technology and societies, and to an open-ended questionnaire on the role of the teacher in the teaching of controversial SSIs. Thirty-four teachers from this sample took part in training on the teaching of these issues. Following the training, we handed out the questionnaires (which they had previously completed) again so that they might validate, invalidate, qualify or give more details concerning their previous answers. This procedure meant that they had to think again before answering.

In addition, two focus groups dealing with the teaching of these issues brought together 21 teachers. All of the data were used as a basis for this article.

The training took place over periods of 3–5 days. The following points were dealt with:

- Definition of SSIs.
- Participation in role-playing to make teachers aware of such situations in the classroom and show them that they were not as difficult to implement as they might think.
- Analysis of debates in the classroom on controversial SSIs.
- Analysis of stakes and controversies about some SSIs.
- Interdiscursive analysis of contradictory discourses on SSIs.
- Analysis of different actors' conceptions and knowledge about controversial SSIs.
- Presentation of the teachers' role according to Kelly (1986).
- Presentation of a method for building debates in the classroom.
- Conception of debating situations on the SSI of their choice in subgroups.

When devising the debate situations, the teachers in their subgroups were invited:

- To clarify the learning goals, for instance: encourage students to adopt a new technology; enable students to understand how research works; stimulate their ability to think critically about ethics, socio-economics and the environment; improve their debating skills; teach them how to define and develop argumentation on issues; identify different attitudes, representations and decision-making criteria; further the acquisition and mobilisation of knowledge in a social context.
- To specify, for the debating topic chosen, the issue(s), controversy or controversies, practical applications and the corresponding spheres of knowledge. It is important that debates be informed and based on significant input, in order to avoid discussions that 'go nowhere'. The scientific content should be dealt with before the debate or during the debate. This may be done at the students' request. Students may either do their own research or teachers may provide the information. The information may be identical for all participants or slightly different according to the roles played by students. Concerning other kinds of knowledge, these are more or less relevant depending on the topics chosen. They might involve sociology, ethics, economics, legal aspects or politics. Obviously, the type of information considered will affect the quality of the students' arguments.

- To choose the context for the debate. The advantage of placing students in specific contexts when studying SSIs is that it encourages them to clarify and take a stand, which would otherwise be more difficult when they have to face an non-contextual abstract problem. The context could be, for instance: a company, a village, a family, a school, the rural/urban environment, or the Western world/southern countries. The situations may be more or less personalised; they may take into account social groups (farmers, consumers, etc.), specific people who are identified and described in terms of their socio-professional category, interests, motivation, questions or even values. This would involve specifying the social characteristics of participants (socio-professional category, age, profession, etc.). It is also necessary to define to what extent the debate will be personalised in order to involve students (will they be speaking for themselves or will they be playing an imposed role to enable them to identify better with different points of view?).
- To determine the type of debate (role playing, conventional debate, consensus conference) and the procedure involved (before/during/after). The sequences may include a varying number of stages; these might be individual or collective stages. Depending on the debating situations proposed, the students will be encouraged to identify the principles (values) underlying their argumentation or not to do so. They will be either be required or not to identify the limits of their reasoning (for instance by asking the question: under what condition(s) would you change your mind?) or to identify the validity of their arguments. Individual phases may alternate with collective ones. Social interaction and individual reflection are encouraged. An emphasis may be put on the post-debate period. This will involve pointing out a posteriori reasoning steps to enable students to reflect more on the issue, in other words to encourage a metacognitive and also a 'meta-affective' approach, as this type of situation can make people feel uncomfortable. This kind of role-playing causes difficulties for students; in addition to the argumentation they have to develop to convince or persuade the others, the students are put in a potentially situation of conflict between themselves and others and in terms of inner conflict (they may not necessarily agree with the arguments of other students and they might thus have to change their own point of view). To sum up, it involves specifying the different methods: content, organisation of the multidisciplinary approach, research into the literature, definition and distribution of roles (students, teacher, etc.), possible voting, reasoning, taking a stand and debriefing.
- To prepare material for the sequence: documentation (shared or not), instructions, material for helping students to learn (block diagram etc.).

3. FINDINGS

Teachers' opinions of the scientists were found to be positive (70 per cent) or very positive (over 20 per cent). They considered that scientific research is beneficial (70 per cent) or very beneficial (over 20 per cent) to society. All of the teachers considered that scientific research produces provisional truth, but at the same time 20 per cent thought that it results in the production of universal truths. Seventy per cent believed that scientific research produces risks and 85 per cent that it produces uncertainties.

They did not believe that scientific research is going to reduce social inequality, nor that it is going to solve the problem of famine in the world (Figure 28.1).

For the various questions, most of the teachers thought that scientific research led to potentially negative effects while still recognising that on the whole they were beneficial (Figure 28.2). Sixty-six per cent considered that research depends on the moral values of the scientists.

Teachers believed that personal motivations affect the outcome of research: satisfying financial backers (81 per cent), wanting to be the first to produce knowledge in their research field (76 per cent), getting personal satisfaction out of their work (67 per cent), career ambitions (65 per cent) and, last

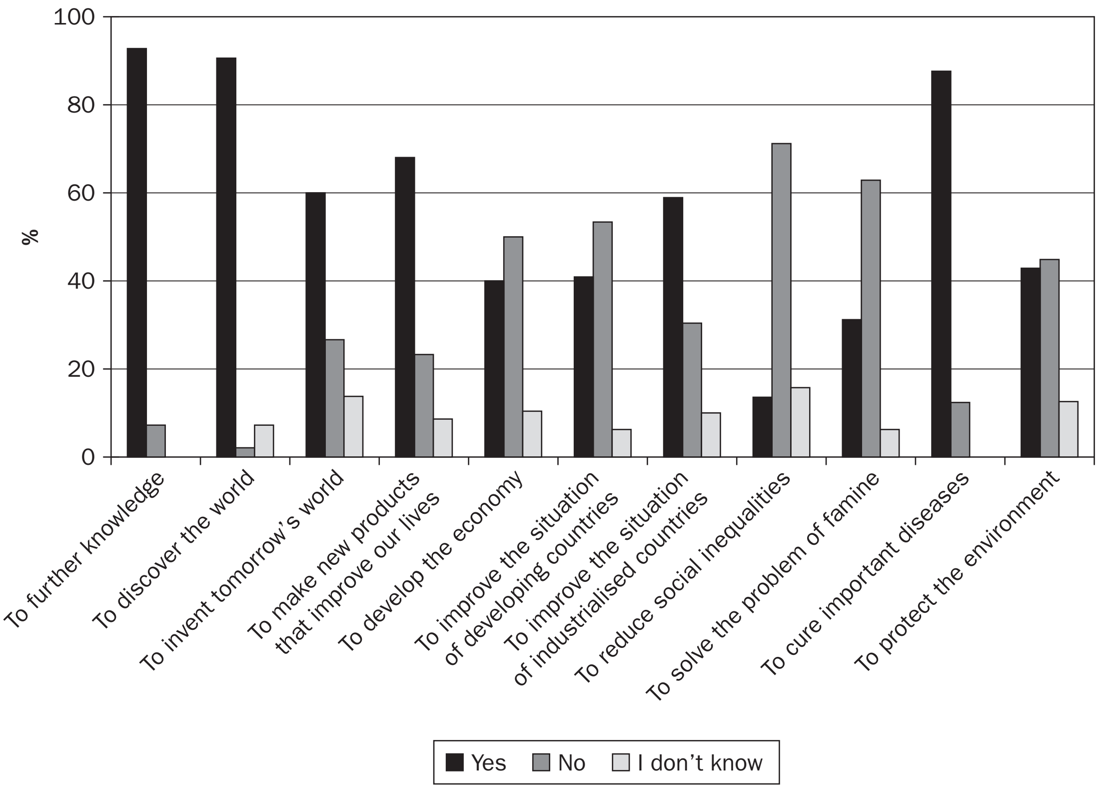

Figure 28.1 Teachers' opinions about the aims of scientific research

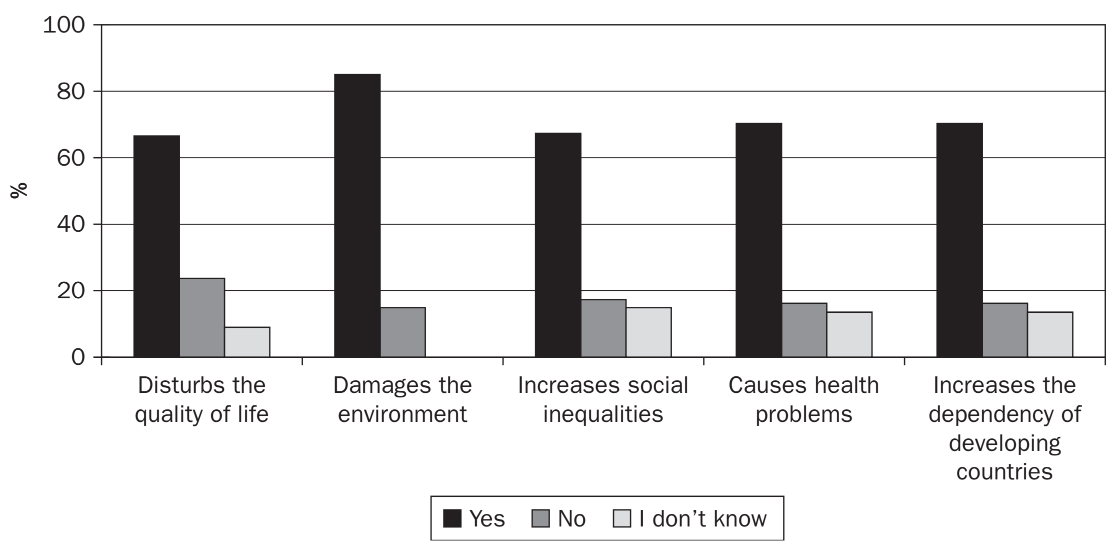

Figure 28.2 Teachers' opinions about the impact of scientific research

of all, satisfying employers (49 per cent) (Figure 28.3). Eight-six per cent of the teachers believed that research is influenced by private financing, 80 per cent believed that it is influenced by public financing and 75 per cent that it depends on policy orientations.

Fifty-two out of 55 teachers believed that controversial SSIs should be dealt with. This confirms the results obtained in 2002 (Albe and Simonneaux 2002). Why was this the case? The responses of the teachers could be classified into three groups according to the number of times they were observed in discourse. The priority opinion for the first group was that SSIs should be dealt with so that students could form their own opinions. The second general opinion was that it was necessary to give students true scientific data, rectifying their mistakes, in order to develop students' critical faculties, to train them to be future citizens, to develop their debating skills and to encourage their open-mindedness. Finally, the following opinions fell into the third group. It is teachers' duty to inform students:

- for their general culture;
- so that they may evaluate what is at stake;
- so that they can identify contradictory points of view and go beyond 'common sense' (which depends on their social background);
- because these issues will affect the future of humanity;
- because the environment is complex and has to be learnt through an interdisciplinary course so that students may be given the means to deal with issues; and
- because 'it is part of the curriculum'.

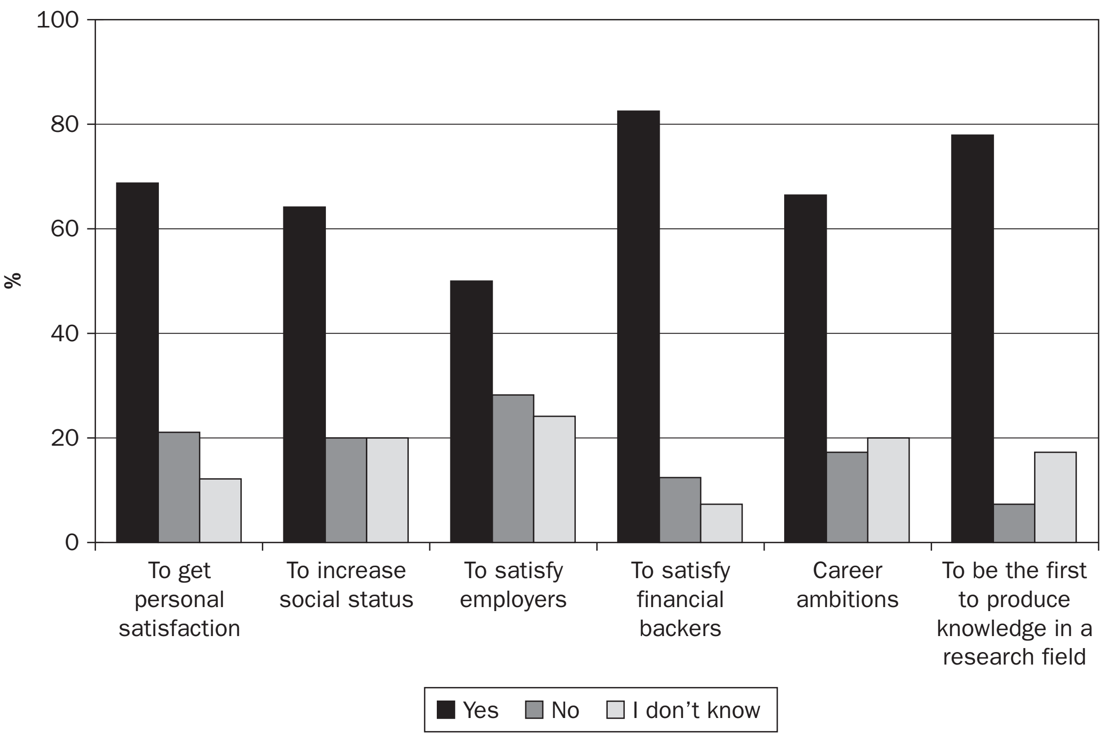

Figure 28.3 Teachers' opinions about researchers' personal motivations

The three teachers who thought that the SSIs should not be dealt with justified their positions by saying, respectively: 'It's up to them to see', 'It's not our role' and 'We don't have time.'

3.1 How should SSIs be dealt with?

The teachers surveyed here thought that the first thing to do was to organise debates. It should also be possible to use recorded articles, broadcasts, visits and talks by visiting lecturers, or to get students to look for information or to give talks themselves. Half of the teachers thought that teaching should be multidisciplinary. In any event, there was a consensus that it was necessary to 'start with true scientific data, while correcting obvious errors'. Some of them thought that a final summing-up should be done; others thought that it was especially important not to conclude the debate by favouring any one position.

3.2 What role should the teacher play?

In response to this open question, teachers said that they thought any teacher should be neutral and objective. The teacher should lead the debate: in other words, be the facilitator, the chairman, the mediator, encourage students to speak out and also listen to others, redefine the debate if necessary, keep order and de-dramatise the debate.

They also said the teachers should provide scientific input, express contradictory view points and encourage a scientific approach and critical thinking, and they reaffirmed that teachers should help students to make up their own minds.

Some of them thought that teachers should teach students how to analyse in order to argue logically, enlarge their scope of investigation, define problems, define the context (identify the context, the stakeholders, the history and the stakes involved), point out the complexity and train students to undertake their own research using the available literature.

A minority of teachers thought that it was necessary to encourage students to be curious about things, 'to get them to ask questions about the impact of human activity', to 'act as objective conscience gadflies', to 'start with the students' conception of issues and then return to them' and that 'the goal is not that they should be absolutely certain about a given issue'.

Before the training sessions, we asked them questions to identify which of the attitudes of Kelly (1986) they might adopt.

3.3 Should the teacher present contradictory information without giving his opinion?

Most thought that they should. 'The teacher should not take sides' and 'he should not format ideas', but 'contradictory information should be validated in a scientific way'. They thus believed that it is necessary to maintain neutral impartiality. Two out of the 55 thought that this was not necessary: 'It is better to separate scientifically proven facts from uncertainty.'

3.4 Should the teacher choose information that enables students to clarify their uncertainty?

Fifty-two out of 55 thought that teachers should not, because 'if the teacher makes a choice, he imposes this on the students, which means that they are not free to make up their mind. Moreover, this would not lead them to think for themselves or to take risks or to make choices, etc.', 'they should rather get students to abandon their certainties', 'it is important to shed light on points which they believe they know but on which they have often been mistaken' and 'to get them to avoid stereotyped thinking, as conveyed by the media for instance'. Most of the teachers did not believe in exclusive partiality.

3.5 Should the teacher give his or her point of view while introducing contradictory information?

This would be the committed impartiality posture. After these teachers had said that the teacher should remain neutral, we were astonished that in response to this question, 21 answered yes. For those who did not agree, they believe that this influences students' opinion and creates tensions. Furthermore, 'the teacher has not necessarily adopted a clear position' and 'the teacher should insist on the fact that it is only a personal position and not an institutional position'. It depended on the subject (for instance, 'on racism, it's absolutely necessary'). Two teachers specified that teachers could give their opinions but only at the end of the session and only if the students asked for it.

3.6 Should the teacher systematically introduce arguments to counter those of the students?

This posture may be called that of the 'gadfly'. The majority of the teachers were in favour of the teacher systematically introducing opposing arguments 'if the opposing arguments are not being expressed by anybody, to widen the debate', and suggested that 'it is an important part of any debate' and 'it makes it possible to upset their complacency, to get them to ask themselves whether their opinions are well-founded, to get them to change their minds or to reaffirm their opinions'. However, students' credibility should not be brought into question and their interventions should be encouraged, and no systematic option should be chosen.

Five teachers were against the introduction of counterarguments as 'students have knowledge of the subjects and some are even politically active. They are no doubt right about certain things so why should teachers reject their opinion if they are valid? Furthermore, if we were to reject their ideas outright, the debate and the discussion would lose their pertinence and we would be setting students against us!' and 'This is not a good idea because this would lead to conflict in the classroom.'

Before training, teachers mainly adopted a 'neutral impartiality' position. Following training, the teachers considered other positions, depending in particular on the controversial issues studied; certain were destabilised and no longer knew what the right position should be. Also, most of them accepted the idea of 'committed impartiality': 'Even if we are not sure of having the right position, we have to commit ourselves; we are not here to tell republican truth'. It should be remembered that before the training session, most insisted that the scientific knowledge introduced should have been proven. After the training, they brought into question the existence of absolute, objective and neutral knowledge after thinking about the stakes and controversies related to SSIs and the interdiscursive analysis of contradictory discourses, but also because they realised that their colleagues had different points of view. They became aware of the impossibility of reducing SSIs to mere scientific facts. They realised that SSIs should be taught in the perspective of complexity: 'Students have to build up the question, no problem is binary; it is complex, and students have to become aware of this complexity.' They saw their role as part of the socio-critical current, but not as defined by Robottom and Hart (1993) concerning environmental education (these authors assigned this current of thought with the objective of developing commitment through individual and collective action). The teachers did not wish to train politically committed people, for instance future destroyers of genetically modified organisms, but they did believe that their job is to identify the quality of the sources used for debates, the limitations of facts and the social repercussions, which would enable students to participate in debates as critical citizens. The fact of choosing committed impartiality showed that they will eventually be prepared to get involved in a cooperative approach with students based on the socio-constructivist theory, which postulates the importance of interaction in peer learning but also between teachers and students.

We should, however, consider whether the evolution of these teachers' opinions is representative. These were teachers who had chosen to undergo the training and they were thus a more motivated sample than the average teacher. Their levels of seniority varied; some were undergoing initial training whilst others were in in-service training.

4. CONCLUSION AND IMPLICATIONS

The importance of teachers' positions on the way they affect students' performance has long been known. The perception that teachers have of the nature of science and the interrelationship between society and science affects their teaching of SSIs. The teachers in our sample, while believing that science is advantageous for society, also believed that it involves risks and uncertainty. They believed that scientific research has potentially negative effects while recognising that it is beneficial on the whole. For instance, they thought that scientific research will not reduce social inequality or famine, among other problems. This ambivalence was probably due to the classic distinction that is made between fundamental scientific researches, which may be neither good nor bad, and its applications, which may prove negative. However, nowadays, with respect to technosciences, the distinction between basic research and applied research is no longer relevant. For instance, European funding for research in the field of life sciences is not likely to be awarded if no private companies are contributing to the project.

The teachers all believed that research produces provisional truths. Moreover they did not believe that research is done in a social vacuum; on the contrary, they believe that it depends on the socio-professional and personal motivations of researchers, with the main motivation being that of pleasing the backers.

Before undergoing training, they were more in favour of neutral impartiality and after the training they were more in favour of committed impartiality.

Classroom debates on controversial SSIs have a different impact to that of debates on scientific notions in general. They both have an epistemological importance in that they enable students to understand the nature of science. However, classroom debates on SSIs, due to their very nature, are not restricted to a single discipline or approach. The knowledge concerned represents 'islets of rationality' as described by Fourez (1997), which are more or less interdisciplinary depending on the extent of the social context involved.

More research should be done on role-playing debates on SSIs in the classroom, on the acquisition or mobilisation of knowledge depending on the types of debate and on the epistemological positions developed by the participants (teachers and students), on more in-depth analysis of arguments during debates and on evaluating the impact of training on argumentation. Following training in the teaching of SSIs, groups of teachers from two or three disciplines, but coming from different schools, can develop interdisciplinary debating situations or analysis of authentic situations. When these are implemented in the classroom, they will inevitably demonstrate a wide range of possibilities. We shall be analysing the positions actually adopted by teachers (neutral impartiality or committed impartiality) and the effect of these actual practices on the way students learn and develop arguments. Might this ultimately characterise a specific, socio-scientific critical approach to the teaching of emerging SSIs in which individual and collective action is identified as the participation in public debate or the analysis of authentic situation?

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29 Examining the ambiguities of the human race concept in biology textbooks: tensions between knowledge and values expressed in school knowledge

Rachel Santos Levy, Sandra Escovedo Selles and Marcia Serra Ferreira

UNIVERSIDADE FEDERAL FLUMINENSE, UNIVERSIDADE FEDERAL DO RIO DE JANEIRO, BRAZIL

escovedoselles@gmail.com

This study examined how the concept of human race is expressed in biology school textbooks, aiming to understand the ways in which biology school knowledge highlights tensions involving curriculum decisions between knowledge and values. The research was supported by the theoretical perspective that considers school knowledge as a unique type of knowledge produced by school that differs from the scientific one. The research methodology was a documentary analysis of six Brazilian secondary biology textbooks. The analytical categories focused on historical and ideological aspects related to the concept of race. The results suggested that the scientific ambiguities involving the definition of race were reproduced in the textbooks. The textbooks tended to search for neutrality to deal with the matter to avoid facing controversies. In spite of the fact that most textbooks explicitly reject ideologies such as racism, the books studied here failed to present a non-typological presentation of human diversity. As a result, the classic typology of three races or six races was presented.

1. INTRODUCTION

School knowledge has been regarded as a unique type of knowledge that differs from scientific knowledge, as the former is shaped to fulfil school social aims and shows specific features related to those aims (Chervel 1988; Forquin 1991). According to Chevallard (1985), school education not only selects knowledge from a number of cultural sources historically available in society but also involves a process of reorganising and transforming such sources into the kind of knowledge that can be understood by pupils. Textbooks are one of the expressions of school knowledge and their special characteristics are directly related to pupils' age groups, social background, length of compulsory education and school location (Forquin 1991). Therefore, the contents of textbooks are selected according to a range of aims, which are different to the aims of the scientific context.

A good way of analysing the characteristics of school knowledge in order to understand how it expresses specific aims consists of examining curriculum topics that allow a discussion of knowledge and values. An example of this is the concept of human race in the biology curriculum. With a history of debate and controversy, the concept of human race was developed within biology circles; it was soon encompassed by social Darwinism and carries a burden of ideological values (Gould 1981; Dávila 2003). The concept was created at the intersection of several sciences newly established in the 19th century to support theories about the origin and diversity of human beings.

The scientific study of the human race effectively started with the end of British slavery in 1833. In the process of elaboration of the concept, the contribution of the natural sciences has been to classify human differences, and this has been used as an assumption to justify social hierarchies (Willinsky 1998). According to Gould (1981), racial prejudice may be as old as human history records, but its biological justification has imposed an additional burden of inferiority over the less favourable groups. To this author, in the 19th century, the manipulation of craniometric research data – generated to justify social hierarchies – and the greed for superiority among men added to prejudice based on biological determinism and increased social differences.

Stepan (2005: 17) points out the role of science – particularly the new field of genetics from the beginning of the 20th century – associated with the social movements to codify a new cultural meaning: 'Eugenics, perceived as science, has produced perceptions and techniques that have framed cultural interpretations and have led to social strategies.' Thus, as the 'science' of racial refinement, the concept of 'human race' has been placed within eugenics since its beginning. To Willinsky (1998), the establishment of races, one of the organising principles of racism, was driven by imperialism and assigned science a relevant role in the political sphere. Schwarcz (1999) added that, in the Brazilian context, evolutionist and social-Darwinist models were originally popularised as theoretical justifications of imperialist practices of domination. Dávila (2003) analysed how racial ideology influenced Brazilian public education policy in the first half of the last century.

Therefore, the concept of human race is an example of a school topic that needs to be understood, in domains other then just the knowledge domain, as it involves values and is ideologically embedded in multiple debates within society. Authors like Willinsky (1998) have stressed the importance of also understanding the extent to which curriculum materials express the relationships between science and the origin of the concept. This author discussed the history of the appearance of the term 'race' to point out several implications in the educational context of the last decades. To Willinsky (1998), the scientific constructions of the concept of race still have an impact in our schools, and this is why he argues that students need to be warned about the historical context of the creation of the term 'race', by discussing not only its origin but also its current implications: 'Students of science have the opportunity, if not the responsibility, to learn how this research on race continues a legacy that once prevailed and, however discredited, still survives' (Willinsky 1998: 175–176).

Taking into account the high relevance of the topic, this study examined how the human race concept is expressed in secondary school biology textbooks in Brazil and aimed to understand the ways in which school biology knowledge makes explicit the tensions involved in curricular decisions between knowledge and values considered socially relevant. We argue that the study of textbooks allows us to understand not only how ambiguities are reproduced but also how curriculum selections demonstrate the difficulties of addressing a biological topic that is placed in the space between knowledge and values.

2. TEXTBOOKS AS STUDY OBJECTS

In a previous work (Selles and Ferreira 2002), we tried to analyse biology textbooks in three dimensions. Firstly, textbooks produce a public and visible witness to the various clashes that occur in decisions related to selecting and organising school knowledge. In this sense, as a written curriculum, they materialise the results of the disputes that historically have involved the intentions and interests from several groups related to the sciences – biological sciences, physics and chemistry – and the various academics and educational authorities. In a second dimension, which takes into account the teaching perspective, school teachers acknowledged the textbooks that they use not only for the content to teach from but also for the teaching methods that strongly influence their practice. Last, in the third dimension, which is specifically related to teacher training, textbooks are often tacitly accepted as a replacement for a more robust professional training. These three dimensions widened our ability to analyse the textbooks, as they allowed us to understand them beyond mere teaching resources. There were similarities and patterns in these materials that have not been produced consensually, but are an invented tradition (Goodson 2005) that broaden the research horizons of textbooks as curriculum materials.

3. METHODOLOGICAL QUESTIONS

We analysed six secondary school biology textbooks published between 1997 and 2003 (Table 29.1). The selection of these textbooks took into account the fact that their authors have been publishing in the Brazilian market for a long time and that their books are widely used in schools in Brazil. Although some books were first editions, their authors have previously published similar books that have been widely recognised in the country.

In order to investigate tensions involving curricular decisions about the human race concept in the textbooks, we used analytical categories that focused on the following aspects: (1) ambiguity in addressing the theme, with emphasis on biological and cultural aspects; and (2) the ideological and historical characteristics of the approach. In the first category, we considered the following elements: how the human race concept was defined; whether the author presented the topic using typologies; and if and how the notion of ethnic groups was presented. In the second category, we considered the following elements: how the social and historical aspects relating to the construction of the human race were presented; the roles of science and the scientists in this construction; and how the authors addressed aspects of imperialism and biological determinism.

Table 29.1 The textbooks analysed

Book	*Title*	*Author(s)*	*Publisher*	*Edition*	*Date*
TB_1	*Biologia das Populações. Genética, Evolução e Ecologia. Volume 3*	Amabis and Martho	Moderna	1st	1997
TB_2	*Biologia 3*	César da Silva Júnior and Sezar Sasson	Saraiva	1st	1997
TB_3	*Biologia. Volume único*	Clarinda Mercadante and José Arnaldo Favaretto	Moderna	1st	2003
TB_4	*Biologia. Volume único*	José Luís Soares	Scipione	9th	1997
TB_5	*Biologia. Série Brasil. Ensino Médio. Volume único*	Sérgio Linhares and Fernando Gewandsznajder	Ática	1st	2003
TB_6	*Bio Volume único*	Sônia Lopes	Saraiva	11th	2000

Our analysis took into consideration how the concept of human race was defined, where it was positioned in the book and how it was related to the other curriculum topics presented in the books. We analysed the human race concept not only in the written texts, but also in the images, activities, exercises and supplementary readings suggested by the authors. It is important to stress that this study did not have the intention of producing quantitative analyses. We assumed that the Brazilian textbooks chosen for this study were representative and that a qualitative analysis would open up new questions and expand the possibilities of understanding the subject under study beyond the Brazilian context.

4. INVESTIGATING THE HUMAN RACE CONCEPT IN BRAZILIAN TEXTBOOKS

Of the six text books analysed – TB_1 to TB_6 – five deal explicitly with the concept of 'human race', the only exception being textbook TB_6. In the other textbooks, the human race concept is presented in the written texts and pictures (TB_4); in supplementary texts (TB_1, TB_2, TB_3 and TB_5) and in exercises (TB_3). In these books, the human race concept is generally mentioned in one or two chapters that address topics such as the origin of species, human evolution and genetics. Supplementary texts are generally used in order to discuss aspects related to this concept that go beyond the scope of biological knowledge.

In unit 7 of TB_4 ('Genetics: the study of heredity, part 3', dealing with the study of population genetics), the author introduces the expression 'gene pool' in order to study the genetic variation among human populations. However, he uses the word 'race' as a term similar to the term population: 'The gene pool expression. . .describes the general background of genes common to all individuals in a given population or race' (TB_4: 264).

Although the author does not clearly define the individual genetic characteristics, he associates human genetic variations with the concept of race:

> The genes for dark skin, curly and hard hair, wider nose, thicker lips and less developed hair are part of the *black race* gene pool, but they are not common in the *white race* and the *Mongolic race*. We can conclude that the genes for blonde hair, blue eyes and lighter lips do not belong to the gene pool of the *black race*. On the other hand, these genes are largely present in the common pool of many ethnic groups of the *white race* (the Nordics, for instance). The gene pool of *the yellow race or Mongolic race* is quite typical. Among them it is quite common to find the genes for 'straight eyes', shallow eye arcade, prominent jaws, black hair and completely straight hair, rounded face etc.
>
> (TB_4: 264, our emphasis)

The association of the notion of a gene pool with morphological traits reinforces among the students the idea that the concept of the human race is based on biological facts that justify presenting race typologies in biology classes. This seems to be the case where, on the same page in TB_4, soon after the above quotation, the author presents three photographs portraying a black woman, a fair-skinned woman and an Asian woman. Although the expression 'remarkable differences distinguish the human ethnic groups' is used in the subtitle of the pictures, one cannot avoid the association with the typology of the three races – black, white and yellow or Mongolic – stated in the previous text explanation. Based on this, we suggest that the expression 'human ethnic groups' is employed here as equivalent for 'human races'.

The author of TB_4 shows an even stronger tendency to equalise the concepts of human races and ethnicity, making this explicit by establishing a progressive line between them that 'evolves' with time: 'Although human ethnic groups may evolve, there will be transformations of the species *Homo sapiens* itself but there will be no diversification of this species into three or more new species' (TB_4: 287). Thus, when the author introduces the notion of this transformation, he uses an initial group – with three races – that has been transformed into another one with four types, shown in another photograph, to represent the current 'human ethnic groups', each with a different phenotype: a black woman, a black young man with a lighter skin colour than the woman, a brunette woman resembling a Native American Indian and a red-haired young man.

In the subtitle of the photographs, there is no more distinction between human racial categories, but the author seems to accept the impossibility of defining them when he states that 'mixture (or miscegenation) has prevented the disintegration of the human species into many' (TB_4: 287). According to this information, it is not possible to define which ethnic group, for instance, the red-haired boy belongs to. Also, it makes it difficult to determine the number of current human ethnic groups, because, according to the author, they have been modified. This seems to be an example that shows that replacing the term 'human races' by 'human ethnic groups' not only makes the treatment of the theme rather confused and imprecise, but also that the textbooks dedicate more space trying to explain the differences to the students than helping them to discuss the issues and its problematic ramifications in society. The option to offer a biological argumentation that becomes complicated and confused is another indication of the ambiguity and an attempt to avoid treating the theme from other disciplinary points of view. It can be seen as an indication of the tensions involving curricular decisions between knowledge and values and a missed opportunity to foster productive debate.

The presence of typologies was also found in the supplementary reading suggested by the authors of TB_1 in the section 'Human races' in Chapter 15. In this material, we found further evidence of the ambiguities of the human race concept. This is expressed when the authors define, and therefore accept, the biological concept of race, and at the same time question the criteria used to define the race concept, especially for human beings. This is evident in the following text from Chapter 15:

> Races are defined as populations of the same species that differ in their gene frequencies. What is the level of difference necessary to consider two populations as different races? The criteria are arbitrary. The most accepted is the 75% criterion by the great taxonomist and evolutionary specialist Ernst Mayr, according to which races or subspecies are populations in which at least less than 75% of the individuals are entirely different from the individuals of other populations. But, the same way that Mayr says 75%, we could say 90% or 80% . . .
>
> (TB_1: 285)

Although the authors state that the criteria for the definition of race are arbitrary, they do not offer any other explanation of the reasons for this arbitrariness. The recognition of arbitrariness does not make the authors abandon the concept of race; on the contrary, the concept is reinforced by the presentation of other criteria of classification – 90 per cent or 80 per cent – which allows the existence of a variable number of races. This can also be seen further on in the same text, when the authors define six races and mention Coon *et al.* (1950) who presented a 30-race typology. This further exemplifies the tensions and ambiguities involved in the way the theme is treated in Brazilian textbooks. Thus, the variation in criteria and the number of races can be seen as strategies that minimise possible ideological interpretations of these questions. Ambiguities may have been used to avoid a clear position concerning the question whether or not the human race concept exists from a biological perspective and in order to avoid a clear position concerning the consequences of a biological human race concept for society.

In four textbooks – TB_1, TB_2, TB_3 and TB_5 – there were references to the scientists' role in the definition of the human race concept. The authors of TB_1 and TB_2 only superficially named science to justify the human race concept, whereas the authors of TB_2 and TB_5 recognised that the construction of this concept has been articulated according to the political interests of the time. For instance, in the supplementary reading 'Human genetics and prejudice' in Chapter 2 of TB_2, the authors address the use of genetics, mentioning the scientists' role, the connections between their works and political interests, and the use of science to justify certain forms of social domination:

> Over time, there have been attempts to prove that certain human characteristics are genetically determined when they were not. The scientist Galton, Darwin's cousin, was the founder of Eugenics, the study of methods to improve the gene pool of the human species. In the name of Eugenics many mistakes have been made.
>
> (TB_2: 40)

Out of the six books analysed, TB_5 and TB_2 were the ones that most critically addressed the human race concept, associating it, albeit only marginally, with imperialism. In Chapter 45 of TB_5, for instance ('The history of living beings'), there is a supplementary reading section in the unit dedicated to evolution, provocatively called 'Races in human species?' within a section called 'Biology and society'. The text suggested for further reading questions the use of the term 'human race' on the basis of biological definitions, stating the impossibility of applying it to human beings. Thus, the authors accept the biological concept of race, although they reject its application to human species. However, they accept the existence of one human race. They question the existence of 'pure races', stressing the biological impossibility of such a classification and its relationship to racism, recognising that it has been a favoured interest of dominant groups:

> It's nonsense to say 'superior race' or 'inferior race' ignoring the great genetic diversity in each population. Any attempt to form a 'pure race'. . .could threaten the survival of humans. Racism . . . has no scientific basis. It has served only as an excuse to justify domination and the exploitation of one group by another.
>
> (TB_5: 467)

In the text above, it is important to stress that the authors emphatically criticise prejudice, but, at the same time, recognise the biological impossibility of sustaining the social and economical hierarchy among individuals. Although this is a true statement, it would be helpful for young people to understand the ways in which racists often use pseudo-scientific ideas to justify their practices. However, the authors do not address the concept of race as a social construction, omitting the responsibility of the sciences concerning the impacts and consequences of this construction.

Biological determinism is only addressed explicitly in TB_2, where the authors state: 'The first studies about the matter defended the idea that prostitution, criminality and alcoholism were genetically determined; the social factors (and therefore, environmental) that are determinant of such problems were not considered' (TB_2: 40). The authors reinforce their critical point of view when they comment on questions related to eugenics and, more specifically, to Nazism:

> Many advocates of Eugenics, including some geneticists, considered certain social classes and races as superior to others . . . In certain regions, the inter-racial marriages were legally forbidden, under the excuse that it was done to protect the 'purity' of the white race. This kind of thought had its climax in Europe, with Nazism, which claimed Arian superiority.

> Millions of people who were not liked by the Nazis, either genetically or politically, were exterminated under Adolph Hitler's regime.
>
> (TB_2: 40)

5. AMBIGUITIES OF THE HUMAN RACE CONCEPT: TENSIONS INVOLVING CURRICULAR DECISIONS BETWEEN KNOWLEDGE AND VALUES

This research took into consideration not only what was written in the texts, the illustrations, the activities and the supplementary readings, but also what had been left out of the textbooks. It is important to stress that, although the theme of the human race was present in almost all of the books investigated, that issues of the social debate about racism were dealt with superficially in a variety of forms within these books. The approaches ranged from ones that supported scientific neutrality to others that took into account some of the cultural meanings codified by and within science, although critiques of the disastrous social implications of such elaborations remained superficial. The dialogue between the analytical categories and the theoretical approach allowed the conclusion that texts about the human race concept are characterised by unresolved ambiguities and tensions. The analytical categories used helped us to identify and understand not only the evidence for ambiguities concerning biological and cultural aspects, but also the historical and ideological aspects of the topic.

The analysis suggested that the scientific ambiguities historically involved in the elaboration of the human race concept are reproduced in textbooks. This aspect is supported by the study carried out by Willinsky (1998: 174) and even here the textbooks 'do not delve into just how "useful" the scientific study of race has been to constructing the moral order that underwrote Western expansion and exploitation during the nineteenth and twentieth centuries'. This omission might mean, as Willinsky (1998) argues, that pupils are led to deal with highly disputable ideas, in an exclusively extracurricular way. He adds: 'In this case, avoidance entails both a lost opportunity for intellectual engagement in the social implications of science and a failure to address the experiences of the young, who are living with race' (Willinsky 1998: 182). In most of the textbooks analysed, the use of supplementary reading to address aspects of the human race regarded as non-biological seemed to be an illustration of Willinsky's study. When authors bring another text/author into the textbook, they not only direct the contents towards an extracurricular context but also make them appear optional.

In spite of the fact that most textbooks explicitly reject ideologies such as racism, they fail to present a non-typological presentation for human diversity. As a result, the classic typologies of three races, six races or even 30 races are presented, even when the written text seems contrary to this view. Willinsky (1998: 170) pointed out that the production of racial typologies was still present in scientific research in the 1960s, and one of them in particular – Coon's (1950) typology – has been regarded as 'the last gasp of a passing science'. The 'scientific' attempts to increase the number of types express uncertainties not only about the definition of the human race concept, but also about the criteria that can be used to classify the diversity of human beings. Thus, we recognise that both the ambiguity in defining the concept and the persistence in the use of typologies in the biology textbooks are signs of tensions involving curricular decisions between teaching knowledge and human values.

Another example of ambiguities in the approach to the human race concept in textbooks is related to the use of the term 'ethnic human groups', which replaces the term 'human races'. In one of the textbooks (TB_4), the explanation was given alongside a photo of the 'classical three races'. The use of the expression 'ethnic human groups' can be understood as a euphemism that smoothes the approach and puts racial issues out of focus. The approach chosen by the author also seemed to express an inability to explain human diversity without using a typological approach. Although such euphemisms are widespread in many social spheres, including the media, this strategy compromises the understanding of both the biological aspects involved in the construction of the concept and the most critical and complex dimensions of the human race concept. It also seems to underestimate the cultural differences if we consider that neither the concept of culture nor the concept of race was clearly defined in the textbooks. Therefore, it could be said that the strategy of replacing terminologies is another way of expressing the tensions and deepening the ambiguities of how to teach this theme in a critical perspective.

Lastly, we found that the authors of most textbooks only superficially addressed issues that focused on the role of science in the construction of the concept of the human race. Only two textbooks assumed more critically the articulation between scientific knowledge and the economical and social differentiation based on inherited biological differences. Even so, the authors made use of supplementary reading matter and did not raise the matter in the written text. Moreover, they took a defensive position in favour of science. This aspect has been reported by Stepan (2005: 17), who stated that 'Science is seen as a productive strength that generates knowledge and practices that marks the world in which we live, and possesses a huge social authority in the modern world – an authority based on its claims on factuality, neutrality and universality.' Thus, if on the one hand the authors of textbooks reject the social hierarchy based on racial criteria, they seem to cling to scientific authority on the other hand by claiming the neutrality of science while they deny the explicit scientific connection with social and cultural interpretations that leads to racism.

It is understandable that textbooks express different levels of tension when they select information to be materialised into school knowledge. The study of human race is a type of school knowledge that is articulated not only by biology as a science, but also by other subjects such as history, anthropology, sociology and geography. When addressing knowledge rooted in disciplinary fields with social–critical methodologies traditions, biology textbooks seem to find it difficult to abandon their own methodological teaching traditions, which are historically less critical. This can be a way of understanding why the textbooks silence the debate.

6. FINAL CONSIDERATIONS

Our analysis revealed how biology textbooks bear the marks of the tension resulting from social and historical clashes related to the construction of the human race concept. It also highlighted how processes of selecting content for textbooks involve conflict between knowledge and values. Lastly, the analysis allowed us to understand the difficulties in teaching the human race concept within the constraints of a certain subject domain – in the case of this research, the school subject of biology – while, at the same time, it opens the possibility of examining the viability of including contents and methodologies from other disciplinary fields in order to foster a deeper discussion of the main issues.

We propose future historical studies in order to broaden the scope of the research and allow further understanding of the extent to which the selection of the contents related to the human race concept in textbooks has changed. It is important to understand not only how changes relate to scientific transformation but also whether they respond to society's demands over time. The possibility of integrating such analyses with the contents of different textbooks for other school subjects seems relevant. This may allow an investigation of the role played by different methodological teaching traditions in relation to those applied mostly in biology teaching. It seems to be a productive way of understanding some of the limitations of the biology textbooks reported in this research.

The results of this research support our view that, whilst textbooks silence important aspects of the social debate related to racial issues and of the role of science, scientific neutrality is a way of facing controversial issues. In an attempt to avoid conflicts and in order to adjust to methodological traditions that are not accustomed to treating contents critically, biological examples and typologies are selected, reinforcing neutrality when treating human race as school knowledge. These aspects support our assumption that school knowledge, as expressed in textbooks, is constrained by specific characteristics related to school culture and is also permeated by other sources of knowledge that circulate within society. Human race is a curriculum topic that allows us to explore such specificities.

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8

Practical work and field work in biology education

30 Testing levels of competencies in biological experimentation

Thi Thanh Hoi Phan[1], Marcus Hammann[2] and Horst Bayrhuber[3]

[1]FACULTY OF BIOLOGY, VINH UNIVERSITY, VINH, VIETNAM; [2]INSTITUTE FOR BIOLOGY DIDACTICS, UNIVERSITY OF MÜNSTER, GERMANY; [3]IPN-LEIBNIZ INSTITUTE FOR SCIENCE EDUCATION AT THE UNIVERSITY OF KIEL, GERMANY

phanthanhhoi@yahoo.com; hammann.m@uni-muenster.de; bayrhuber@ipn.uni-kiel.de

Currently, national efforts are being made to improve German biology education and assess student competencies. Among them, there has been a growing need for criterion-oriented tests, i.e. tests that assess whether or not a specific level of competency has been reached. Here, we present an approach to measuring students' levels of competencies in experimentation. In particular, the focus was on the competencies of forming hypotheses, planning experiments and analysing data. These competencies were selected because they are crucial to experimentation for problem-solving (Klahr 2000) and because they are central to the newly introduced biology standards. In this study, closed test items were developed with response categories that could be related directly to a specific level of competency. The item construction ensured that each test item could be answered in a way that was indicative of a particular level of competency. The tests were taken by 1006 students (aged 11–12 years). The test design systematically crossed different biological subject matters with the three competencies in experimentation. Also, an independent knowledge test was administered that measured the students' knowledge about the science content. This design allowed analysis of the interactions between the competencies and the influence of the students' knowledge on the competencies.

1. INTRODUCTION

Recently introduced in Germany, national science education standards focus on developing and assessing students' competencies. The introduction of science standards raises new questions for empirical research in biology didactics. In biology, experimentation as well as criteria-related observations and comparisons are specific forms of scientific inquiry. They are both characterized by formulating a question and setting up hypotheses, planning and executing an experiment, analysing data and interpreting the data with reference to the hypotheses.

This study examined the testability of levels of competencies in experimentation. In particular, this paper presents the findings of empirical studies with students (n = 1882, aged 11–12 years) who took a test that assessed basic experimental skills in three dimensions – forming hypotheses, planning experiments and analysing data – as well as the students' pre-knowledge about the related science content. The main focus of this paper was a theoretical test one: can levels of competencies in experimentation be tested by means of multiple choice questions with response categories (i.e. the correct answer and distractors) that were developed on the basis of prior empirical studies, which found evidence for qualitative differences between levels of competencies in experimentation?

2. BACKGROUND

Tests for determining students' levels of competencies are relatively new and the approach presented here differs significantly from previous ones. Carey *et al.* (1989) investigated levels of understanding about the nature of scientific knowledge and inquiry in young students by interviews. They identified three general levels of response. The levels were determined by making a distinction between ideas and activities, and by understanding the motivation for experimentation.

Tamir (1989) argued that individuals who engage in an active experimentation show three levels of competencies. He asked subjects to do experiments using prepared materials and asked them questions about the experiments. Afterwards, he assessed levels of competencies when students reported on the experiments and analysed the results.

One of the specific reference points of this study was the description of levels of competencies for scientific literacy (Bybee 1997), which was used and adapted for reporting on the results of the Programme for International Student Assessment (PISA) study, especially in the PISA 2000 survey. More specifically, the maximum test score of the international PISA science test was divided into five segments. These segments were equated with levels of competencies. Thus, a low overall test score in the PISA study equalled a low level of competency and a high overall test score in the PISA study corresponded to a high level of competency. PISA test questions were thus mapped to the levels of competencies by means of their item difficulty.

Interesting questions remain unanswered by the PISA approach to testing levels of competencies. One of them relates to the borderlines between levels of competencies. Normalisation of items – i.e. assessing the likelihood with which a student with a certain sum score can solve a particular test item – does not help to define the borders between one level of competency and the next one. This is the case because two test items that mark the boundaries between two levels of competencies can be expected to be very different in terms of the requirements necessary to solve them. Otherwise, these items cannot be used to differentiate between two qualitatively different levels of competencies. After all, from the perspective of test theory, tests that assess levels of competencies belong to the category of criterion-oriented tests, the criterion being whether or not a certain level of competency has been reached. However, if a continuous sum score is divided up into segments (i.e. the process that led to the PISA levels of competencies) and if test items are mapped to the levels by question difficulty, it is common to find a high number of items with minimally different item difficulties that mark the borders between two levels of competencies. A content analysis of these items does not help to illuminate differences between levels of competencies unless the items have been developed against some kind of theoretical background that clearly sets off one level of competency from another. This, however, is not the case for the test items used in the PISA study.

3. AIMS

This paper presents an alternative approach to measuring students' levels of competencies in experimentation. We explored whether it was possible to design a test with items that could be solved in different ways that could be predicted – from theory – to be at different levels of competencies. For example, for measuring students' competencies in planning experiments, we used research findings that revealed that students sometimes change all of the variables from one test to the next (level 0), that students can be more systematic in their handling of variables but confound a few variables (level 1) and that students at a higher level of competency systematically change the test variable and control all other variables (Tschirgi 1980; Carey *et al.* 1989). Thus, we developed items for this tests that cover the three dimensions described by Klahr (2000) (forming hypotheses, planning experiments and analysing data), formulated research-based levels of competencies (Hammann 2004) and used these levels for the development of question responses.

4. RESEARCH QUESTIONS

The main aim of this study was to develop closed-end test items with response categories that could be related directly to a specific level of competency. Using this test, we want to determine whether a paper-and-pencil test could be used to assess levels of competencies in experimentation (Research question 1).

The test design included three processes in experimentation (mentioned above), each of which forms a single dimension. This allowed investigation into how the three dimensions in experimentation interacted (Research question 2).

In addition, research has shown that an individual's pre-knowledge affects the processes of experimentation. Therefore, a knowledge test was also designed and each dimension in experimentation was crossed with a particular science subject matter to look at which correlations could be found between biological content knowledge and levels of competencies in experimentation (Research question 3).

5. HYPOTHESES

There is empirical evidence for the relationship between students' pre-knowledge and the processes of experimentation. Research shows that pre-knowledge affects the ways in which students deal with experimental evidence (Chi *et al.* 1981; Lord *et al.* 1979; Kuhn *et al.* 1988). Also, student conceptions about the method of experimentation were found to have an influence on the ways in which students plan experiments (Schauble *et al.* 1990). Moreover, the processes of formulating and evaluating hypotheses are guided by the acquisition of particular domains of knowledge and metaconceptual knowledge (Carey 1985). Dunbar and Klahr (1989) showed that the dimension 'search in the hypothesis space' is guided both by prior knowledge and by experimental results. 'Search in the experiment space' may be guided by the current hypothesis, and may be used to generate information to formulate hypotheses.

In this study, we test the following hypotheses. We expected the dimensions 'search in the hypothesis space' and 'data analysis' to be dependent on the students' pre-knowledge about the science subject matter of the experiment. In contrast, we expected the students' performance in the dimension 'search in the experiment space' to be dependent on the students' knowledge about the experimental method. Thus, we expected students with high content knowledge to be able to gain high levels in experimentation, especially in the dimensions of 'search in the hypothesis space' and 'data analysis'. Also, we expected students who gained high levels in 'search in the hypothesis space' to gain high levels in 'data analysis', and vice versa.

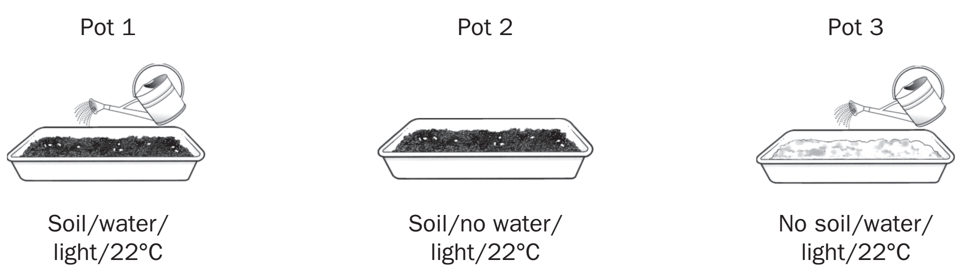
6. RESEARCH METHOD

This study focused on the development of two independent paper-and-pencil tests to assess the students' content knowledge and competencies in experimentation. The competency test possessed three dimensions: 'search in the hypothesis space', 'search in the experiment space' and 'data analysis'. For each of these dimensions, levels of competencies have been described that are based on empirical evidence and specify two levels of competencies (Hammann 2004). These levels of competencies take into consideration major empirical findings of student performance in tasks that involve forming hypotheses, planning experiments and analysing data. The answering format was a simple multiple choice with four options, which could be related directly to a specific level of competency. If students solved the test item correctly, they gained level 2; if they choose the incorrect option, they achieve level 0; and if they choose the partly correct option, the students obtain level 1.

Our test questions were designed to test the students' knowledge about the method of designing controlled experiments. In the dimension 'search in the hypothesis space', an experimental design was illustrated by text and pictures. The students had to identify the hypothesis that could be tested with this experiment. In the experiment, there were four or five variables, one or two of which was/were tested (depending on the difficulty of the question version). Four options were given, but only one of them was correct. In the other options, only one hypothesis, but not the other was correctly identified (intermediate level) or no hypothesis was stated (lowest level).

A sample question for the dimension 'search in the hypothesis space' is given in Figure 30.1. A student named Jan did an experiment about seed germination. He used two pots with soil (pot 1 and pot 2) and one pot with cotton wool instead of soil (pot 3). He sowed bean seeds in the three pots and put all three pots in the sunlight at a temperature of 22°C. He watered pot 1 and pot 3, but he did not water pot 2.

In the dimension 'data analysis', the findings of the same experiment were presented to the students. Four explanations were given, one of which is correct because it related to the hypothesis tested and correctly explained the cause-and-effect relationship between a tested variable and the findings. One of the four explanations did not relate to the hypothesis at all (lowest level). The other two explanations related to a specific hypothesis, but not to the hypothesis tested (intermediate level). It was also possible that the answer related only partly to the tested hypothesis or that the explanation was not based on findings but relied on the pre-knowledge. For full credit, the findings had to relate logically to the hypothesis.



Why does Jan do this experment?

A Because he wants to make the seeds germinate faster. → Level 0

B Because he thinks that light and warmth are necessary for seed germination. → Level 1

C Because he thinks that water, soil, light and warmth are necessary for seed germination. → Level 1

D Because he thinks that water and soil are necessary for seed germination. → Level 2

Levels of competencies

Level 0: Students try to achieve an effect. No cause-and-effect relationship can be explained.

Level 1: Unsystematic search for hypotheses.

Level 2: Systematic search for hypotheses.

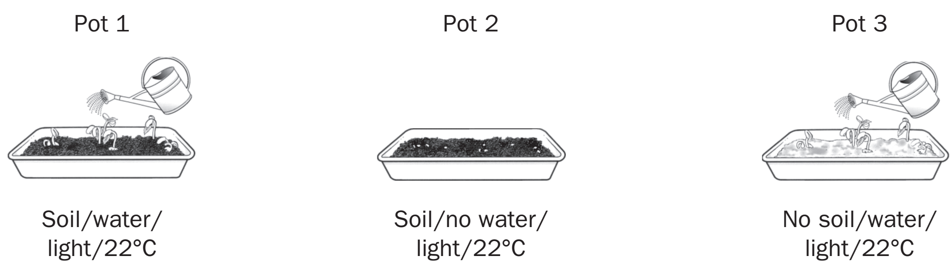
Figure 30.1 Sample test item for the dimension 'search in the hypothesis space'

In the questions for the dimension ‘search in the experiment space’ the hypothesis is clearly stated, but the experimental design is incomplete. The students are asked to complete the experimental design by choosing an experiment that can be compared to the one already described. Again, the students have to choose between four options, only one of which is fully correct because the test variable is changed and the others are kept constant. One of the four experiments is completely incorrect because in this experiment either all variables are changed or no variable is changed. This option was given because students were found to show a strategy called ‘change all’ (Tschirgi 1980). In the other two options, either the test variable and one other variable are changed or only one variable that needs to be controlled is changed constant, so that the students confused the two different types of variables.

A sample test item for the dimension ‘data analysis’ is given in Figure 30.2. After a few days, Jan got the following results: the seeds in pot 1 and pot 3 germinated, whereas those in pot 2 did not.

A sample question for the dimension ‘search in the experiment space’ is shown in Figure 30.3. Jan thinks the bean seeds will germinate faster if they are put at a warm temperature. He plans an experiment to test this idea. This is Jan’s experiment. He puts the bean seeds in a pot with soil (pot 1), waters them and keeps the pot at a temperature of 22°C in the sunlight. Jan needs another pot to compare with pot 1.

For the competency test, we designed two versions that we expected to be at different levels of difficulty. The test items presented above were examples of the more difficult ones: version 2. In version 1, the students were asked to compare only two pots of seedlings, rather than three. In this version, only one variable was tested. Each unit – for example ‘seed germination’ – involved six test items corresponding to three dimensions of experimentation. In version 2, each unit consisted of three test items corresponding to three dimensions of experimentation. In this version, the experimental design was more complex because two variables were tested. The aim of developing two versions was to test which version was more appropriate for students in grades 5 and 6.



Which one is the best explanation of the findings?

A The experiment did not work because the seeds in pot 2 did not germinate. → Level 0

B The experiment showed that seeds need light and warmth to germinate. → Level 1

C The experiment showed that seeds need soil and water to germinate. → Level 1

D The experiment showed that seeds need no soil, but water to germinate. → Level 2

Levels of competencies

Level 0: Data are not related to the hypothesis tested.

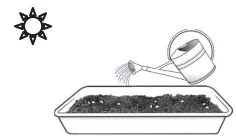
Level 1: Data are related to a hypothesis, but not to the hypthesis tested.

Level 2: Data are related to the hypothesis tested.

Figure 30.2 Sample test item for the dimension ‘data analysis’

Jan thinks bean seeds will germinate faster if they are put at a warm temperature. He plans an experiment to test the idea. He puts the seeds in a pot with soil (Pot 1), waters them, and keeps them at a temperature of 22°C in the sunlight. Jan needs another pot in order to compare with Pot 1.

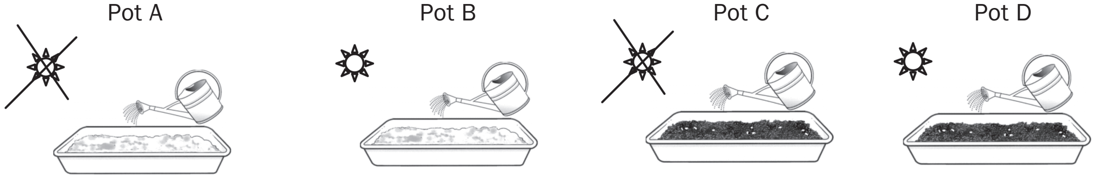
Pot 1



Soil/light/22°C

Which one of the following pots (A–D) should he choose?

Pot A | Pot B | Pot C | Pot D



No soil/no light/10°C | No soil/light/10°C | Soil/no light/10°C | Soil/light/10°C

Pot A → **Level 0:** The student changes all variables.
Pot B → **Level 1:** The student does not control all variables that need to be controlled.
Pot C → (Level 1)
Pot D → **Level 2:** The test variable is changed. The other variables are kept constant.

Figure 30.3 Sample test item for the dimension 'search in the experiment space'

A knowledge test was also developed in order to assess the students' knowledge of the biological content of the experiment, for example, knowledge about seed germination. In the knowledge test, complex multiple-choice (pre-test 1) or simple multiple-choice questions (pre-test 2 and main study) were used.

7. SAMPLE

7.1 Pre-test 1

In pre-test 1 (February 2005), nine units with different biological content divided into seven booklets were used. A total of 799 students (grades 5–6, mean age 12 years, 1 month) in 24 schools in Germany was tested. The design of the test was such that each student was asked to solve the questions in the competency test and in the knowledge test. Participants were randomly divided into two groups. One group did version 1 and the other version 2. The knowledge test consisted of complex multiple-choice questions.

7.2 Pre-test 2

In pre-test 2 (July 2006), version 1 of the competency test was used again. This time, however, only four units with different biological content were used. A total of 77 students (grade 6, mean age 12 years, 5 month) in a high school in Kiel, Germany, was tested. The design of the test was such that each student completed two tests, the competency test and the knowledge test. The knowledge test consisted of simple multiple-choice questions.

7.3 Main study

In the main study (November 2006), the tests in pre-test 2 were used. A total of 1006 students (grades 5 and 6, mean age 11 years, 8 months) in Germany was tested.

8. FINDINGS

8.1 Test item difficulty of the knowledge test

The mean test item difficulty at the unit level ranged from 56 to 78 per cent in pre-test 1, from 50 to 62 per cent in pre-test 2, and from 43 to 60 per cent in the main study. The mean test item difficulty at the booklet level ranged from 64 to 70 per cent in pre-test 1. It was 55.7 per cent in pre-test 2 and 51.7 per cent in the main study.

8.2 Test item difficulty of the competency test

In pre-test 1, the mean test item difficulty at the unit level ranged from 38 to 66 per cent in version 1 and from 40 to 54 per cent in version 2. The mean test item difficulty at the booklet level ranged from 39 to 57 per cent. The mean test item difficulty was 51.6 per cent for version 1 and 44.1 per cent for version 2.

In pre-test 2, the mean test item difficulty at the unit level ranged from 68 to 83 per cent. It was 74.9 per cent at the booklet level.

In the main study, the mean test item difficulty for units ranged from 54 to 70 per cent and the mean test item difficulty at the booklet level was 62.3 per cent.

8.3 Reliability of the knowledge test

The test items were analysed according to classical test item analysis, i.e. reliability analyses were performed in order to verify whether the test items had a corrected question–total correlation higher than 0.2. After question selection, Cronbach's α coefficient was examined. Depending on the unit, the Cronbach's α varied, but for most units it ranged from 0.4 to 0.7 in both pre-tests and in the main study.

However, the reliability coefficients at the booklet level (all units combined) were higher. In pre-test 1, the reliability coefficient ranged from 0.54 to 0.78 before test item selection. After test item selection, the reliability for the different booklets tested improved, with all booklets having an α coefficient greater than 0.7.

In pre-test 2, the reliability coefficient at the booklet level was 0.76 after test item selection. However, in the main study, with the same test as in pre-test 2, Cronbach's α value was only 0.63. The difference between the two reliability coefficients could be traced back to differences between the two samples, probably to knowledge differences.

8.4 Reliability of the competency test

In pre-test 1, the Cronbach's α coefficients at the unit level in version 1 ranged from 0.47 to 0.75 with most Cronbach's α values being higher than 0.6. In contrast, in version 2, most Cronbach's α values were lower than 0.5. Also, the reliability coefficients for the scales 'forming hypotheses', 'planning experiments' and 'analysing data' were higher in version 1 than in version 2. In version 1, the Cronbach's α values for 'forming hypotheses' ranged from 0.62 to 0.75, whilst the α values for the same scale in version 2 ranged from 0.36 to 0.58. Similarly, the Cronbach's α values for 'analysing data' and 'planning experiments' were much higher in version 1 than in version 2. Moreover, at the booklet level, the Cronbach's α value was also much higher in version 1 than in version 2. For all three booklets in version 1, the Cronbach's α value was higher than 0.8. In particular, booklet 111 had a Cronbach's α value of 0.89, which indicated a very high reliability. In contrast, in version 2, the Cronbach's α value at the booklet level ranged from 0.59 to 0.74.

In pre-test 2, the Cronbach's α value at the unit level ranged from 0.66 to 0.84. All questions had a corrected question–total correlation value higher than 0.2. On the other hand, the Cronbach's α value for the three scales ranged from 0.67 to 0.79. In particular, the Cronbach's α value at the booklet level was very high, with a value of 0.89. In addition, 23/24 questions had a corrected question–total correlation higher than 0.2.

In the main study, the reliability coefficients at the unit level ranged from 0.63 to 0.77. In addition, the Cronbach's α value for scales ranged from 0.69 to 0.78, and the Cronbach's α value at the booklet level was 0.88 with all questions having a corrected question–total correlation higher than 0.2.

8.5 Discussion

There are two possible reasons for the low reliability of version 2. On the one hand, version 2 had shorter scales than version 1. However, even after adapting the scale length of the test in versions 1 and 2 according to the Spearman–Brown formula, test version 1 still had a higher Cronbach's α coefficient than test version 2. On the other hand, question difficulty can be expected to affect the reliability of the test. The fact that test version 2 consisted of harder questions than test version 1 is likely to be the reason for the higher reliability of version 1, because the question difficulty was more appropriate for the level of the students sampled.

8.6 Findings for research question 1

We used the WINMIRA program for latent class analyses for the sample of the main study. Three test models were considered consisting of two, three and four latent classes. Although the two-latent-class solution had the lowest BIC and CAIC indices, the three-class model was chosen because it delivered a stronger differentiation of the question profiles than the two-class model. In order to ensure that the selected test model was appropriate, especially when it was not the best solution, we looked at the second criterion, which was the mean of maximum response probability of the students. After assigning the students to three classes of competencies in experimentation, the mean of maximum response probability of one class was at least 89 per cent, which was a satisfactory result. Thus, the three-class model was used to assign students to three classes of competencies in experimentation (Figure 30.4).

In the three-latent-class model, students in class 3 always outdid the students in the other two classes, and the students in class 2 always outdid the students in class 1 in all three dimensions of experimentation. This corresponded to high, medium and low levels of competency in experimentation. Qualitative differences between the three question profiles, however, were not found.

8.7 Findings for research question 2

Table 30.1 shows that the correlation coefficients between the three dimensions ranged from 0.607 to 0.785. Among them, the correlation coefficient for the relationship between 'forming hypotheses'

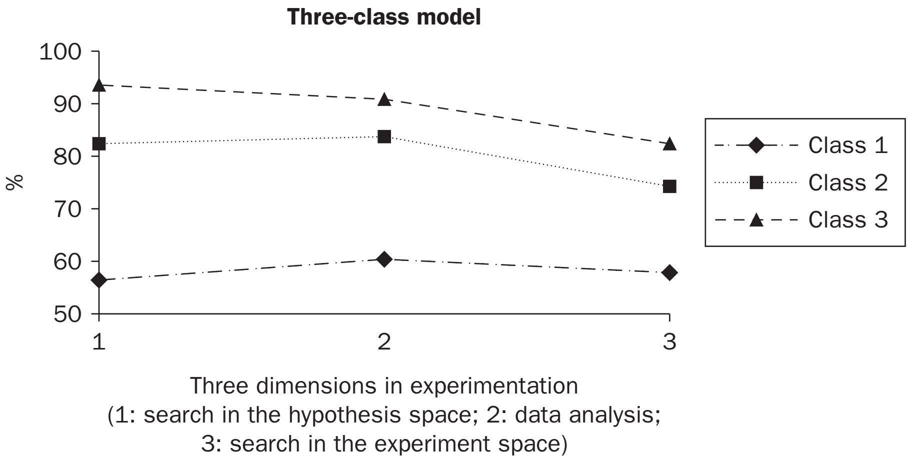


Figure 30.4 Relationship between the classes of students and the three dimensions in experimentation (the three-class model)

Table 30.1 Correlation coefficients (Spearman) between the three dimensions in experimentation (n = 1006)

	*'Forming hypotheses' * 'analysing data'*	*'Analysing data' * 'planning experiments'*	*'Forming hypotheses' * 'planning experiments'*
Correlation coefficient	0.785	0.615	0.607

and 'analysing data' was the highest. *Z*-tests revealed significant differences between this correlation coefficient and the other two correlation coefficients.

The findings indicated that there was a higher degree of similarity between the dimensions 'forming hypotheses' and 'analysing data' than between the dimensions 'forming hypotheses' and 'planning experiments'. Also, there was a higher degree of similarity between the dimensions 'analysing data' and 'forming hypotheses' than between the dimensions 'analysing data' and 'planning experiments'. This finding confirmed our expectation that the three dimensions of experimentation are driven by different kinds of pre-knowledge. In particular, the dimension 'planning experiments' was expected to be based on knowledge about the method of experimentation, which sets this dimension apart from the other two dimensions, which are driven by the students' pre-knowledge about the science content of the experiment. This explains that there is a significant difference between the correlation coefficient for the pair 'forming hypotheses' * 'analysing data' – i.e. the two dimensions motivated by the students' pre-knowledge about the science content – compared with the other two correlation coefficients for the pairs of variables that contain the dimension 'planning experiments', which requires methodological knowledge.

In addition, the findings revealed no significant difference between the correlation coefficients for the pairs 'analysing data' * 'planning experiments' and 'forming hypotheses' * 'planning experiments', which can be interpreted as an indication that the test used in this study was two-dimensional. The difference between the dimensions can be related to two different requirements to solve the test questions. Whereas the test items in the dimension 'planning experiments' required students to select an appropriate experiment to test a specific hypothesis, the questions in the other two dimensions required students to interpret a given experiment in terms of the conclusion that could be drawn or the hypothesis that could be tested.

The overall high level of the three correlation coefficients suggested that there were high- achieving students who possessed high content knowledge as well as high methodological knowledge and who did well in all three dimensions. The opposite was true for low-achieving students. This was also evident from the results of the multivariate analyses that revealed questions profiles without characteristic crossings, so that there were only quantitative differences, but no qualitative differences between the classes of students in this sample.

8.7.1 Relationship between the dimensions (cross tables)

If we used the three-latent-class model and assigned students into three classes in each dimension of experimentation, class 3 was the best. We analysed cross tables for students who reached class 3 in one dimension and also in the other dimensions. Thus, 75.1 per cent of the students who were in class 3 in 'search in the hypothesis space' were also in class 3 in 'data analysis', but only 59.9 per cent of the students who were in class 3 in 'search in the hypothesis space' were also in class 3 in 'search in the experiment space'.

Similarly, 80.5 per cent of the students who were in class 3 in 'data analysis' were also in class 3 in 'search in the hypothesis space', but only 62.1 per cent of the students who were in class 3 in 'data analysis' were also in class 3 in 'search in the experiment space'.

However, 72.2 per cent of the students who were in class 3 in 'search in the experiment space' were also in class 3 in 'data analysis' and 74.4 per cent who were in class 3 in 'search in the experiment space' were also in class 3 in 'search in the hypothesis space'.

Cross tables can be used in order to identify the degree of similarity among the three dimensions in experimentation. The results of the cross tables supported our hypotheses. The findings supported our assumption that the dimensions 'search in the hypothesis space' and 'data analysis' were more closely related than the pairs 'search in the hypothesis space' and 'search in the experiment space' on the one hand and 'data analysis' and 'search in the experiment space' on the other. These findings also support the assumption that 'search in the experiment space' requires methodological knowledge

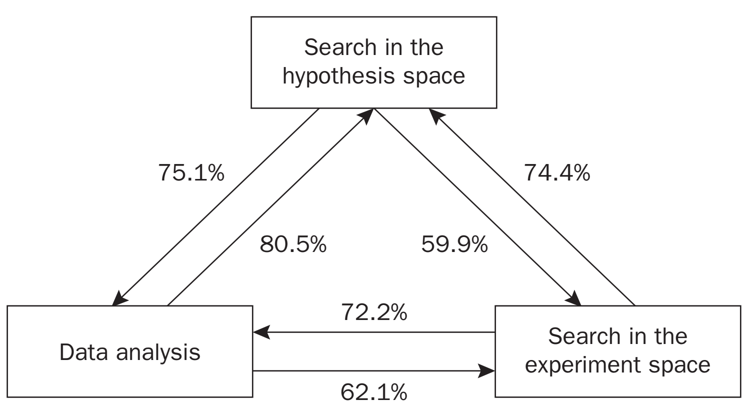


Figure 30.5 Percentage of students who gained class 3 in one dimension and also gained class 3 in the other dimension (n = 1006)

about the conventions of scientific experimentation, whereas the other two dimensions are more dependent on the student's content knowledge.

8.8 Findings for research question 3

Table 30.2 shows that the correlation coefficients between the students' pre-knowledge and the three dimensions of experimentation ranged from 0.353 to 0.400. Among these, the correlation between the content knowledge and 'planning experiments' was slightly lower than the correlations in the two other combinations, but the difference was not significant.

The correlations between the students' pre-knowledge and the three dimensions were lower than the intercorrelations. In contrast, we expected that there would be high correlations between the students' pre-knowledge and the three dimensions in experimentation, especially between the students' pre-knowledge and the dimensions 'forming hypotheses' and 'analysing data', because these dimensions were hypothesised to be influenced by biological pre-knowledge rather than by methodological knowledge. This finding suggested that it was possible to respond successfully to the questions in the competency test without doing particularly well in the knowledge test.

9. CONCLUSIONS

The test development was successful insofar as it was possible to develop reliable scales for the three dimensions. As this is a new approach to measuring student achievement in fairly finely grained subdimensions of experimentation, it might prove helpful for teachers and researchers who want to assess students' competencies in experimentation with a paper-and-pencil test. Further arguments in favour of a paper-and-pencil test are that they are less time-consuming and easier to code than practical tests. The validity of the described test, however, still needs to be analysed. What is missing from a paper-and-pencil test, however, is the interactivity and complexity that comes with the situation of solving problems experimentally in a laboratory.

Latent class analyses revealed students who performed well in all three dimensions, whilst others performed at an intermediate level and others at a low level in all three dimensions. Our analysis of the influence of the students' content knowledge on the processes of experimentation indicated that correlations between the students' pre-knowledge and all three dimensions in experimentation were equally low. This was in contrast to the main hypothesis of this study, namely that the ability to plan experiments is informed by methodological knowledge, whereas the ability to form hypotheses and interpret data is informed by the students' domain-specific pre-knowledge. There are three possible reasons for this. One reason is the reliability of the knowledge test (0.63). Secondly, there may be a general factor that underlies all three dimensions but which could not be identified by the test instruments of the study, for example the students' intelligence, i.e. their ability to think logically and make inferences. Thirdly, it is possible that solving the questions does require different kinds of knowledge as we assumed.

Table 30.2. Correlation coefficients (Spearman) between pre-knowledge and the three dimensions of experimentation (n = 1006)

	*Pre-knowledge * 'forming hypotheses'*	*Pre-knowledge * 'analysing data'*	*Pre-knowledge * 'planning experiments'*
Correlation coefficient	0.400	0.385	0.353

The main finding of this study was the high correlations between the dimensions of experimentation. The questions in the test seemed to measure two dimensions, rather than three. Questions in the dimension 'search in the experiment' were intended to measure the student's ability to design appropriate experiments when the hypothesis was stated. Correlation statistics revealed that this is a different ability to interpreting the findings of an experiment and identifying the hypothesis that can be tested in a given experiment. All three test item types can be recommended for test item construction in order to assess students' competencies in experimentation.

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31 Animal dissection in biology education: attitudes of South African university students

Rian de Villiers

UNIVERSITY OF PRETORIA, SOUTH AFRICA

jjr.devilliers@gk.up.ac.za

Prospective biology teachers at a South African university responded to a questionnaire on animal dissection in the biology classroom. The students were required to answer questions relating to their attitudes towards and experiences of animal dissection. The influence of gender, culture and religion on their attitudes is discussed and the implications of animal dissection for teaching biological science are considered. The advantages and disadvantages of alternatives to animal dissection are also discussed. A number of recommendations are made with regard to animal dissection in the biology classroom.

1. BACKGROUND

The use of dissection in biology education as part of mass education rather than medical training began in the early 1900s (Kinzie *et al.* 1993). In schools, colleges and universities, the debate about the role of dissection in biology education continues, especially with regard to mammals. There are inherent contradictions in killing animals and dissecting them to study the processes of life. Whilst some educators and scientists have advocated alternatives to animal dissection (Rowan 1981; Orlans 1988a, b, 1991; Gilmore 1991; Davis 1997), others have at some stage or another expressed support for dissection (Lord 1990; Smith 1990; Keiser and Hamm 1991; Offner 1993; Wheeler 1993; Kline 1995).

Pressure groups such as animal rights campaigners have forced biology teachers and students to question the necessity and relevance of animal dissection. Over the last three decades of the 20th century, the increasing public visibility of animal-rights campaigners in North America and Europe has influenced opinion in the academic community. In the 1980s, animal dissection in biology education was formally challenged when students began to object to dissection and refused to participate, demanding alternative assignments. Consequently, effective alternatives to animal dissection have been sought.

In northern/western countries the trend has been to decrease the number of live animals used for teaching purposes and to replace dissection with acceptable alternatives. Finding acceptable alternatives is becoming an increasingly important issue worldwide. The alternatives available today include ‘low-tech’ variants such as preserved specimens, books, charts, slides, photographs and three-dimensional anatomical models, and 'high-tech' variants namely computer-based simulations, films and interactive DVD-based simulations.

1.1 What are the advantages of alternatives?

The following list outlines some of the advantages of using alternatives to animals:

- *Cost*: Animals are expensive and can only be used once, and usually only by one to four students. Initially, some of the alternatives may themselves appear very expensive. However, many students can use videos, interactive videos and soft-tissue organ models over a period of years.
- *Time*: Considerable time can be spent dissecting an animal. If procedural knowledge and skills are valued, then this is time well spent. However, if declarative knowledge is the goal, then some of that time is wasted. It may be better to be on track in declarative learning rather than spending time with dissecting trays, pins, scalpels and tweezers.
- *Procurement and disposal*: With all specimens, there is a need to order them from suppliers in advance. With live specimens, there is a need to order in advance to a fairly tight schedule so that the specimens do not become either burdensome or deteriorate in condition. With computer simulations and videos, the equipment needs to be to hand but it will be in the same institution/department/room as the teacher.
- *Confusion and frustration*: We have seen that computer simulations and interactive DVDs enable students to progress at their own pace. The limited research reported above shows that students appear to benefit more where the simulation or DVD carries a commentary, thereby providing guided discovery. Animal tissue has to be disposed of in a safe way using protocols that have been agreed by provincial and national bodies. There are usually procedures that have been designed with health and safety in mind, and in many countries these are open to scrutiny by an independent inspectorate. As regulations change, so the staff of the department need to be kept up to date.

1.2 What are the disadvantages of alternatives?

Some of the disadvantages of alternatives are:

- *Realism*: The feel of models and preserved specimens is definitely different from the feel of live and freshly sacrificed specimens. Alternatives have been faulted for their lack of realism (Orlans 1988a; Kinzie *et al.* 1993, 1996). Greenfield *et al.* (1995) pointed out that some of the models used in their study were more friable than real tissues. Offner (1993) argued that when students know a specimen is real, their attention is increased and the information they learn is somehow registered as 'real'. Leonard (1985) found that students in biology classes had a strong perception that the images on a DVD learning system were not real.
- *Sensory experience*: We learn from the outside world through sensory experience. The more senses that are involved, the more powerful will be the learning experience. Students viewing dissections with high-tech alternatives will not have the same sensory experience as students examining actual animal tissues and organs. Viewing any alternative engages one or two of the senses, whilst actually doing the dissection engages at least three of the four senses.
- *Dissection skills*: If emphasis is placed on learning practical dissection skills, alternatives should not be considered as a replacement for an actual animal dissection.

- *Visual–spatial thinking*: Alternatives may not stimulate visual–spatial thinking in the student so effectively. Lord (1990) was of the opinion that activities such as handling, rotating, manipulating and envisioning objects greatly contribute to the development of visual–spatial perception in the individual during dissection.

To date, few studies have examined the attitudes of students towards animal dissection. It was not until the late 1980s that such studies were first undertaken. Sieber (1986) examined undergraduate students' and scientists' attitudes to animal research, finding that more than half (59 per cent) of the respondents thought that there were preferable ways for students to learn about certain aspects of anatomy and physiology, rather than by killing and dissecting animals. Millett and Lock (1992) revealed that only 32 per cent of secondary school students found it interesting to dissect dead animals. A study conducted by Stanisstreet *et al.* (1993) revealed that 48 per cent of secondary school students believed animal dissection to be wrong. In a study of the attitudes of undergraduate educational psychology students towards animal dissection, Bowd (1993) found that 27 per cent reported exclusively negative reactions to dissection, whilst others (38 per cent) reported mixed, i.e. both positive and negative reactions. In their study of the opinions of undergraduate students from various disciplines with regard to animal dissection, Lord and Moses (1994) found that almost half (48 per cent) objected to the idea of dissecting a rabbit, but a large proportion of the students (80 per cent) did not object to the dissection of preserved animals. Interestingly, none of the aforementioned surveys explicitly involved prospective biology teachers.

As it is the responsibility of teachers to provide the best education and to encourage the greatest possible learning, whether or not to dissect is a question that can be answered only through reflecting on the learning outcomes of the curriculum. In some countries, particularly in North America and Europe, this controversial question has been debated for decades, whilst in others, such as those in Africa, the debate is new to the public domain. In addition, the extent to which the curricula take into account biology teachers' and students' cultures and religions needs to be determined. Should teachers in the 21st century still be killing animals to help people learn about the internal structures of animals? In Africa, this controversial question has not been debated before.

2. OBJECTIVES OF THE STUDY

The following research questions were addressed in this study:

- What are the attitudes of prospective biology teachers in South Africa towards animal dissection?
- Do gender, culture and religion influence these attitudes?

3. RESEARCH DESIGN AND METHODOLOGY

This research was conducted at one university in South Africa, where strong elements of North American and European culture coexist with traditional African cultural elements. A sample of 242 undergraduate, prospective biology teachers in first-, second- and third-year biology and zoology courses participated in the study. Information was collected by means of questionnaires, which students completed during routine classes. The students were informed that the questionnaire was not a test, that there would be no time limit and that they should answer the questionnaire individually. The questionnaire contained both open-ended and closed questions, which elicited responses with regard to individual actions, experiences and beliefs. The responses to the open-ended and closed questions were analysed and coded to provide quantitative data. The responses yielded demographic data as well as information on students' personal experiences of and attitudes towards animal dissection. The demographic questions related to gender, age, religion, cultural group, year of study and area of specialisation. The students' personal experiences at school and at university, as well as outside school and university, were explored through questions about animal dissection, types of animal dissected and students' emotional reactions during the dissections.

One of the four attitudinal items consisted of 50 statements requiring students to tick the relevant box (1 = strongly agree, 2 = agree, 3 = don't know, 4 = disagree, 5 = strongly disagree) on a Likert scale to indicate the extent of their agreement or disagreement with each statement. The statements were randomly organised and covered 17 epistemological, 27 ethical and six physical aspects. The epistemological issues included, for example, elaborating on text information, discovery learning, investigation and developing intellectual independence. Ethical issues included the acceptable treatment of the dead, the killing of animals, reflections on self and cultural beliefs. Physical issues included the students' reflections upon the immediate physical experience of animal dissection. Statistical analysis [summary statistics, two-way tables and analysis of variance (ANOVA)] of the survey data was used to elaborate and enhance the discussion. The epistemological, ethical and physical areas were represented by the mean score of each student with regard to the questions in each of the three areas. An ANOVA was carried out to explore the influence of culture, gender and religion on the responses to the epistemological, ethical and physical areas. Cronbach's α coefficient test was used to measure reliability.

4. RESULTS

4.1 Sample profile

4.1.1 Demographic traits of students

Two hundred and forty-two prospective biology teachers (83 per cent of the total biology and zoology registrations) completed the questionnaires. One hundred and seventy-two (71 per cent) were biology students and the rest zoology students. Forty-three per cent were first-year students, 32 per cent second-year students and 25 per cent third-year students. The majority of students (82 per cent) were female. Regarding religious background, 3 per cent had no religious background, 3 per cent had an Eastern religious background (Muslim, Hindu or Buddhist), 23 per cent were Catholic and 71 per cent were Protestant. The majority (69 per cent) were Afrikaans, 15 per cent were English, 13 per cent were African (Ndebele, Northern Sotho, Southern Sotho, Swazi, Tsonga, Tswana, Xhosa and Zulu) and 3 per cent were from a different background (Portuguese, Indian, Greek or German). Thus, the sample represented a wide variety of demographic groups in South Africa.

There were some limitations of the study. As some of the groups were too small for statistical testing, the focus fell on larger groups. This is in keeping with the view expounded by Babbie and Mouton (2001) who state that it is never possible to observe all the actions and actors relevant to the social phenomenon under scrutiny. Thus, whilst the majority of students (82 per cent) were female, only 13 per cent of the biology and zoology students were African. A mere 3 per cent of the respondents practised an Eastern religion, whilst 3 per cent practised no religion. These low representations in the sample may have affected the outcome of the analysis of responses in terms of culture and religion.

4.1.2 Previous dissection of animals

Two-thirds (67 per cent of the males and 67 per cent of the females) had dissected an animal at school or university. It was of particular interest that 48 per cent of all the students (84 per cent males and

41 per cent females) had dissected an animal outside of school or university. Only 19 per cent of the students had never dissected an animal.

The respondents had dissected a large variety of animals (Figure 31.1). They appeared to prefer dissecting smaller mammals and invertebrates. More vertebrates than invertebrates had been dissected, as the dissection of animals has been standard instructional practice in accordance with the biology and comparative anatomy school curriculum. Approximately a quarter (26 per cent) of the total dissections had been carried out on mammals. The mammals most often dissected (in decreasing order) included rats, rabbits, mice, deer, cattle, sheep, dogs and pigs. The invertebrates most often dissected (in decreasing order) included earthworms, locusts, tapeworms, cockroaches, molluscs, bees and crickets.

More than two-thirds of the students (66 per cent) had dissected between one and four types of animal. One student had dissected 14 different types of animal. Four students had dissected a dog, which is considered a pet. Most of the students who had dissected sheep, cattle and chickens grew up in rural areas.

4.2 Demographic comparisons

The responses from students were 0.8 for epistemological, 0.86 for ethical and 0.81 for physical issues when tested using Cronbach's α coefficient.

4.2.1 Culture

The analysis suggested that a student's cultural group could influence the responses to the physical statements but it was not statistically significant at the 5 per cent level ($P<0.05$) (Table 31.1).

4.2.2 Gender

The analysis provided statistical evidence that male and female students respond differently to the ethical and physical statements. The mean female responses were less positive than the male responses. The responses to the epistemological issues were similar for males and females (Table 31.2).

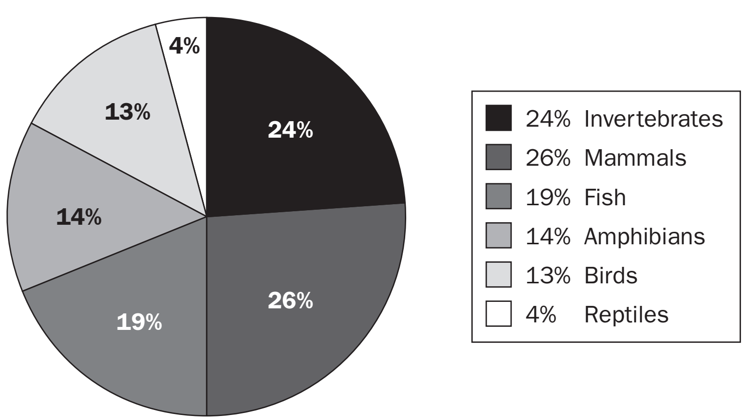

Figure 31.1 Classification of animals dissected

Table 31.1 Results of ANOVA comparing epistemological, ethical and physical areas in terms of culture

Culture	*Epistemological (mean±SD)*	*Ethical (mean±SD)*	*Physical (mean±SD)*
Afrikaans (*n* = 166)	2.23±0.65	2.54±0.57	2.81±0.91
English (*n* = 37)	2.44±0.63	2.62±0.48	3.00±0.84
African (*n* = 31)	2.26±0.68	2.55±0.64	2.97±0.87
Other (*n* = 8)	2.19±0.49	2.81±0.73	3.64±1.02
P value	***0.265***	***0.695***	***0.099****

*, Significant at the 10 per cent level (P<0.10).

Table 31.2 Results of ANOVA comparing epistemological, ethical and physical areas in terms of gender

Gender	*Epistemological (mean±SD)*	*Ethical (mean±SD)*	*Physical (mean±SD)*
Male (*n* = 43)	2.18±0.61	2.32±0.62	2.47±0.85
Female (*n* = 197)	2.28±0.65	2.61±0.54	2.98±0.89
P value	***0.505***	***0.001*****	***0.0001*****

**, Significant at the 5 per cent level (P<0.05).

4.2.3 Religion

The analysis provided no statistical evidence of a relationship between students' religion and their responses to the epistemological, ethical and physical statements.

4.3 Attitudes towards animal dissection

A large number (87 per cent) of the respondents were in agreement with the question, 'Will you as a teacher do hands-on animal dissection in the biology classroom yourself? Of these positive responses, a very high number of the English students (94 per cent) preferred to do animal dissections themselves rather than expect the students to do them. Eighty-seven per cent of the Afrikaans students and 81 per cent of the African students indicated that they would not mind dissecting animals in the classroom themselves. Their responses to the open-ended, follow-up question 'Why?' were classified into two categories, namely cognitive (CO) and affective (AF) (Figure 31.2). Students with positive responses drew almost exclusively on the cognitive domain, whilst students with negative responses drew mainly on the affective domain.

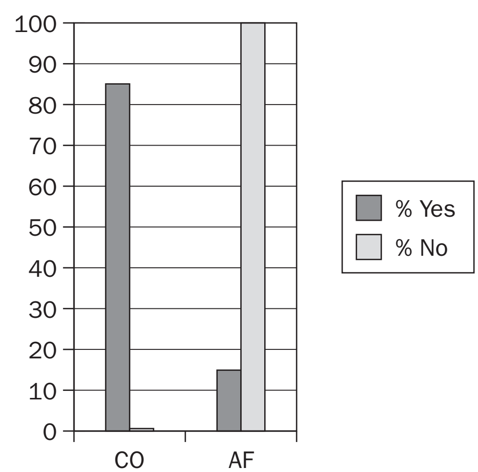

Figure 31.2 Responses by prospective biology teachers as to why they would dissect animals themselves in the classroom. CO, cognitive; AF, affective

In response to the question, 'Would you as a biology teacher expect the students to do animal dissection?', 71 per cent indicated that they would. All of the students with an Eastern religion (3 per cent) gave a positive response, followed by those with no religion (86 per cent), the Protestants (70 per cent) and the Catholics (67 per cent). The African students (84 per cent) had the highest percentage of positive responses in spite of the fact that 64 per cent had negative emotional reactions the first time they did a dissection themselves. The students' responses to the open-ended, follow-up question as to why they would expect the students to do the dissection were classified into cognitive (CO), skill-based (SK), sensory (SE), affective (AF) and procedural (PR) categories (Figure 31.3). Students with positive responses drew almost exclusively on the cognitive domain, whilst students with negative responses drew mainly on the affective domain.

4.3.1 Ethical issues

Respondents strongly indicated (84 per cent) that it was acceptable for a student to watch other people carrying out animal dissection. In response to the statement 'I do not mind if an animal has already been prepared for me to use in dissections, but I would not actually kill animals for dissection myself', most (56 per cent) of the positive responses (84 per cent) were in the 'strongly agree' category. Surprisingly, exactly half of the respondents preferred to dissect an animal organ, rather than the whole body.

An unexpected finding was that 67 per cent of the respondents would rather do dissections themselves than watch a videotaped dissection. More than half (56 per cent) of the respondents agreed that the study of anatomy justifies the dissection of animals. Most of the respondents (69 per cent) disagreed with the statement 'In my culture it is ethically wrong for man to kill animals for dissection.' Three-quarters (75 per cent) of the respondents thought that the way they had been brought up would not prevent them from dissecting. Many students (70 per cent) indicated that animals should be used for dissection only for the purposes of education and research. It is significant that approximately two-thirds (64 per cent) of the respondents indicated that dissecting animals for teaching/learning purposes increased their respect for life. More than half (60 per cent) of the respondents were comfortable with the thought that an animal had been killed 'as long as it is for a good reason'. Most students (70 per cent) preferred to dissect a preserved rather than a fresh animal in a biology investigation.

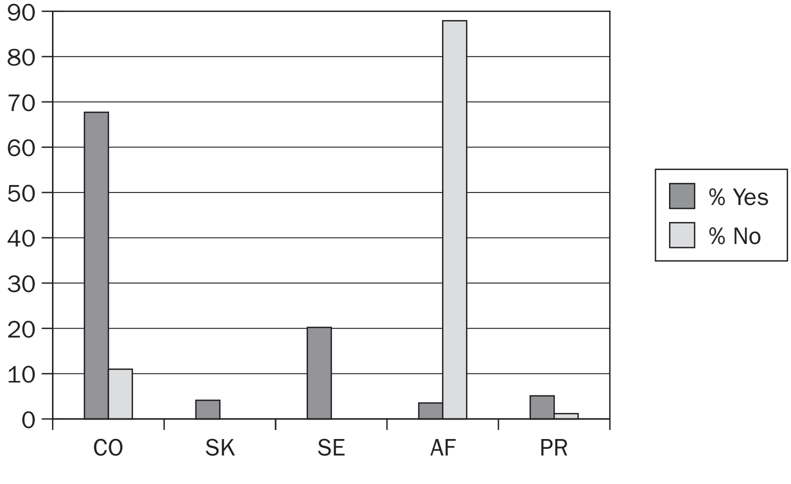

Figure 31.3 Responses by prospective biology teachers as to why they would expect students to dissect animals. CO, cognitive; SK, skills-based; SE, sensory; AF, affective; PR, procedural

4.3.2 Physical issues

More than two-thirds of the respondents (69 per cent) did not regard dissection as 'something dirty or unclean, and not a pleasant sight'. Almost two-thirds (63 per cent) of the respondents agreed that they would not be discouraged from dissecting animals by the sight of blood. On the other hand, more than half (59 per cent) dislike the smell associated with live and preserved animals.

4.3.3 Epistemological issues

Some of the outcomes of the survey were unexpected; for example, 61 per cent of the respondents agreed with the statement 'Since an animal body closely resembles the human body, dissection is exciting.' In addition, a large number of the respondents (83 per cent) felt that they could learn more about their bodies from animal dissections, as an animal's body closely resembles the human body. The fact that the human and animal bodies are similar would not deter them from dissecting animals.

A preference for discovering more about an animal during a dissection, rather than by using alternative sources such as models and videotapes, was indicated by 68 per cent of the respondents. More than three-quarters of the respondents (77 per cent) disagreed with the statement that 'Dissection is unnecessary in biology education because one can find all the information in a textbook.' The statement 'I believe dissection is an effective way to study the anatomy of an animal' elicited positive responses from 91 per cent of the respondents. Animal dissection was regarded by 42 per cent of the respondents as the only technique that can assist them to develop manipulative skills. A large proportion of the respondents (92 per cent) indicated that dissections gave them more precise information about the anatomy of an animal than other sources. Most of the responses were in the 'strongly agree' category.

No major differences were found in the distribution of responses to statements about the phylogeny of mammals. However, the respondents preferred to dissect small mammals rather than larger mammals. In answer to the statement 'I would prefer to dissect a rat rather than a rabbit', 48 per cent of the respondents agreed with the statement. The students indicated that some organisms are more acceptable for dissection than others. Most students indicated that they preferred to dissect a cold-blooded animal, e.g. an earthworm, rather than a warm-blooded animal, like a dove.

5. DISCUSSION

The questionnaire responses with regard to dissection have implications for biology teachers in terms of their approach to animal dissection in the classroom. Ultimately, it is the teachers' responsibility to decide whether to dissect or not, and therefore teachers should be aware of the possible responses of different demographic groups.

Although more than two-thirds of the students had positive attitudes with regard to animal dissection, a minority of students were against it. Most students coped with animal dissection and indicated that they learnt from it. Students from rural areas were likely to have more liberal attitudes towards animal dissection than students from urban areas. They were more likely to be familiar with animal dissection, as a result of their lifestyle. The teacher educator and the biology teacher must be sensitive to students' intellectual, moral and emotional needs, and should create an awareness of alternative instructional tools.

As teachers are mediators between the students' views of the world and the generally accepted scientific view, their attitudes have important implications for the students they teach. Those teachers who are proponents of animal dissection as an effective instructional tool should acquaint themselves with the religious concerns of all students in a diverse society. Some religions do not support the killing of certain types of animals, or any animals, unnecessarily.

Biology teachers can assist students by encouraging consistent and responsible behaviour towards animals. This should be done in the early elementary years when students' values systems are still developing. In order to accommodate the changes in biology and medical technology, primary and secondary school biology teachers should include a bioethics component in their courses.

Students' attitudes may impinge on the subject the teacher is teaching and result in detracting from or resisting effective learning. A teacher's opposition to animal dissection could oppress the intellectual needs of some students. Students have the right to learn and the biology teacher must accommodate them in a manner they find acceptable. Biology teachers may not exclude students who are strongly concerned about animal rights from a course. Teachers need to be aware of the fact that the vast majority of students forced to perform dissections in secondary school will not enter professions in which such skills will be required.

Students at universities can learn about internal animal structure through a number of alternative methods. If the acquisition of practical dissection skills is essential, alternative methods cannot completely replace dissection. Prospective biology teachers should have training in using alternatives. This could endorse the current emphasis on field-based and ecological research, as the focus continues to shift away from the laboratory to the investigation of life in the natural environment.

Biology teachers should take note of the following recommendations resulting from this research. They are advised to:

- consider ethical and moral issues with regard to animal dissection;
- be aware of different cultures and religions in the biology classroom;
- present alternative options, such as videotapes and models, and ensure that the resultant activities are equal with respect to time and effort;
- offer students a choice between fresh and preserved animals;
- be aware that female students are more averse to dissection than male students;
- insist that the animals dissected should be treated respectfully;
- never allow animals normally kept as family pets to be dissected;
- ensure that the learning outcome will be achieved by means of the dissection, e.g. if the learning outcome entails the use of manipulative skills, then only organs need be used.

Dissection, perhaps more so than any other laboratory exercise, is dramatic. Teachers need to be aware that it entails more than the intellectual stimulation of examining and identifying the inner parts of an organism. Students should respect all forms of life, including the animals dissected and should appreciate and be aware of individual variation, as well as the continuity of life. A positive attitude towards and respect for animals can be instilled by allowing students to observe the characteristics of various species.

The results of this research could be useful to curriculum designers responsible for biology curricula, and to policy-makers. The results can also be used to inform biology teachers in primary and secondary schools, as well as teacher educators in the higher education sector.

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