

BIOLOGY EDUCATION FOR THE REAL WORLD

Student - Teacher - Citizen

Proceedings of the IVth ERIDOB Conference

Edited by
Jenny Lewis
Alexandra Magro
Laurence Simonneaux

Toulouse - France

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Westfälische Wilhelms-Universität
Münster
Institut für Didaktik der Biologie
Friedrichstr. 23
48149 Münster

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Toulouse-France, October 22nd - 26th 2002.

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THE IVTH ERIDOB CONFERENCE

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INTRODUCTION

From modest beginnings in 1996, when IPN (Kiel) hosted the first European conference on biology education research, ERIDOB has developed into an established bi-annual conference attracting both European and International researchers. The 2002 conference, held in Toulouse, attracted 100 participants drawn from 17 countries (14 European;3 International). Together they presented a total of 54 papers and 58 posters.

For the first time, two major international figures were invited as keynote speakers - Jaques Desautels (Laval University, Canada) spoke on 'Biological Literacy and Citizenship Education'; Ian Robottom (Deakin University, Australia) considered the question 'What is the contribution of biology in environmental education?'. These themes, which considered biology education in a wider context, brought into focus the changing nature of our biology curricula. Increasingly there is an expectation that these will draw on real world contexts to make the biology more accessible and relevant to young people. There is also an expectation that young people should be encouraged to consider the real world issues that arise from the application of recent and rapid developments in biology. This extends to an expectation that biology education can and should make a significant contribution to citizenship education, helping to prepare young people for further engagement with science related issues in their adult lives. Biology education is also seen as the route through which young people will come to a better understanding of sustainable development.

These changes – in content, context and aims – present biology educators with many challenges and do not go uncontested. These issues and concerns were reflected in many of presentations in Toulouse. Alongside papers relating to more traditional interests in cognition, conceptual change and teaching and learning strategies were those on environmental education, decision making in a biological context and attitude formation.

At such an exciting and challenging time for biology education we look forward to ERIDOB 2004, where we will have an opportunity to consider the progress which has been made and the further implications for biology education research.

Dedication to Sheila Turner:

These proceedings are dedicated to Sheila Turner (28 August 1938 - 4 November 2000), a founder member of ERIDOB. Her cheerfulness, her generous support for and encouragement of new researchers and her dedication to science education will be missed by all.

CONTENTS

Jacques Désautels Université Laval TECHNOBIOLOGICAL LITERACIES AND EDUCATION IN CITIZENSHIP	9
Ian Robottom Deakin University WHAT IS THE POSITION/CONTRIBUTION OF BIOLOGY IN ENVIRONMENTAL EDUCATION	27
TEACHING BIOLOGY	
Claudia Nerdel, Helmut Prechtel, & Horst Bayrhuber Institute of Science Education INTERACTIVE ANIMATIONS AND UNDERSTANDING OF BIOLOGICAL PROCESSES: AN EMPIRICAL INVESTIGATION ON THE EFFECTIVENESS OF COMPUTER-ASSISTED LEARNING ENVIRONMENTS IN BIOLOGY INSTRUCTION	45
Michiel van Eijck, Ton Ellermeijer & Martin Goedhart Universiteit van Amsterdam DIFFICULTIES IN THE USE OF QUANTITATIVE DATA IN UPPER SECONDARY BIOLOGY EDUCATION IN THE NETHERLANDS	59
Roald Verhoeff, Arend Jan Waarlo & Kerst Boersma Universiteit Utrecht LEARNING AND TEACHING CELL BIOLOGY FROM A SYSTEMS THEORY PERSPECTIVE – AN INTERIM REPORT OF A DEVELOPMENTAL RESEARCH PROJECT	75
Lynn du Plessis ¹ , Trevor R. Anderson ¹ , Diane J. Grayson ² University of Natal ¹ , University of South Africa ² STUDENT DIFFICULTIES WITH THE USE OF ARROW SYMBOLISM IN BIOLOGICAL DIAGRAMS	89
Mats Hagman, Clas Olander & Anita Wallin Göteborg University RESEARCH-BASED TEACHING ABOUT BIOLOGICAL EVOLUTION	105
Laurence Simonneaux & Virginie Albe Ecole Nationale de Formation Agronomique TEACHING SOCIALLY CONTROVERSIAL SCIENTIFIC ISSUES : RESISTANCE AND MOTIVATION, REAL OR PERCEIVED ?	121
Patricia Schneeberger University of Bordeaux 2, INTERACTIONS AMONG CHILDREN IN SCHOOL SCIENCE CONTEXTS AND KNOWLEDGE ACQUISITION IN BIOLOGY	135
Maryline Coquidé Institut Universitaire de Formation des Maîtres de Bretagne WHAT BIOLOGY TEACHERS SAY ABOUT LABWORK AS PART OF BIOLOGY EDUCATION	147

REASONING

- Milena Bandiera
"Roma Tre" University
DISCURSIVE INTERACTION AND SCIENCE EDUCATION IN PRE-PRIMARY SCHOOL 161
- Marida Ergazaki, Vassiliki Zogza
University of Patras
STUDENTS' REASONING WHILE COLLABORATING ON A TASK
IN THE CONTEXT OF GENETIC ENGINEERING 171
- Marie-Hélène Lavergne, Rodolphe M. J. Toussaint
Université du Québec à Trois-Rivières
BIODIVERSITY AND ILL STRUCTURED PROBLEMS:
ADOLESCENTS' REFLECTIVE JUDGMENT 185

LEARNING BIOLOGY

- Jutta Lumer, Friederike Picard & Manfred Hesse
University of Münster
"PROTEINS HAVE THE BASES URACIL, THYMINE, ADENINE, GUANINE, CYTOSINE"
CONCEPT MAPPING AS A TOOL TO CLARIFY TWO BIOCHEMICAL CONCEPTS. 199
- Alexandra Magro¹, Laurence Simonneaux¹, Didier Favre² & Jean-Louis Hemptinne¹
¹Ecole Nationale de Formation Agronomique,
²Lycée d'Enseignement Général Technique Agricole de Tours Fondettes
LEARNING DIFFICULTIES IN ECOLOGY. 211
- Annette Schmitt-Scheerso¹, Helmut Vogt² & Clas M. Naumann¹
¹Zoologisches Forschungsinstitut und Museum Alexander Koenig
²Universität Kassel
THE DEVELOPMENT OF SITUATIONAL INTERESTS
IN AN INFORMAL LEARNING ENVIRONMENT – A VISITOR EVALUATION STUDY
IN AN EDUCATIONAL EXHIBITION ON INDIVIDUALITY 219
- Horst Bayrhuber, Lore Hoffmann (IPN),
Ingrid Hemmer (Catholic University of Eichstaett),
Michael Hemmer (University of Muenster), Päivi Taskinen, Sylke Hlawatsch
& Marion Raffelsiefer (IPN)
IPN-University of Kiel
STUDENTS' INTEREST IN „SYSTEM EARTH“ WITH SPECIAL CONSIDERATION
OF BIOLOGICAL ASPECTS 229
- Carolyn Boulter, Sue Dale Tunnicliffe & Michael Reiss
University of London
PROBING CHILDREN'S UNDERSTANDINGS OF THE NATURAL WORLD 243
- Marcus Hammann & Horst Bayrhuber
IPN-University of Kiel
HOW DO STUDENTS USE CRITERIA IN COMPARISONS? 259

Gustav Helldén, Kristianstad University 19-YEAR-OLD STUDENTS' REFLECTIONS OVER THEIR UNDERSTANDING OF ECOLOGICAL PROCESSES	273
Kristin Hildebrandt & Horst Bayrhuber IPN-University of Kiel STUDENTS' CONCEPTIONS ABOUT SYSTEM EARTH –SYSTEM THINKING AND MULTI-PERSPECTIVE LEARNING IN THE CARBON CYCLE CONTEXT	285
Sverre Pettersen & Jeanette Solberg Faculty of Technical and Vocational Teacher Education Akershus University College STUDENTS OF HEALTH SCIENCES' EVALUATION OF MEDIA REPORTS OF HEALTH RESEARCH: A NORWEGIAN STUDY.	293
ENVIRONMENTAL EDUCATION	
Franz X. Bogner University of Education Ludwigsburg OUTDOOR ECOLOGY EDUCATION AND ITS INTERACTION WITH ASPECTS OF ENVIRONMENTAL PERCEPTION	309
Ramón López Rodríguez & María Pilar Jiménez Aleixandre Universidade de Santiago de Compostela SHARING THE AUTHORITY TO EVALUATE ENVIRONMENTAL ATTITUDES: A CASE STUDY IN PRIMARY SCHOOL	319
Kai Pata, Tago Sarapuu University of Tartu DEVELOPING STUDENTS' MENTAL MODELS OF ENVIRONMENTAL PROBLEMS BY DECISION-MAKING ROLE-PLAY IN SYNCHRONOUS NETWORK-BASED ENVIRONMENT	335
Kirsten Schlüter IPN-University of Kiel REALISATION OF ENVIRONMENTAL EDUCATION CONCEPTS IN TEACHER TRAINING	349
LIST OF PARTICIPANTS	361

TECHNOBIOLOGICAL LITERACIES AND EDUCATION IN CITIZENSHIP

Jacques Désautels

Département d'études sur l'enseignement et l'apprentissage

Faculté des sciences de l'éducation

Université Laval & CIRADE, QUÉBEC

jacques.desautels@fse.ulaval.ca

The universality of scientific knowledge resembles that of the English language: following multiple power relationships, resistances, negotiations, this language has become the obligatory (and imposed) passageway for those who want to participate in certain types of exchanges. [Like this conference for instance.] Thus, in a like manner, the conceptualizations of the sciences, little by little, eliminate other knowledges in favor of those that the scientific community has standardized.

Fourez, *et al.*, (1997, 17)

Any educational system is a political way of maintaining or modifying the appropriation of discourses, with the knowledge and powers that come with them.

Foucault (1971, 46)

Many biology educators are likely to react strongly to the above statements. How is it possible, they would say, for someone to argue that the universality of scientific knowledges does not stem from their intrinsic qualities, which qualify them as knowledges that are valid at all times and in all places for any reasonable person, but is rather the result of a somewhat brutal social process of persuasion, almost a symbolic *coup de force* involving power relationships.¹ Admittedly, they might acknowledge that a certain number of valuable traditional knowledges are lost in the process, but they would immediately ask if it is not true that the sciences generate more efficient techniques. Who would think twice if given a choice between using certain local plants and taking antibiotics? Is there no longer any room for distinguishing between knowledge and superstition? While they might possibly agree that Foucault's discourse is relevant as far as the teaching of the humanities is concerned, they would also claim that the teaching of the concept of heredity or cell division has nothing to do with politics or ideology for all that. Indeed, what is taught in biology classes is not discourses but facts, concepts, laws, and theories.

Nevertheless, in this paper, I will argue that if we accord credibility to the above statements about the production of scientific knowledge and their epistemological status, then we are led to throw

¹ These power relationships are quite obvious when one considers the cultural effects of science education in non-Western cultures. For instance, Waldrip and Taylor (1999) have clearly shown that the young Malaysians they interviewed denigrated the knowledges developed in their local culture to explain natural phenomena, once they had completed their high-school science education. Furthermore, when these youngsters returned to their native village, they created a significant disturbance in the local culture, as expressed by one of the villagers: "[The younger generation] does not know the old ways. They see them as foolishness. They think they know better" (295). There is no doubt that such situations raise many ethical questions, as Gray (1999) claimed in an editorial in a special issue of the *Journal of Research in Science Teaching* on science education in developing countries.

into question the necessary political and ideological goals of an education in the technosciences, our understanding of the relationships between scientific literacy and citizenship education, and, by the same token, our teaching methods and approaches. However, since I do not have much space to develop those ideas, I will use the following two-pronged strategy: first, I will proceed according to the approach taken by Van Gulik in his detective novels when he presents the adventures of a Chinese judge. The outcome is given right from the start: the reader knows who the victims, the guilty, and the innocent all are. The entire interest of these novels is to try to understand how the judge framed the mystery and to predict or guess what path he will take in order to solve it; in the process, the reader has to open his or her own trail in order to arrive at the same conclusions. Likewise, I will state the conclusions of the paper in the following paragraphs. Furthermore, and again for reasons of space, I am unable to deal with the subject in all the complexity it deserves. Thus, I will take conceptual shortcuts and get rapidly to the point I want to make. Obviously, there is an abundance of questions to be asked at every turn of my path, but I nevertheless believe this approach will be useful for generating a debate about a very controversial and sensitive subject. For, as we all know, the stakes involve nothing less than the enhancement of the democratic character of politics in our societies.

The aims of an education in the technosciences

The preparation of critical, well-informed citizens should be the aim of education as a social institution. It should contribute to the formation of social actors who have developed the intellectual instruments, potentials for action, and the attitudes required to participate, *here and now*, in enhancing the practice of democracy in our societies.² Thus, the objective should be to provide the greatest possible number of students with an introduction to the *politics of the technosciences*, so they may become citizens capable of participating in their development and enactment both locally and globally—in particular, by becoming actively involved in the solution of sociotechnical controversies (Désautels & Larochelle, 2003). From this perspective, literacy is more aptly conceived of as an emergent property of the interactions of social actors through their participation in the politics of the technosciences, rather than as the feature of a singular mind or as the accumulation or development by an individual of increments of knowledge or skills, regardless of whether or not he or she is a scientist (Roth & Lee, 2002). But what grounds are such educational aims to be based on, and what specific educational tools must be developed in order to achieve them?

Technobiological education as a political endeavour

In a recently published book, William Kyle Jr. (2001) claimed that “What the discipline of science education lacked—and continues to lack—is a political philosophy of science education” (XV). It is this situation which he holds responsible for the failure of the reforms in science education and, in particular, the STS (Science-Technology-Society) movement, which strived mightily to integrate the social and political aspects of science, but which never met with

² Metaphorically, one can argue that our students have been put into some kind of disciplinary confinement. First, their mind is disciplined to see the world in a certain fashion through the teaching of the traditional academic disciplines. Second, they are confined to the school building most of the time and disciplined to obey and move on to another subject at the sound of a bell that rings at the end of a lesson. Indeed, they are not treated as reflexive citizens. They are thought to be able to understand sophisticated pieces of knowledge or to take moral positions in artificial and decontextualized dilemmas, but, paradoxically, not able to engage in the political life of their community. Ironically, as the rhetoric goes, schooling is always framed as a preparation for the next class and for a later life that they will experience once they are out of school.

widespread acceptance among either science educators or science practitioners. Although one may well sympathize with what Kyle wants to convey, the way he expresses those ideas is misleading all the same. Indeed, whether we are aware of it or not, whether we like it or not, science education has always had a political philosophy, since any statement of objectives and principles underlying a science curriculum embodies a sociopolitical program.

In conjunction with the language, history, and geography curricula, the science curriculum gives consistency to the socially negotiated ends of education—translating, among other things, into a teaching model that is founded on certain values, a certain conception of human development and cognition, and, more globally, a view of society and the role ascribed to citizens in maintaining and promoting some form of democracy. More specifically, the science or biology curriculum integrates a description of the sciences, their epistemological status, their historicity, and their sociality. Thus, it encourages students to construct a particular relationship to scientific knowledges and the powers associated with them in the context of the hierarchy of knowledges³ that characterizes a society, and, as well, a relationship to those people who possess these knowledges, namely, the experts called scientists. From this particular perspective, there is no ideologically and politically neutral science or biology curriculum for the following four reasons: First, because this relationship embodies a position about the kinds of truths that characterize specific types of knowledge. And the possession of truth is a powerful means for establishing who will be allowed to mobilize the scarce economic, material, and symbolic resources in any given society. Moreover, it can contribute to defining the criteria for establishing a hierarchy among all possible types of knowledge and their possessors in a society and among societies (Désautels, Fleury, & Garrison, 2002). Indeed, as Venville, Wallace, & Rennie (2002) have observed, there is an astonishing correspondence worldwide between the relative positions occupied by the different school subjects within this hierarchy of knowledge.

Second, because this relationship says something about its historical conditions of production, and it is clear to all that there are many histories of the sciences. For example, a hagiographic type of history centred on the feats accomplished by socially secluded, exceptional minds—the great scientists—bears more than one similarity with what Isabelle Stengers (1996) calls a religious war machine. It leads on to a disciplinary and dogmatic type of teaching, notably through the ritualization of laboratory activities (Delamont, Beynon, & Atkinson, 1988; Gough, 1998)

Third, because this relationship circumscribes the type of presence the sciences are supposed to have in a society. It specifies their role within that society and, therefore, their political status. For instance, in the majority of our schools, the sciences are described as a world apart, so we only have to worry about their impact on society. In other words, the sciences are not described as social practices and do not, through their own research activities, generate any ethical problems. Such conundrums are dumped in the backyard of those who make decisions about whether or not it is appropriate to go on with certain applications of the knowledge produced.

Fourth, because this relationship will contribute to the development among the students of particular ways of relating to knowledges and their possessors that can be more or less inhibiting

³ In any society, at any historical time, only a limited number of discourses will be thought of as authentic knowledges rather than as beliefs (Barnes, 1990). So, within this social disciplinary order, the prestige of a particular type of discourse will vary according to its location in a hierarchy of types of knowledge and thus generate an uneven distribution of political power among citizens (Messer-Davidov, Shumway, & Sylvan, 1993). For instance, in Galileo's time, theology occupied the top of this hierarchy, while mathematics, considered as a type of mechanical art, occupied the lowest echelon (Biagioli, 1993). And, whenever the disciplinary order is contested, the reactions of the different stakeholders can be vociferous indeed, as illustrated by Galileo's ordeal.

or emancipating. The reaction of many citizens, including ourselves, when confronted with a medical doctor in his office is a good example of what is meant here by a relationship to knowledge and those who possess it. In many cases, and for many people in our societies, how health and sickness is grasped is totally dependant on the judgement established by the medical institution.

All in all, the science or biology curriculum promotes a certain political ideology. So, in any reflection devoted to the relationship between an education in the sciences and an education in citizenship, the type of descriptions of the technosciences targeted for promotion in education is an issue that immediately comes to the fore. However, these descriptions can have ideological and political implications, as exemplified by the recent “science wars” and the Sokal affair. Indeed, for some of the protagonists in this debate, the stakes seemed to be very high. For instance, following what was conceived as an encroachment on their personal purview by anthropologists and sociologists who were accused of fostering a dangerous, relativist, epistemological stance about scientific knowledge (Biagioli, 1999; Pickering, 1992), scientists and their allies reacted strongly, as the very titles of the books published on the subject indicate: *Higher Superstition. The Academic Left and its Quarrels with Science* (Gross & Levitt, 1994), *The Flight from Reason* (Gross, Levitt, & Lewis, 1997). They also claimed that the promotion of the post-modern view of knowledge, as advocated by the French *clique* (Baudrillard, Derrida, Foucault, Latour, Lyotard, and others), would jeopardize the legacy of the Enlightenment and foster the spread of irrationality in our societies. In the field of science education, the same kind of phenomenon was observed in the form of a reaction against the constructivist view of teaching and learning. Thus, Michael Matthews (1997), one of the strongest opponents of constructivism in science education, wrote the following in the very serious and credible *Science Education* journal:

On the other hand, a steady diet of relativism, constructivism, and postmodernism in schools—not just in the humanities and the arts, but in science as well—has the potential to corrupt public debate and undermine scientific and social institutions. If, on matters of great public concern, there is no truth to be ascertained, then rhetoric can be substituted for argument and propaganda for investigation, and non-cognitive goals proposed for research. (309)

He even went as far as relating constructivism to Nazi propaganda, which banned any truth other than the one promoted by the National Socialist ideology. And if the reader thought that this reference was too far-fetched, he suggested that constructivism could be compared with the following politically correct doctrines: Christian fundamentalism, Marxism, monetarism, feminism, postmodernism, etc. This critique of constructivism was considered by many to be exaggerated, but he was not alone in his camp, as one can see by reading the titles of the following articles: *A Critique of Radical, Social Constructivism* (Slezak, 2000); *The Changing Perspectives of Constructivism: Science Wars and Children's Creativity* (Solomon, 2000).

What, then, are the lessons to be learned from this controversy? It has become quite obvious that questions raised in various discourses about the sciences are by no means confined to the realm of classical philosophy. They are simultaneously ideological and political, since they: propose a description of the status of social actors; legitimate certain social practices; sanction a particular social hierarchy of knowledge; and aim to mobilize people at the same time that they, at least partially, mask their origins through the use of commonplace ideas (Fourez, 1990; Lewontin, 1991). But what also becomes clear is the impossibility for any discourse to be devoided of any presupposition, in other words to be self-transparent as Ricoeur claims (Changeux & Ricoeur,

1998). Therefore we are all invited to become reflexive,⁴—that is, to constitute some of our presuppositions as objects of reflection without also becoming paralyzed by an unceasing questioning of the foundations of our discourses. This is the reasonable path that I will try to follow in the next sections of this paper.

From Science to the sciences to the technosciences

In the last forty years or so, through the hard work of philosophers, historians, sociologists, and anthropologists of the sciences, we have experienced a shift in our descriptions of the sciences that I should like to schematize as follows. In a non-linear fashion, we went from:

SCIENCE >>>> to >>>> the sciences >>> to >>> the technosciences

The positivist dream of the unity of SCIENCE worked out in terms of a common neutral observational language, a common method, and a conceptual structure that was simultaneously integrative, reductionist, and indefinitely perfectible has been shattered (Galison & Stump, 1996; Pestre 2001). Associated with the deconstruction of the positivist dream of the unity of SCIENCE is the work of distinguished scholars such as: Bachelard, Duhem (underdetermination), Quine, Hanson (theory-laden-ness), Feyerabend, Popper, and many others. Therefore, in response to the question appearing in the title of Chalmers' (1982) celebrated book—What is this thing called science?—we are now in a position to answer that it is a fiction or an ideological Trojan Horse if it is used without quotations. Such is often the case in science education, especially when we fail to recognize that the enactment of any curriculum is a political venture.

And then came the ambiguous Mr. Kuhn (1983), who has been championed as the one who helped open the Pandora's Box of SCIENCE. According to some interpretations of his work, which he apparently combated until his death (Fuller, 2000-a), he is credited with having shown that:

- Scientists in their day-to-day practical activity work on puzzle-solving within the framework of a paradigm. This practical activity, which involves a good deal of tacit knowledge, is viewed as accounting for the accumulation of anomalies or unsolvable problems within a particular paradigm that, in the long run, make it vulnerable.
- Therefore, debates within scientific communities become possible and new theoretical propositions become open for consideration. The adoption of a new paradigm, which follows those debates, is not a strictly rational process and involves a shift in the worldview of scientists. It in fact renders successive paradigms incommensurable, since the concepts associated with each epistemological framework are viewed as having different meanings. In other words, it is as though scientists working in the frameworks associated with two paradigms were speaking foreign languages. This makes the idea that scientific knowledge is a steady progress in the direction of truth quite problematic.
- However, the thing that is of utmost importance for what was to follow is that he is credited with showing that the sciences were simultaneously social and cognitive. The paradigm is constitutive of a community that is constitutive of the paradigm, and its stabilization is accomplished though the recruitment of other members who will go on with the task until it is contested, usually by newcomers in the field.

⁴ In this context, reflexivity is not equated with the possibility of removing ourselves from the world through some kind of enigmatic process of mental removal or escape. It is merely a matter of delimiting new topics of discussion in a conversation about the presuppositions that underlie our positions. Furthermore, discussions and conversations can be described as recursive, cybernetic processes that converge towards quasi-stable states or Eigen values, as von Foerster (1990) has claimed.

Now, whether or not Kuhn's model can be criticized⁵ on various different grounds is not of great importance at this point. But, it must be admitted that many scholars in the sociology of the sciences have recognized that, following Kuhn, it became legitimate to study the "hard" core of the sciences. They could then study the production of scientific knowledge by following and describing what scientists were doing on the "worksites" of scientific production rather than listening to what scientists had to say about their activities after the fact. These studies of the production of scientific facts in laboratories and the closure of scientific controversies have put a definitive end to the empiricist and positivist mythologies of SCIENCE taught and that continue to be taught in most schools. And, at this point, I will jump ahead and comment on some the lessons that I have learned from my interpretation of work performed in the social studies of the sciences.

What exactly has been learned from those studies? First, that if we are to talk about the sciences, we should refer to the myriad of practices through which scientists produce knowledge and artefacts. Moreover, these practices, as courses of action, could be described as social practices. In what way, then, is it possible to view as a social practice what a biologist all alone in the laboratory is doing while he or she interprets a print-out produced using an electronic microscope in order to write a paper?

First, it should be noted that there can be no good grasp of what this biologist is doing if his or her activity is not placed in relation to other activities connected to this particular instance and the network of actors making this endeavour possible. The following are some of the elements that are constitutive of this network and some of the activities conducted by it: 1) the community of physicists who have standardized the knowledge without which electronic microscopes would not even exist; 2) the engineers and technicians who have constructed the microscope using different types of knowledge and produced the standards for running the apparatus and interpreting the inscriptions; 3) the quality and preparation of the material used to produce the images; 4) the skill of the technician operating the microscope; 5) the biologists that have constructed and tested theories related to the interactions between electrons and cellular materials in order to interpret the images; 6) the papers he or she recently read on the subject; 7) his or her colleagues with whom he/she spoke the previous day before and who might have given him/her some advice; 8) colleagues elsewhere who will read the discursive interpretations this biologist is producing for the paper and who eventually will cast doubts on its value; etc.

It is at the end of this networked social process that entities and/or artefacts will come into existence (bacteria, viruses, proteins, vaccines, etc.); sometimes it is an enduring existence, but it is nevertheless an existence that cannot be detached from the network. We can never put our finger on something directly and say "there is a gene"—without meaning that we have pointed our finger in the direction of a trace or inscription (photographs, graphs, data, etc.). The more or less precarious existence of these entities is tellingly illustrated by the way many of them vanish—e.g., Lavoisier's caloric or Maxwell's ether, which, in their day and age, were part of the very air that scientists breathed. In other words, it would be more accurate to say that it is the network of actors that is making the observation rather than a specific person, which is not to ignore or deny that he or she is intellectually and bodily active while mobilizing material,

⁵ It is somehow surprising that Kuhn probed a model of the production of scientific knowledges centered on the functioning of rather isolated small groups of scientists later designated by the concept of invisible colleges, since he certainly was aware that the sciences had been integrated to the militaro-industrial (Big Science) complex for quite a long period of time.

discursive, and other symbolic resources to accomplish his or her work. In keeping with this perspective, the following is a non-exhaustive list of some of the social activities involved in the production of scientific knowledge which, incidentally, contribute to the survival of any laboratory: shop talk and coffee breaks; reading and commenting on articles; communicating with other people in the network; using protocols and standards; judging the quality of products (not all transgenic mice have the same quality); considering the quality of instruments; stabilizing phenomena and experiments; discussing interpretations of inscriptions (data); making good use of theoretical resources (controversy about the concept of gene⁶ and genetic determinism); writing articles and testing the statement market; reviewing articles; editing journals; travelling to conferences; writing research proposals and seeking research money; creating political and strategic alliances; performing public relations; and producing PhD's and technicians.

It is through this mangle of practices, which more closely resemble a kind of *bricolage* than some disembodied cerebral activity, that scientists collectively (co)produce bits and pieces of knowledge, facts, and artefacts, through the mobilization of material and discursive resources (Pickering, 1995). What these studies of sciences-in-the-making have also shown us is that these practices, these courses of action (all of which can be described), are social through and through, and also that the bits of knowledge acquire a certain acceptability, a certain stability through their circulation in heterogeneous networks of actors. After a certain time, some of these bits of knowledge become standardized or black-boxed and thus acquire a degree of generalization which is equivalent to the extension of the network, as illustrated by Atten & Pestre (2002) in their historical account of Heinrich Hertz's work on electromagnetic waves.

In thus claiming that scientific knowledge is relative to its conditions of production, I am not seeking to launch another science war in the science education community. But what we have also learned from these case studies is that we do not need any sort of *deux ex machine*—whether it is the realist *view from nowhere* or the radical relativist *view from everywhere*—to make sense of the sciences. We need only to adopt a more modest epistemological posture, which can be qualified as relativistic and realistic and which denies the possibility of transcending our human condition and history. From this perspective, we must accept the idea that: “*in some society, sometime, somewhere, someplace, somehow, some bodies, someone with some others, scrutinize settings, simulate and specify situations, systematically search for signs that secure speculations, structure statements, show or say something, though a standpoint or a stance*” (Biagioli, 1996). In doing so, we form judgments about the existence of the entities⁷ that people our shared, realistic world, and act accordingly. In other words, we live in flat land without the possibility of reaching the banks of a river to describe the flow of events past, present, and future; further, in this scenario, the sciences do not constitute an exception.

⁶ A very interesting article was published on this subject in the December 2001 issue of *La Recherche*. Some 15 researchers in genetics were asked to answer the following question: What is a gene? The descriptions they gave could be classified under three different models, and one scientist even said that no one no longer knows what genes are. Moreover, even those who gave a classical definition did not have a strict causalist or deterministic view of the development of an organism.

⁷ Judgments of existence are judgments we are responsible for in the process of constituting our common world. This is not to claim something about the essence of a world out there, which an observer outside this world could have access to, as though peering at it through a peephole. However, the entities that are brought into existence after having gone through a series of well-designed tests may be enduring. From that point of view, it seems that atoms, molecules, and microbes, for instance, will be with us for quite a while. This being said, they are no less or more real than the scent of roses or the taste of wine or honey (Stengers, 2002).

However, the focus on the micro-functioning of the sciences in action may have led us, as Fuller (2000-b) claims, to forget to reintegrate these activities within a larger social framework. Indeed, Big Science—that is, the integration of the sciences in the military-industrial complex—has been with us ever since the end of World War II. And, if we now understand that we are faced with a myriad of sciences or biologies that inhibit any attempt to produce an overview of the different fields (80 000 journals published every month), it seems more accurate to describe them as technosciences⁸ for the following reasons: 1) a greater part of the research funds is allotted to finalized projects; 2) even the smallest laboratory incorporates sophisticated technologies, which has caused some people to wonder, not without some irony, whether the sciences have not become applied technologies; 3) most of the research is now conducted within the military-industrial complex; and 4) think-tanks produce science policies for our governments. What, then, are the main features of this position that should be kept in mind, from the perspective of an education in the technosciences that is informed by the aims set out at the beginning of this paper?

From STS (science-technology-society) to STS (society and the technosciences)

Following the discussion above, where it is claimed that the technosciences can be described as social practices, we are forced, not surprisingly, to re-conceptualize the way by which their presence is understood within societies. The traditional separation between science and society becomes obsolete, as are the related concepts of impact and influence of science on society. Indeed, the technosciences are not described anymore as having consequences or influences on a society “out there,” but are instead described as practices that contribute to performance and governance within societies. And, what may initially appear to be an example of semantic wordplay ultimately produces overwhelming impacts on our way of orienting our educational ventures, as shall be seen below. How are we to understand the concepts of performance and governance?

The technosciences “perform the social” by introducing a variety of candidates for existence (reified entities, knowledge, practices, intellectual techniques, substances, artefacts, etc.) that are more or less uncertain, more or less controversial, and which we can decide to integrate or not into the makeup of our common world. In the process, the technosciences contribute to the reconfiguration of social relations—that is, the relations that we establish with humans and non-humans (Callon, 1999; Latour, 2001). The following personal experience, familiar to most readers who have lived through similar situations, will help clarify this theoretical statement.

For more than 25 years, I have been a member of a cooperative banking institution, and, until recently, I was fairly well acquainted with the people who worked on the premises. Going to the bank for whatever reason (deposits, money order, etc.) was an opportunity to chat with the teller and inquire about the family and kids. But things have changed dramatically in the last ten years since it became possible to do all sorts of banking operations through automatic tellers. The use of a small plastic card has, for better or for worse, reconfigured the long-running relationships I had with the people working at the bank. Moreover, the card and the wicket themselves have also become actors since they somehow prescribe how and what can be done in terms of operations;

⁸ The very title of this paper now acquires intelligibility. Within the framework developed in my discourse, BIOLOGY, as with SCIENCE, if separated from societies, is a kind of fiction. The myriad knowledges produced by biologists in the present day can be more appropriately described as technobiologies for the reasons stated above. Further, the complexification of the field is such that it becomes absurd to think in terms of biological literacy as a kind of unified culture.

they have, as a result, transformed the relation I had with banking altogether. Although far from constituting a spectacular example, it helps clarify what is meant by the reconfiguration of the relations established between humans and non-humans (Callon, 1999). In some other situations, all of society can undergo a profound transformation; such was the case when, following Pasteur's work, microbes became part of the everyday landscape of French society. From this perspective, it is easy to imagine that depending on whether a common world has, or is devoid of, HIV, atomic energy and nuclear waste, electromagnetic waves, an ozone layer and ultraviolet rays, asbestos, prions, the unconscious, cognitivism, antibiotics, genes and genetic determinism, GMOs, xenotransplantation, or communication satellites is not the same. Furthermore, where such phenomena are said to obtain is not the effect of an impact originating from a world "out there," but rather the result of the enactment of social practices "in here." However, since social life is transformed by the introduction of new actors into our common world, it is legitimate to say that the issue is of concern to all of us as citizens; stated simply, the technosciences become everyone's business and are no longer scientists' exclusive purview.

The technosciences also participate in the governance⁹ processes of our societies, both locally and globally, and can therefore be considered sociopolitical practices. For instance, the technosciences are involved in the following types of activities: the definition of global environmental problems and protocols; the design of military armament and war strategies¹⁰; biopiracy; the set-up and operation of financial markets; the creation of transnational "knowledge-intensive" industries (agrobusiness, drugs, communication, etc.); the redefinition of patent laws; the redefinition of the universities through "science policy"; the surveillance of citizens; the redefinition of evidence in courts of law (genetic prints); police force operations; the administration of government agencies; etc. The participation of scientists in activities such as these, which are simultaneously institutional, commercial, public, ideological, educational, theoretical, empirical, material, discursive, symbolic, and strategic constitutes the *politics of the technosciences*. As such, they concern everyone in our societies.

It is the claim of this paper that unless students are brought into the politics of the technosciences, they cannot become well-informed, critical citizens capable of playing an active, positive role in the democratic life of our societies. The usual arguments against such a project are generally worked out in terms of a view ascribing a cognitive deficit to students and laypeople alike, according to which the complexity of technoscientific problems is such that they can only be

⁹ As it is used here, the concept of governance refers to the numerous control, rule-making, and steering processes through which power and authority are distributed and exercised in our societies (Steans, 2002; Rosenau, 2000). It takes into account the fact that in a period of growing world globalization, these processes are no longer the sole prerogative of the state and national governments, if ever such had been the case. As Rosenau (2000) claims: "It follows that systems of rule can be maintained and their controls successfully and consistently exerted even in the absence of established legal or political authority. The evolution of intersubjective consensus based on shared destinies and common histories, the *possession of information and knowledge*, the pressure of active and mobilizable publics, and/or careful planning, good timing, clever manipulation, and hard bargaining can—either separately or in combination—foster control mechanisms that sustain governance without government" (183, italics are mine).

¹⁰ The war in Irak broke out while I was working on the final draft of this paper. This catastrophic human and environmental tragedy would not have been possible without the participation of scientists who designed the lethal war instruments and strategies that were deployed. It is a clear case of the participation of the technosciences in the governance of our societies and it is time to do away with the specious arguments that lead so many people to claim that it is only in the application of knowledge, after the fact, that moral problems emerge. For a subtle discussion of the means-ends relations as far as technology is concerned see Latour's article entitled *Morality and Technology: The End of the Means* (2002).

solved intelligently by people who have been trained for long periods of time in the various fields concerned. For instance, Fensham (2002) advances a claim of this kind in his critique of the democratic assumption underlying the idea that socio-scientific issues can be tackled by scientifically literate citizens:

Such wishful thinking may show their own ignorance of the complexity of the science that is involved in issues such as global warming, cellular phone radiations's effects or the conservation of endangered species. It is an unrealistic hope that—even through the best of schooling—a level of science knowledge can be achieved that enables citizens to critically evaluate the scientific claims of the various expert groups. (16)

Fensham's view would appear to be correct, provided that scientific literacy is conceived of in terms of individuals taking in and assimilating pieces of knowledge or developing supposedly specific scientific skills or methods. However, if scientific or biological literacy is thought of as an emergent property of a collective action driven by concerned citizens according to democratic procedures (Callon, Lascoumes & Barthe, 2001), things appear in quite a different light, as will be seen in the next section of this paper.

Lay expertise in action

Given that most of my colleagues do not read French, it is very unfortunate indeed that no translation has yet been made of the essay published by Callon and his colleagues on technical democracy as an invitation to act in an uncertain world. For, in my view, the authors have, with their call for an engagement of concerned citizens with scientists in “collaborative field research” (their term), presented an irresistibly compelling case for doing away with the cognitive deficit model of laypeople—a model that has, until now, informed even the most laudable efforts to rethink the role of citizens in solving sociotechnical problems and controversies. They make a masterful demonstration that laypeople—in the case they have studied, sick youngsters and their parents—can make a difference by participating in the very definition of the problems affecting them and becoming acquainted with the intricacies of scientific knowledges, otherwise deemed to be the province of specialists. Admittedly, a survey of laypeople would show that not everyone is on speaking terms with all the particulars, but that is actually quite beside the point, as this group of concerned people has nevertheless managed to accomplish a genuine feat. Not only did they succeed in drawing the attention of scientists to an orphan disease (spinal amyotrophy), but in the long run they also significantly influenced the development of the French research policy on genetics. The whole story is too long to be told in this short paper, but for the present purposes, I have included the following excerpt about a meeting chaired by one of the parents, named Alain. During this meeting, Alain made a technical presentation to other parents, patients, and scientists about the genes and proteins involved in this particular disease.

In his talk, Alain [a parent who lost two children] left no stone unturned: positional cloning, microsatellites, disease modelling strategies, drug-related hopes, etc. He then launched into a course on molecular biology, starting from the basics but focusing on the essentials with the aid of magnificent computer-generated diagrams.

“It is believed that there are approximately 100 000 genes,” said Alain.

“That was changed just last week; it is thought that there are 160 000 of them,” shouted a scientist in the audience.

“No! Apparently, there are 35 000,” retorted another scientist.

A murmur swept over the audience, dazzled by all these numbers.

Alain went on talking about the different types of child spinal amyotrophies, the history of trends in classification, the symptoms, the correlations between the disease and the general genetic characteristics. A short time later, he presented the most recent results, concluding this segment as follows:

“There are four different proteins and, therefore, four different forms of the disease.”

“Very interesting, I did not know that,” remarked another scientist.

Alan moved on from the description of the role of the protein in the cell to make a series of clarifications respecting the second stage in the maturation of messenger RNA. Since this proposition fits with the latest research results, he asked:

“Do we know anything more about this?”

“The model has changed a bit, but we are not really sure,” replied one researcher.

“Nevertheless, another function has been described by Fujimoto,” adds Alain.

“Would you like me to comment on that?” interjected another researcher. “It is completely untrue. Nobody has been able to replicate those results.”

“But they have been published in a very good journal!”

“These things will happen.”

The discussion continued among the scientists—those who work on muscles and those who work on motor neurons—about muscle/motor neuron interactions. We were plunged into a debate between specialists who were at the very centre of ongoing controversies and hesitations. The whole scene unfolded before parents and sick children. Persuaded that he would be able to make up his own mind on the subject, Alain listened closely throughout, allowing no information to slip by him, as shown by his interjection:

“I’m not sure I’ve really understood. Could you start your explanation over again?”

(108–109, my translation)

What more is there to be said, really? Through their involvement in such controversial situations, concerned laypeople and scientists enact *technobiological literacy* as an emergent property of their interactions. This is a point that can now be substantiated in light of recent research in Public Understanding of Science (Irwin & Wynne, 1996; Irwin, 2001); as evidence for this claim, please see the documented cases presented in the first appendix to this paper.

Educational strategies and citizenship education

The next question that comes to mind is whether it is possible for students to engage with such complicated situations and, in the process, familiarize themselves with the politics of the technosciences. According to many scholars in the field there are no reasons why this should not be the case (Aikenhead, 1996; Eisenhart, Finkel, & Marion, 1996; Fourez, 1997; Gough, 2001; Jenkins, 2002; Kolsto, 2001; Roth & Désautels, 2002; Weinstein, 2001). More so, some researchers have conducted field experiments that tend to show that students are quite capable of becoming involved in the politics of the technosciences at one level or another (Aikenhead, 1992; Désautels & Roth, 1999; Greenall Gough & Robottom, 1993; Laroche & Désautels, 1992; Roth & Lee, 2002; Simonneaux, 2001). The following nutshell description of a case study will serve as an illustration for this claim.

The students and their science teachers at the Queenscliff high school must have been quite happy when Tom Roper, then the Australian Minister for Planning and Environment, made it an obligation for their municipality to revamp its water treatment facilities. This decision put an end to a sociotechnical controversy in which they played an important role following an environmental educational project (Greenall Gough & Robottom, 1993). Central to the educational project of Queenscliff High School, associated with Deakin University, was the determination to empower the students to participate in improving the quality of democratic practice in their community. Inspired by a critical approach to education, the learning activities were designed as authentic occasions for the students to collectively develop intellectual instruments and potentials of action through participation in community life. The project consisted in examining the quality of the water along the ocean beaches, and provided the students (ages 15–17) and teachers with the opportunity to test the viability of this educational initiative.

This activity could become meaningful for the students who, like other members of this oceanside community, were well aware that the apparent cleanliness of the beaches had been

degrading. At the very least, they were aware the sea was washing up all kinds of things on the beaches (syringes, plastic bottles, condoms, etc.) even though the water treatment facilities were located offshore. The question of water safety and hygiene gradually emerged as a concern of the community, all the more so because pollution was beginning to jeopardize the economy of this summer resort. It was against this background that the decision was eventually made to closely examine water quality in the context of an environmental educational project specifically dealing with bacterial content.

In collaboration with their teachers, the students prepared a plan of action that included the following activities: recognizing and delimiting the problem, identifying the relevant knowledge and techniques, developing a sampling strategy, consulting experts, developing a protocol governing data analysis, etc. The first operation consisted in collecting water samples along the beaches. Then it was decided to solicit the cooperation of the people at the water treatment facility for some technical advice and consultations concerning water quality data.

To everyone's surprise, the administration of the water treatment facility refused to cooperate and the students were told to go back to their lessons and homework. But this did not prevent the project from continuing, and data was nevertheless analyzed under the supervision of the teachers. In order for this operation to succeed, the students obviously had to learn the established knowledges related to specific contents in biology and chemistry and assimilate relatively sophisticated laboratory techniques. That is why the teachers solicited the help of experts in the field to come and work with the students. After some months of hard work, the first findings came in. If one of them were true, it was bound to create a commotion in the community: the level of coliform bacteria was 40 times the accepted norm for safe bathing. How could this be possible?

Once again, the water facility people refused to cooperate, so it was decided to inform the general public about the potential dangers of bathing in the ocean waters. The news was published by the local paper, but rapidly spread through the other media, including television. In addition, other interest groups (surfers, health clinics, etc.) joined the movement initiated by the students and their teachers. Thus, political pressure steadily built up until the Minister decided to order the municipal authorities to take the appropriate action.

Over and above the spectacular character of this experience, it is worthwhile to ask questions about the type of learning that the students were probably able to accomplish. Like other students, they constructed scientific knowledges and assimilated different techniques, but quite possibly in a meaningful way. It is also likely that they produced authentic knowledge not figuring in their textbooks—with all the risks entailed by an endeavour of this kind. Indeed they had to produce results robust enough so that the technicians and scientists working at the water treatment facility could not contest their validity. In other words, they experienced, at least in part, what it means to produce scientific knowledges in context, rather than mimicking the activity of scientists within the framework of staged simulacra. The difference between these two situations is such that these students are bound to have developed a type of relationship to knowledges different from that which is usually held by high school students (Larochelle & Désautels, 2001). In the former situation, students know what to expect if they decide to participate in the “risky business” of the inescapably social production of scientific knowledges, whereas in the latter, students will go on idealizing and mystifying this activity. The Queensclift students also had the opportunity to collectively plan and carry out a complex activity and thus learn to collaborate with their peers, which is no small accomplishment. Moreover, they experienced the operation of social structures and the art of negotiating with other social actors. They might, for instance, have become conscious of the role of the media in those social structures, of the possibility of having some

political power, and thus, making a difference in the outcome of events. It is also possible that for some of them, learning will no longer be equated with a banal academic exercise for the sake of obtaining the grades necessary to move on to the next class, while waiting to be mature enough to exercise the rights and duties of full-fledged citizens in a democracy.

There are surely some reasons to doubt that a single learning experience was able to accomplish so much. However, by reporting this case study, my intention was simply to illustrate that it is possible to engage students in the politics of the technosciences, through their involvement in a sociotechnical controversy in their community. The other case studies presented in the second appendix to this paper also support this assertion. When conditions such as those described in these examples obtain, schooling can become an asset in enhancing the democratic life of our societies.

Epilogue

Initiating students into the politics of the technosciences no doubt requires a major change in the orientation of the school curriculum. However, in this epilogue, I will make do with setting out a few necessary conditions for such a transformation to happen.

First of all, our professional identities must be overhauled. Indeed, many of us constructed this identity in relation to the academic discipline in which we majored. However, we are not in the service of the interests of the scientific communities or the promotion of the technosciences. We are educators dedicated to the empowerment of our students so that they can become informed, critical citizens who are able to participate in enhancing the democratic life of their societies. Therefore, our knowledge of the technosciences must play an instrumental role in accomplishing this educational aim.

Second, we must remain aware that sociotechnical controversies are complex phenomena having aesthetic, ethical, moral, cultural, economic, political, technical, and epistemological dimensions. Thus, solutions cannot be developed within the confines of a traditional disciplinary or multidisciplinary approach, but rather through what Ardoino (1993) has called a multi-referential approach that multiplies the perspectives, including that offered by lay knowledge, available for framing and solving problems.

Finally, school activities should be integrated into the life of the community. This does not mean that the students should be running about neighbourhood streets all the time, but rather that they be given the opportunity to become significant actors who help catalyze the democratic life of the community.

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Appendix 1: Public Understanding of Science Cases

1. **Aids activists perform the politics of knowledge**
Steven Epstein, 'Impure Science; AIDS, activism, and the politics of knowledge' University of California Press USA 1996, ISBN 0-520-20233-3.
2. **The power of the patients: the case of an orphan disease [C'est le veritable titre en anglais?]**
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3. **The regulation of research in biotechnology: The Swiss referendum**
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7. **Sheep-breeders become doubtful about the value of scientific explanations:Sellafield is more than a step away from Chernobyl....!**
Irwin, A. and Wynne, B. (1996). *Misunderstanding Science?* New York: Cambridge University Press.
8. **Worried and angry citizens become well-informed epidemiologists, reconstruct the causal chain, and spot the toxic waste at the source of the abnormal rate of leukaemia in the community: the noxious and mortal effect of thrichlorethylene.**
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Appendix 2: Teaching strategies

1. **The STS (science, technology, and society) perspective: From the study of the breathalyzer.....to the integration of indigenous Amerindian knowledge in the curriculum and the school.**
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 Cross-Cultural Science & Technology Units (CCSTU) Project
http://capes.usask.ca/ccstu/main_menu.html

2. **Australian high school students put pressure on the Minister of the Environment: The municipal authorities have to invest money in water cleaning facilities.**
 Greenall Gough, A. and Robotom, I. (1993). Towards a socially critical environmental education: Water quality studies in a coastal school. *Journal of Curriculum Studies*, 25 (4), 301-316.

3. **Young, high school students present their research findings at city hall: Turbidity, fauna, and flora in a local stream.**
 Lee, S. & Roth, M-W. (in press) How ditch and drain become a healthy creek: Representations, translations, and agency during the re/design of a watershed. *Social Studies of Science*.

4. **About the idea of a "rationality island" a pedagogical strategy inspired by the social evaluation of technologies.**
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WHAT IS THE POSITION/CONTRIBUTION OF BIOLOGY IN ENVIRONMENTAL EDUCATION

Ian Robottom, PhD

Scientific and Developmental Studies, Deakin University (Geelong – Australia)

ian@deakin.edu.au

Abstract

In this paper I intend to argue that biological science education and environmental education have traditionally represented fundamentally different discourses - that they have explicitly or implicitly adopted different epistemologies and ontologies - and that this difference has had implications for the conduct of research in these fields. I will draw on recent developments in theory, policy and practice in the field of environmental education to argue that this field tends to be located within a social discourse - that there is a foundation in policy and practice for considering environmental issues as fundamentally social and ethical in nature, rather than in some sense objectively existing. I then consider a rising topic in biology education (that of Biotechnology) as one which while tending to be treated within a scientific discourse, would be more fully explored educationally within a social discourse. I conclude by suggesting that in biology education research we need to consider a reconciliation of these historically differing perspectives.

1. Introduction

Just as the environment is not a synonym for nature, social-environmental conflict is not the same as an environmental problem; an environmental crisis is not synonymous with ecological imbalance, and environmental education is not the same as teaching ecology (Layrargues 2002: 172).

One of the fundamental qualities of environmental education that has emerged is that issues related to the environment have economic, cultural, aesthetic, political and spiritual dimensions, as well as scientific and technological ones. This has been a particular challenge of any educator or those that plan the curriculum (Gayford 1998 p 102).

In this paper I intend to argue that biological science education and environmental education have traditionally represented fundamentally different discourses – that they have explicitly or implicitly adopted different epistemologies and ontologies – and that this difference has had implications for the conduct of research in these fields. I will draw on recent developments in theory, policy and practice in the fields of environmental education and in biology education (especially Biotechnology) to suggest that in research we need to consider a reconciliation of these historically differing perspectives.

2. Background: a perspective on environmental education

Historically, environmental education tended to be regarded as a step-child of science education. The people who became active in environmental education tended to have a scientific (or geographical) background. The editorial boards of journals in environmental education tended to have primary qualifications in science and science education. Environmental education-related correspondence arriving in schools tended to be passed on to biology teachers. This same phenomenon occurred at teacher training institutions. However, in some countries there has been an official shift in the positioning of environmental education in government policy. For example in Australia in the early 'nineties, the federal government developed a new national curriculum that positioned environmental education within social education rather than within science education. A new 'key learning area' titled Studies of Society and Environment that included environmental education was developed. This and other policy developments – including some of those emanating from important international conferences – have located environmental education within a social discourse rather than within, as formerly seemed to be the case, a scientific discourse. However, the consequence of this move is that science education is left without environmental concerns and hence without overt consideration of values – giving the impression perhaps that science is essentially value-free.

The subject matters of environmental education come to be constructed differently within a social discourse from the way they are in a scientific discourse. Environmental issues do not fundamentally consist of objectively existing facts that are more usually the concern of science and science education. If it is recognised that environmental issues actually consist of differences of opinion among human beings about the appropriateness of certain environmental actions, then

it can be seen that environmental issues are best understood within a social discourse rather than a scientific discourse.

Similarly, in terms of pedagogy in environmental education, learning is seen within a social discourse in constructivist terms, as the human (individual and social) construction of the meaning of environmental issues, rather than the reception of transmitted facts about the environment. One of the implications of this is that an appropriate starting point in environmental education is the feelings and perceived problems and issues of individuals and their contexts, rather than a search for common, generalisable content as is the case often in education conducted within a scientific discourse.

The sought-for outcome of environmental education within a social discourse is an improved (more complex and sophisticated) understanding of debates about environmental issues rather than the acquisition of knowledge gained towards certain agreed objectives. The former, I would argue, has a greater capacity for social change towards environmental improvement than the latter, which tends to assume rather than challenge existing structures and relationships in social life.

So, what are the implications of this for biology teaching, and for research in the didactics of biology? In light of newer developments in biology education such as Biotechnology, can the differences in pedagogy and research between biology teaching and environmental education be sustained? What is the position of environmental education vis-a-vis biology education? I intend now to consider some perspectives from the policy and project practice of environmental education and from the topic of Biotechnology to reflect on these questions.

3. The nature of the subject matters of environmental education

My intention is to address this question from the starting point of the subject matters of environmental education, and to do so by drawing upon the 'authorities' of policy and practical project experience in community-based environmental action programs.

3.1- From policy...

Statements emerging from the International NGO Forum at Rio de Janeiro, Brazil, in June 1992 (The NGOs Working Group on the Treaty on Environmental Education for Sustainable Societies and Global Responsibility) (NGO, 1992) produced a strong social agenda for environmental education, recommending inter alia that:

- 2 Environmental education ... should be grounded in critical and innovative thinking in any place or time, promoting the transformation and reconstruction of society.
- 3 Environmental education is both individual and collective. It aims to develop local and global citizenship with respect for self-determination and the sovereignty of nations.
- 4 Environmental education is not neutral but is values based. It is an act for social transformation.
- 5 Environmental education must involve a holistic approach and thus an interdisciplinary focus in relation between human beings, nature and the universe.

...

7 Environmental education should treat critical global issues, their causes and interrelationships in a systemic approach with their social and historical contexts. Fundamental issues in relation to development and environment, such as population, health, peace, human rights, democracy, hunger, degradation of flora and fauna, should be perceived in this manner.

...

10 Environmental education should empower all peoples and promote opportunities for grassroots democratic change and participation. This means that communities must regain control of their own destiny.

11 Environmental education values all forms of knowledge. Knowledge is diverse, cumulative and socially produced and should not be patented or monopolized.

...

13 Environmental education must stimulate dialogue and cooperation among individuals and institutions in order to create new lifestyles which are based on meeting everyone's basic needs, regardless of ethnic, gender, age, religious, class, physical or mental differences.

Recognition of the role of human values and an interest in social transformation are clearly evident in the above statements.

In Australia, national and state-level statements and curriculum profiles have been developed for each of the following 'key learning areas': the Arts, English, Health and Physical Education, Languages other than English, Mathematics, Science, Technology, and Studies of Society and Environment. Although the interdisciplinary nature of environmental education was recognised in the development of all eight areas, the last statement is the one most identifiably concerned with environmental education. Unlike many environmental discourses, Studies of Society and Environment does not ascribe primacy to science as the ultimate referent in the resolution of environmental issues. It is explicit in recognising the proper role that values play in environmental issues. For example, the National Statement on Studies of Society and Environment has this to say on 'the place of values' (AEC, 1993).

Values play a part in studies of society and environment in three important ways.

First, they are an object of study. When students consider people and their actions within societies and environments, they investigate and analyse the values and beliefs that influence them. As social and environmental participants themselves, students learn to subject their own values and actions to careful scrutiny ...

Second, values influence what is selected for study. No curriculum is value-free or value-neutral and so, because of the diversity and changing nature of values held by Australians, it is important to identify areas of agreement on what values should influence studies in this learning area ...

Third, certain values are a result of study. Through their studies of society and environment, students come to value diversity in viewpoints, curiosity and questioning, thorough and balanced investigations, logically developed and well-corroborated argument and justification ...

It was in my view a crucial development to locate environmental education within a social discourse, rather than within a scientific discourse, which was historically the tendency in Australia and elsewhere. In addition, the perspective on values advanced by this national policy resonates strongly with the position on values underpinning the UNCED statement cited above.

At the level of provincial or state government in Australia, the Victorian Ministry of Education's (1990) Environmental Education Policy (MOE, 1990) offers further support for a kind of environmental education work that explores real environmental issues, recognises values and is socially critical in perspective, suggesting that curriculum approaches to environmental education should have the following characteristics:

- they should be based on real problems;
- they should clarify values;
- they should make use of both ecological and interdisciplinary skills and concepts;
- they should be socially critical;
- they should be action orientated;
- they should encourage the development of a sustainable environment;
- they should involve students working together in groups (p. 83).

These selective examples of policy in environmental education (drawn from international, national and provincial levels), in advocating a recognition and exploration of the roles played by personal and cultural values in constructing local environmental issues and problems, indicate some of the features of environmental education content matter.

Other developments in the literature of environmental education bear directly on the relationship of (biological) science and environmental education, and further expand on the particular features of this field.

The need for teacher understanding of the nature of science for effective science teaching is generally accepted. There is also a need for an understanding of the relationship between science and environmental education which draws on science to support knowledge of the causes of environmental problems, as well as the complexity of ecological systems Littleddyke 1997 p. 641

Historically, and perhaps this is still the case, science was seen as the most competent discipline for dealing with environmental problems. Littleddyke suggested in 1997 that

Teachers who agreed most strongly with the claim that science is about facts, is a way of finding truths and is free of values ... tended to hold the view that science is the main means of solving environmental problems (Littleddyke, 1997)

Gayford suggests a possible reason for this:

It is likely that because environmental education has had its roots in curriculum subjects like science and geography, the links have remained firm between environmental education and knowledge and understanding of the natural environment, particularly ecology... (Gayford, 1998)

However there is growing support in the literature for the view that environmental education is about the educative exploration of environmental issues, and that these environmental issues are necessarily value-laden, and perhaps more social than scientific in character. These perspectives suggest that environmental education is not a case of ecology education, neither in relation to substantive content matter nor as a procedure:

Just as the environment is not a synonym for nature, social-environmental conflict is not the same as an environmental problem; an environmental crisis is not synonymous with ecological imbalance, and environmental education is not the same as teaching ecology (Layrargues, 2000) (my emphasis).

Environmental problems are being perceived in much more multi-disciplinary ways:

One of the fundamental qualities of environmental education that has emerged is that issues related to the environment have economic, cultural, aesthetic, political and spiritual dimensions, as well as scientific and technological ones. This has been a particular challenge to any educator or those that plan the curriculum (Gayford, 1998)

The social nature of environmental problems – not just in terms of a social context, but in terms of being socially constructed – is quite strongly advanced:

The environment is what surrounds us, materially and socially. We define it as such by use of our own individual and culturally imposed interpretive categories, and it exists as the environment at the moment we name it and imbue it with meaning. Therefore, the environment is not something that has a reality totally outside or separate from ourselves and our social milieux. Rather it should be understood as the conceptual interactions between our physical surroundings and the social, political and economic forces that organise us in the context of these surroundings. And if we view the environment as a social construct then we accept that certain qualities of it can be transformed according to whichever social relationships are in operation.

If we view the environment as a social construct, we can also view the "environmental problem" very differently ... Environmental problems are ... social problems, caused by societal practices and structures, and only viewed or socially constructed as problems because of their effects on human individuals and groups (of course other living things and systems are also affected) (Di Chiro, 1987).

.. awareness of environmental problems is social awareness rather than ecological awareness. Such problems will be solved through collective action aimed at eradicating the social and economic causes of the degradation of the human environment (Vidart, 1978).

The Tbilisi document goes beyond older conceptions of educational practice by linking environmental questions to political, economic, social and cultural elements within a given system rather than restricting them to their biological aspects... (Layrargues, 2000)

Barkin, commenting on the essentially contested nature of environment development projects, stresses the need for local participation and control in determining the direction taken by the projects in question. He also makes the important point of the need to adopt a politicised perspective – one in which the role of the relatively more powerful ‘elite’ is understood and questioned as local groups determine their own futures. Barkin makes a telling point about the need for reorganising political and economic power structures and relationships in contexts seeking solutions to their social, economic and environmental interests. In such contexts he states that the strategy “...must focus on the importance of local participation and control over the way in which people live and work”. Barkin goes on to say that for such an approach to work, it requires that the elites become aware of the need to integrate people into real power structures in order to confront the major problems of the day; this entails a redistribution of both political and economic power, a fundamental prerequisite for any program (Barkin, 2000)

So there is significant support from both governmental/intergovernmental policies and from the academic literature for the proposition that environmental issues or problems are social rather than solely or even mainly scientific in nature. Furthermore, there are arguments that as a consequence, environmental education needs to take a participatory, politicised approach to its work.

But words are cheap, and practice more difficult. The next section draws on some recent project research in environmental action programs to describe in more practical detail what this might actually mean in real situations.

3.2- From project practice...

In this section I will draw on recent projects currently taking place in western Scotland. I intend to describe something of the everyday circumstances and practice of this project, in a way that I hope is consistent with the principle of reflective action – of relating theoretical perspectives to practical experience.

3.2.1- CADISPA Project in Scotland: Cooperation and Development in Sparsely Populated Areas (see Robottom, 2003)

The CADISPA project is based in the Department of Community Education in the Faculty of Education at the University of Strathclyde in Glasgow, Scotland. The project is currently coordinated by Geoff Fagan (CADISPA, 2001) of the Department of Community Education.

Stated aims and principles of CADISPA

According to a recent (December 2001) brochure on the CADISPA project, CADISPA is concerned with developing a definition of sustainability that will be of help to local people and to the economic community. The emphasis on participation and localness is clear, and is echoed in the following statements:

For CADISPA, all economic and social regeneration must stem from within a framework of sustainable economic, environmental and social factors.

CADISPA builds social capital by non-formal education, active engagement and local decision making.

CADISPA uses standard community development techniques to enable people in individual communities to own, understand, and act upon their own preferred sustainable agenda (CADISPA, 2001).

The aim behind the CADISPA model is to help local people identify their development needs and support them whilst they both pursue their collective agenda and form the partnerships with the Economic Development Agencies and the local authorities (Hampson & Fagan, 1997).

CADISPA builds rural partnership groups by seeking agreed entry into local communities and working always with existing community groups, describes and publishes with them a development agenda for their locality. CADISPA starts with local people and their vision of the future – gradually building the picture and extending the consultation and partnership base until each feels confident with both the potential development, but also with its appropriateness, extent, cost and cultural ambience (Hampson & Fagan, 1997).

There is a clear participatory, power sharing interest expressed in the comment that “people are central to the identification and prioritisation of their own local agenda. It is they who prioritise and decide on their own local development”. Thus CADISPA is linked with (draws from and potentially makes a contribution to) the enduring environmental education discourses of community, environmental issues, and participatory approaches, and to the literature that critically appraises these discourses.

The role adopted by CADISPA staff is facilitatory – it lies in identifying project opportunities, establishing links among community groups and support agencies and funding bodies of various kinds, in setting up Articles of Association and companies limited by guarantee to provide a measure of legal protection to the community groups, and in supplying a positive and supportive spirit to the work of projects that are always complex and often problematic. CADISPA staff attend many community group planning meetings, though their role is generally low key and responsive rather than highly visible and directive. Through the capacity-building support of CADISPA, community groups are encouraged to ‘make a statement’ that is sustainable and lasting; this ‘statement’ is often on the form of a community edifice of some kind that owing to its bricks and mortar characteristics, has both immediate functional and lasting iconic value in communities. The CADISPA project team work with the communities in developing a series of case study reports describing the natural and social history of the community, its current structure, and social, economic and environmental issues. There is an iterative process by which these case study reports are ‘fed back’ to the community committees. Further details on the CADISPA project may be found in publications and reports presenting a number of case studies of CADISPA community eco-developments and drawing on these case studies to reflect on educational issues in pedagogy and research (Robottom, 2002), (Robottom, 2003).

4. What can we learn from project research such as this about the nature of environmental issues?

We all relate to the environment (however we construct it) in certain ways. We are all affected whenever our environment is changed. When there are proposals for changing the environment, there are nearly always differences of opinion about if and how the environment we relate to ought to be changed. When there are differences of opinions concerning environment change proposals, we have an 'environmental issue' of some kind. The educative exploration of such environmental issues is an important part of an education aiming at an improved understanding of our relationships with the environment (Alblas, van den Bor, & Wals, 1994; Aleixandre & Gayoso, 1996; Boschhuizen & Brinkman, 1995; Dove, 1996; Harris & Robottom, 1997; House, Eide, & Kelly-Laine, 1994; Izadi & Kurtakko, 1994).

It is clear from the CADISPA project that environmental issues (which tend to be the subject matters of at least some approaches to environmental education) share certain characteristics. I propose that in order to make sound deliberative choices about environmental education curriculum development, professional development and research, we need to be reflective about the nature of these environmental issues -- to treat environmental issues like these as the starting point in curriculum deliberation in environmental education (Robottom, 1996). Projects like CADISPA can potentially illuminate such deliberations (Robottom, 2003).

These projects show that the environmental issues, about which we attempt to be educative in our chosen field, are complex and contextual, contentious and difficult, and politically and socially constructed. This does not mean that they are to be avoided as in some sense inappropriate subject matters for environmental education; however it might mean that a curriculum seeking to simply transfer knowledge and skills as commodities to be learned might be an inappropriate medium for this kind of subject matter. Environmental issues are not matters of transferable knowledge and skills; rather they are personal and social constructions which are intelligible within complex contexts, and they possess the following features:

- they are complex in their structure;
- they are contextual in the way they express themselves;
- they involve a wide range of stakeholders;
- these stakeholders express a wide range of values and interests;
- a politicised perspective is a necessary component in their resolution;
- their resolution requires negotiation and reconciliation, and these are usually difficult processes;
- the process of their resolution is a function of social, cultural, political and environmental elements, and is often a case of 'cultural survival'; and
- above all, environmental issues are socially constructed and need to be recognised and treated as such.

That is to say, for a form of environmental education attempting to be educative about environmental issues, it is important to recognise that the subject matters do not exist subjectively, as factual material to be transmitted, but instead are human constructions to be

explored, with underpinning social and economic interests and that all need to be critically assessed (Robottom, 2003).

In this sense, the subject matters of environmental education are qualitatively different from those of some other disciplines. I used to think that the subject matters of environmental education may be closer in character to those of health education and peace education than those, for example, of science education (Robottom, 1983) – now, in the light of the recent rise of interest in Biotechnology as a topic of biology education, I am not sure.

5. Biotechnology as a subject matter in biology education

Just as we have looked at a practical example of a project concerned with environmental issues with a view to gaining a perspective on the nature of such issues as subject matters in environmental education, I'd like now to look at some instances of Biotechnology topics as potential subject matters of biology education.

5.1- Example 1: University of New South Wales (Australia)

Website: <http://www.biotech.unsw.edu.au/what.htm>

What is Biotechnology?

Biotechnology is an applied science, aimed at harnessing the natural biological capabilities of microbial, plant and animal cells for the benefit of people. Biotechnology couples scientific and engineering principles with considerations to develop and improve products and processes made from living systems.

Biotechnology is part of our daily lives. It is used in making foods we eat, the medicines we take, and the plants we grow. It is used in caring for the environment. It solves problems in places as diverse as high-technology pharmaceutical facilities and the laundry room at home.

Since the discovery of the structure of DNA, huge leaps have been made in understanding the mechanisms of cell function, metabolism, replication and product formation. Scientific advances in genetic engineering and molecular biology continue at a rapid pace. These advances develop opportunities for creating new industrial production systems based on living cells and cell components....

The elements of this message suggest that Biotechnology is an applied science. The descriptions use the language of biology, stress scientific and engineering principles in problem-solving, and place its activities within an applied science discourse that is objectivist, realist, and abidingly positive (positivist?). There is no mention of any pressing philosophical problems that might be entailed by developments in Biotechnology.

5.2- Example 2: Biotechnology Australia – A Commonwealth Government Initiative.

Website:

http://www.biotechnology.gov.au/Community_Issues/Fact_Sheets/what_is_biotechnology.asp

What is Biotechnology?

Biotechnology is a broad term covering the use of biological discoveries for the development of industrial processes and the production of useful organisms and their products. Uses include the production of foods and medicines, the reduction of wastes and the creation of renewable energy sources.

Traditional Uses of Biotechnology

Biotechnology, in the form of traditional fermentation techniques, has been used for decades to make bread, cheese and beer. It has also been the basis of traditional animal and plant breeding techniques, such as hybridisation and the selection of plants and animals with specific characteristics to create, for example, crops which produce higher yields of grain.

Modern Biotechnology

What is new about biotechnology today is that researchers can now take a single gene from a plant or animal cell and insert it in another plant or animal cell to give it a desired characteristic, such as plants that repel specific and targeted insect pests. An example of this is Bt cotton, which has been grown in Australia for several years.

Frequently asked questions

This fact sheet aims to provide answers to some of the more common questions asked by members of the community about biotechnology and gene technology. More detailed information on these topics may be obtained from fact sheets that concentrate on specific issues.

Issues covered by this fact sheet are:

1. Are genetically modified (GM) foods safe?
2. Can genetically modified foods cause allergies in some people?
3. Can genetically modified organisms escape into the environment?
4. Who is responsible for regulating GMOs and GM products in Australia?
5. What is the approval process that food companies or agribusiness firms must follow to get GM food products onto the market?
6. Are companies subject to any penalties if they break rules governing GMOs?
7. Doesn't the fact that genetically modified crops are owned multinationals mean that international agribusiness companies will control Australian farmers?
8. Are the characteristics placed in a genetically modified plant, e.g. soy beans, passed onto the next generation of soy bean plants? Put another way, do genetically modified plants pass on that trait in reproduction?

9. Is it possible to place animal genes in plants and vice versa?
10. Is this occurring?

This site at least admits to some problematics within this new topic, posing some interesting 'frequently asked' questions about Biotechnology. But most if not all of these questions suggest dichotomous (yes/no) answers rather than manifold, contested responses, and are of empirical rather than philosophical/ethical character. There is an obvious absence of philosophical and ethical questions such as:

"Should we genetically modify food?"

"Ought scientists be 'tinkering with nature'?"

"To what extent is monetary profit a factor driving these developments?"

"What human vested interests and social values lie beneath the rush towards Biotechnology?"

5.3- Example 3: Gene-Altered Babies Born in USA

http://news.bbc.co.uk/1/hi/english/sci/tech/newsid_1312000/1312708.stm

Friday, 4 May, 2001, 15:26 GMT 16:26 UK BBC online

Website: <http://www.organicconsumers.org/patent/gebabies.cfm>

Genetically altered babies born

By BBC News Online science editor Dr David Whitehouse

Scientists have confirmed that the first genetically altered humans have been born and are healthy. Up to 30 such children have been born, 15 of them as a result of one experimental programme at a US laboratory. An "unwelcome" development say scientists. But the technique has been criticised as unethical by some scientists and would be illegal in many countries, including the United Kingdom. Genetic fingerprint tests on two one-year-old children confirm that they contain a small quantity of additional genes not inherited from either parent. The additional genes were taken from a healthy donor and used to overcome their mother's infertility problems.

Even in this most extreme example of Biotechnology, we see only a minor reference to the deep philosophical and ethical issues associated with the development. The account is tendered within an applied-science discourse, and the obvious ethical considerations are almost dismissed in the comment that "the technique has been criticised as unethical by some scientists..."

In light of developments in the field of environmental education, an issue for me is that these developments in Biotechnology, if constructed within a scientific discourse, may fail to engage seriously the philosophical issues that the developments pose, and which might be seriously engaged if the developments were constructed within a social discourse. There is an avoidance of the fact that Biotechnology topics and their associated philosophical issues are socially-constructed rather than objectively existing – that they are issues that essentially consist in differences of subjective opinion among different people who construct the meaning and significance of these Biotechnology issues in different ways with different interests being served. They seem to be presented as if they have an independent, objective existence. In light of

developments in the field of environmental education, I would argue that a better understanding of these Biotechnology topics is less likely to be gained through treating them in an objective, factual 'scientific' manner than through exploring them 'socially' as essentially contested human and social constructions (Roth & Desautels, 2002) (Bader, 2001).

6. A summary of differing orientations in environmental education and science education

So far in this paper I have considered some policies and practices in environmental education in order to illuminate the character of environmental issues as a common subject matter in environmental education. I have argued that biological science is a necessary but insufficient consideration in seeking to understand environmental issues. As a way of raising further issues about biology education in relation to environmental education, I have provided some examples of perspectives on Biotechnology as a subject matter in science education. I have argued that while in environmental education, there is policy-based justification for environmental issues to be presented as if they are complex, contested, contextual and socially constructed, in biology education there is the danger that Biotechnology topics, despite seemingly sharing certain features in common with environmental issues, are constructed and presented educationally within a scientific rather than a social discourse/ conceptual frame. I would summarise these differences as follows (while acknowledging the often false dichotomies that such tabulations may promote):

Field	Representative concepts	Ontology	Epistemology	Ideology	Learning Theory
Environmental Education	Environmental issues; Sustainability	Mainly constructivist	Mainly subjectivist	Consciously addresses philosophical questions	Social constructivism as a theory of understanding both subject matter and learning
Biology Education:	Biotechnology; Ecosystem concept	Mainly realist	Mainly objectivist	Largely un-selfconscious about philosophical questions	Constructivism as a learning theory, not a subject matter theory

7. What are the Implications for Research?

I'd like now to consider some possible implications of these considerations for research in biology education. I'd like to do this by reflecting on the response of research to a similar situation when it arose in the field of environmental education. In terms of professional development, and the research base informing professional development activity, it was when environmental education was perceived as being located with a social discourse, rather than a scientific discourse, that an argument for approaches like participatory action research as an

alternative to applied-science research designs for professional development was the more strongly made. Participatory research, as reflective inquiry into practice and circumstance with an interest in improving equity and justice of social life, proceeds through opportunities to explore the kind of problematique (the philosophical questions) that environmental education within a social discourse presents. I would argue that the same applies in the case of curriculum seeking to be educative about Biotechnology topics.

So, if Biotechnology issues are socially constructed as I have argued, what are the implications of this for research in the didactics of biology (Jenkins, 2001)? What forms of research are epistemologically, ontologically, ideologically and practically coherent with this perception of Biotechnology issues? This is a difficult question to address within the scope of this paper, and I will restrict myself here to three propositions that I believe are congruent with the considerations advanced here and leave a further explication of research issues to discussions which I hope will ensue:

- to say that concepts like ‘environment’, ‘ecosystem’, ‘environmental issue’ and ‘Biotechnology’ are socially constructed is to say that their particular constructions are functions of particular subjective human values and interests. Appropriate forms of research may need to be capable of engaging, rather than denying and marginalizing, the subjective human values and interests that have historically shaped, constrained and defined particular social constructions of biological topics like Biotechnology. An interest in interpretive categories and subjective meaning is crucial.
- because the way that concepts like ‘environment’, ‘ecosystem’, ‘environmental issue’ and ‘Biotechnology’ are socially constructed is a function of particular values and interests, for research to be productive and practically useful (to ‘generate new knowledge and make this public’), research in biological education may need to engage networks of research participants in the process of critically appraising and explicating the ways in which particular constructions of biological topics like Biotechnology come to be shaped, constrained and defined by particular subjective human interests. In an example provided by Uzzell, “the object of environmental education should not be, for example, to understand the chemico-biological causes of stream pollution but the clash of interests in society which regards the polluted stream as a problem” (Uzzell, 1999).
- as a consequence, perhaps one of the purposes of research in biology education can be described as: “through a process of identifying, gathering and marshalling information and perspectives, to create the conditions for a critical debate about how Biotechnology topics come to be constructed in the way they are in different contexts of time and space”. This is an approach being addressed effectively by such authors as Laurence Simonneaux (Simonneaux, 2001), who explores the use of role-play and debate as appropriate pedagogical approaches for the teaching of Biotechnology topics.

These principles, while indicating a broad positioning of research in Biotechnology, still leave unaddressed a number of procedural issues about how such an approach to research can be operationalised in particular settings. This is a methodological – and pedagogical – issue which

continues to require attention from researchers in the didactics of biology and from biology educators.

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TEACHING BIOLOGY

INTERACTIVE ANIMATIONS AND UNDERSTANDING OF BIOLOGICAL PROCESSES: AN EMPIRICAL INVESTIGATION ON THE EFFECTIVENESS OF COMPUTER-ASSISTED LEARNING ENVIRONMENTS IN BIOLOGY INSTRUCTION

Claudia Nerdel, Helmut Prechtel, and Horst Bayrhuber

IPN • Leibniz-Institute of Science Education (Kiel - Germany)

nerdel@ipn.uni-kiel.de, prechtel@ipn.uni-kiel.de, bayrhuber@ipn.uni-kiel.de

Abstract

In this empirical investigation the effects of computer-assisted interactive animations on the understanding of complex biological processes are examined from a cognitive psychological point of view.

Different learning environments were used to demonstrate dynamic processes on biological membranes: The experimental design consisted of four different groups working with still images, animations, interactive animations, or interactive animations with additional help, respectively. Subjects were 11th-graders of German Secondary Schools. Before the treatment students' prior knowledge of the biological topic was registered. After the treatment students' increase of knowledge was tested, particularly knowledge of biological facts and deeper understanding of processes at the biological membrane, as well as their cognitive load. This paper focuses on one study in a series of four. The biological topics of the learning environment of this study were the primary reactions of photosynthesis at the thylacoid membrane of chloroplasts.

Data were examined by analysis of variance as well as by latent class analysis. Selected results of the treatment comparisons are reported. Of the four experimental groups the one working with interactive animations showed the best learning success. Effects are further analysed considering the interactions of treatments, prior knowledge and learning success.

1. Introduction

Biological phenomena are characterized by complexity and dynamics. In biological instruction, students have to acquire knowledge about structures, processes and causal relations within complex systems, in order to understand scientific concepts characterizing these phenomena. In this regard, biological topics are exemplary for other natural sciences. An example for complex and dynamic concepts is the biological membrane, which is basic to many biological processes, e.g. metabolism and information processing. Fostering students' acquisition of knowledge about such basic concepts is a major challenge to biological instruction in schools.

One means to cope with this challenge comes from learning technology. Modern educational technology offers the opportunity to visualize dynamic processes by use of computer-based animations to help learners building up adequate mental representations of dynamic systems. Furthermore, interactive animations – usually called simulations – invite learners to investigate actively causal relations within complex systems. Thus, simulations foster self-regulated learning styles which are assumed to be highly effective for motivation and understanding. However, simulations impose a high cognitive demand on the learner, especially on those with less prior knowledge, as they have to choose parameters and to process totally new information at the same time. To prevent these learners from cognitive overload in complex learning environments such as simulations it is necessary to provide them with specific instructional support. So prior knowledge is a learner specific feature that thoroughly should be taken in to account in computer-based learning situations.

In this study, the effects of computer-based animations and simulations on the understanding of complex biological processes taking place at the biomembrane were examined. Accordingly, 11th-graders of German Secondary Schools learned about this topic with different versions of a computer-based learning environment and different kinds of instructional support. The major focus of the study was on the relation between learners' prior knowledge, their cognitive load, and the computer based learning environment. Special attention was paid to the importance of instructional aids aiming to support learning with simulations. Variance analysis as well as latent class analysis of data revealed a complex pattern of interaction of prior knowledge as an individual learner feature with the characteristics of the multimedia learning environment.

2. Theoretical Background

2.1. Learning with text, pictures and computer-based animations

Various studies based on Mayer's "Generative theory of multimedia learning" seem to show, that the combination of text and pictures or animations promote comprehension and problem-solving transfer (Lewalter, 1997b; Mayer, 1997; Plass, Chun, Mayer, & Leutner, 1998). Mayer's theoretical framework has derived from the "Dual coding theory" of Paivio (Clark & Paivio, 1991; Paivio, 1978). According to these theories there are two ways of information processing and hence two kinds of mental representation in the cognitive system. In the verbal system information of a sequential structure like written texts or spoken words are processed. In the non-verbal system spatial information and pictures are processed. A major assumption is that connecting these two cognitive representations in a proper way should improve learning results. There is empirical evidence that this can be achieved at best by combining coherent pieces of pictorial and textual information in the learning material (Mayer, 1997).

In modern educational technology dynamic processes are usually visualized by animations, instead of still images. Animations are supposed to help learners to imagine processes properly and thus to be able to build up adequate mental representations of causal relations within an investigated system. The advantage of animations in comparison to still images is attributed to the complete representation of a movement or any kind of spatiotemporal change. The unequivocal representation of a dynamic process helps to avoid misinterpretations of movement indicators used in still images, e.g. arrows, by the learner. Additionally, the external simulation of a movement by an animation is supposed to ease the working memory load in favour of cognitive processes beneficial for comprehension, e.g. control of understanding (Lewalter, 1997b; Rieber, 1991; Salomon, 1979). Limitations to these supposedly beneficial effects of animations arise from individual learner features, with domain specific knowledge being one of the most important.

2.2. Domain specific knowledge and computer based learning

Empirical findings point to the fact that animations encourage better understanding for learners with less prior knowledge (Lewalter, 1997b; Mayer, 1997). For learners with more domain specific knowledge the superiority of animations diminishes. This could be due to the fact that in their cognitive system proper mental representations of the shown processes already exist. For these individuals a textual piece of information together with a still image will do, even more, a very explicit external dynamic representation might interfere with the integration of new information into an existing mental model.

2.3. Learning with computer-based interactive animations

Another type of animation are interactive animations which are usually called simulations. Simulations invite learners to manipulate and explore a system by means of parameter choice. Thus they are enabled to investigate actively causal relations within a complex and dynamic system. Interactive animations of this kind foster active and self-regulated learning behavior, which is considered as highly advantageous for motivation and for acquiring a deeper understanding in complex domains (de Jong & Njoo, 1992; Euler, 1994; Haack, 1995; Leutner, 1993; Schnotz, Bockheler, & Grzondziel, 1999). Yet, elements of interactivity in a computer-based learning environment are not only advantageous for the learning process, but can also impose additional cognitive load on the learner and thereby deteriorate learning outcome (de Jong & Njoo, 1992; Schnotz et al., 1999). According to Sweller's cognitive load theory (Sweller, van Merriënboer, & Paas, 1998) in a learning situation the limited capacity of the working memory is affected by two factors: The nature of the learning material and the instructional interventions. If instruction is poorly designed, it requires additional cognitive action of the student without eliciting adequate learning processes. On the contrary, any additional mental effort caused by appropriate instructional interventions should help learners to build up mental representations without exceeding working memory capacity.

This led us to the assumption, that specific instructional aids can prevent learners from cognitive overload in interactive learning environments and thus sustain the benefits of interactivity. Instructional aids comprise special tasks referring to the learning material (Dean & Kulhavy, 1981; Peeck, 1993, 1994; Weidenmann, 1988), tutorial advice how to handle a simulation successfully, as well as additional information about the topic, making basic concepts explicit which are implicitly given in the simulation (Leutner, 1993). Above all, learners with less prior knowledge should profit from additional instructional support, because their cognitive system presumably suffers higher vulnerability to cognitive overload, having to cope with the manipulation of all the elements in a simulation and with the processing of new information. So domain specific knowledge seems to be of major importance for computer-based learning, too. Considering all these findings, a major task of research on

multimedia learning is to analyze interactions of learner specific features on the one hand with those of computer-based learning environments on the other. One important focus should lie on instructional aids providing optimal support for learners in computer-based environments with regard to their domain specific knowledge.

3. Objectives of the Study, research design and methods

This study is designed to investigate, if animations and interactive animations are suited to foster understanding of complex biological processes and what kind of instructional aids can support learners in a computer-based learning situation.

3.1. Topics of computer-based instruction

In the computer-based learning environments of the study, dynamic processes and causal relationships at biological membranes were presented to the students. The whole study consisted of four parts: biological membranes in general, inner membrane of mitochondria, thylakoides of chloroplasts and nerve cell membrane. This sequence aimed to foster a deeper understanding of the concept of the biomembrane. The main focus was on the causal connection of energy transfer and transport mechanisms at these membranes. To distinguish the different examples of membranes their structural and functional features were represented in detail. This paper focusses on the third part of the whole study that had photosynthesis as biological topic.

3.2. Hypotheses

The general assumption is that animations are well suited to adequately represent any kind of dynamic processes. So the question is, if animations are superior to still images for the representation of biological processes, too. Therefore, our first hypothesis reads as follows:

Hypothesis 1:

Animations are better than still images for the understanding of biological processes.

A further assumption is that a certain kind of interactive animation, namely simulations with parameter choice, is able to invite learners actively to explore causal relations in a simulated dynamic system by manipulating several variables. This is assumed to help learners to get a deeper understanding of the processes within this system to a greater extent than passively watching an animation running in a fixed sequence.

Hypothesis 2:

Interactive animations (with choice of parameters) foster more than simple animations a deeper understanding of biological processes.

Elements of interactivity in a computer-based learning environment are not only advantageous for the learning process, but can also impose additional cognitive load on the learner and thereby deteriorate learning outcome. This leads to the assumption, that specific instructional aids (tasks, questions, notes for the correct working order, additional information about the topic) can prevent learners from cognitive overload. Learners with less prior knowledge should profit the most from these instructional measures.

Hypothesis 3:

Instructional aids (tasks, questions, notes for the correct working order, additional information about the topic) reduce cognitive load and foster understanding in learning environments with interactive animations (simulations with choice of parameters), in particular for subjects with low prior knowledge.

3.3. Research design of the study, part 3: “Primary reactions of photosynthesis”

The research design comprised five experimental groups, each working with a different kind of computer-based learning environment. The first group worked with *still images*. In this version of the learning environment arrows in still pictures illustrated motions at the thylakoide membrane. Subjects additionally had access to text explanations for the pictures. In accordance with the theories of dual coding and multimedia learning every piece of textual information was closely related to the information given in the associated picture. The second group worked with a computer program called *animation*. Its structure was identical with the still images version in all points but one: in this version every motion of the actors at the membrane was animated. Text explanations for the illustrated processes could be accessed as in the version with still images.

Futhermore, there were three kinds of simulations. They were all interactive animations with adjustable parameters. The difference between the versions was the amount of instructional aids. In *simulation 1* only tasks and questions were included. Tasks were intended to give learners a clear learning target. In addition tasks included hints to guide the learners' attention to essential aspects of the simulation. Questions served as starting points for a feedback process that ideally invited learners to control their learning success in a self-directed way. These means were assumed as the indispensable minimum of instructional aids. Thus it was the same for all simulations. In *simulation 2* subjects were, in addition, provided with notes for the correct working order of the simulation. Finally, *simulation 3* contained additional information about the topic “primary reactions of the photosynthesis” on top of the instructional aids from *simulation 2*. This additional information made the information implicitly given in the simulation explicit to the students. All instructional aids aimed to reduce cognitive load and to foster comprehension.

Subjects of the study were 11th-graders of German Secondary Schools, six classes of biology at Gymnasia (grammar schools) and four classes of biology at comprehensive schools, each with 10 to 25 students. All together 150 persons participated in this part of the study. Lot assigned the treatments. Table 1 gives an overview about occupation of the treatments.

Table 1. Sample for each treatment of the study “Primary reactions of photosynthesis”

Treatment	N
Still images	30
Animation	30
Simulation 1 (with minimal instructional help)	33
Simulation 2 (with additional instructional help)	30
Simulation 3 (with additional instructional help)	27
Total	150

3.4. Methods of data collection

In a pre-test at the beginning of the learning session subjects' prior knowledge on the topic “The primary reactions of photosynthesis” was tested. The items of the test were created to examine both, factual knowledge and deeper understanding of the subject-matter. The test

consisted of 15 items (7 items testing factual knowledge, 8 items testing understanding) in single-choice format.

Below two examples of factual knowledge items are given:

Item 1 of the pretest: The educts of the primary reactions of photosynthesis are...

- Water, Oxygen, ADP
- Carbon dioxide, $NADP^+$, ADP
- Water, $NADP^+$, ADP
- Water, $NADPH+H^+$, ATP

Item 3 of the pretest: Which sequence of the electron transport during the primary reactions of photosynthesis is correct?

- Photosystem I \rightarrow Photosystem II \rightarrow $NADP^+$
- Water \rightarrow Cytochrome-complex \rightarrow $NADP^+$
- Photosystem II \rightarrow Photosystem I \rightarrow Oxygen
- $NADPH+H^+$ \rightarrow Ubichinone \rightarrow Oxygen

And an example for an item testing deeper understanding (Item 11 of the pretest):

In the dark, the pH-value in the stroma of the chloroplast decreases from 8,2 down to 7,2.

This is due to the fact that

- $NADPH+H^+$ is synthesized in the stroma
- ATP is synthesized, until the proton gradient is completely diminished
- water is split at the photosystem II
- protons are transported into the thylakoid lumen at the cytochrome-complex

The pupils had to make their choice between the four possible answers: in each case one answer was right, the other ones were wrong. Additionally, students' computer experience was registered by 8 Items with a 4-point answering scale ranging from "I don't agree" to "I completely agree" in order to control influences on learning outcome. This questionnaire was followed by an one hour working period with the different learning environments.

In a post-test directly after this treatment, the learning outcome was registered by a questionnaire identical to the one testing the prior knowledge of the topic "The primary reactions of photosynthesis". Thus the learning outcome was examined by the same items and differentiated in factual knowledge and deeper understanding likewise (see examples above). Subjects were also asked about their cognitive load by 8 Items during the learning session.

The cognitive load was measured by items like the following:

"How difficult was it for you to understand the subject-matters of the learning environment?" and *"How strong did you exert yourself mentally while learning with the learning environment?"* respectively. Each item had a 5-point answering scale ranging from "not at all" to "very ...".

3.5. Methods of data analysis

For analyzing the data we used two different methods: a quantitative and a qualitative one. First we analyzed our data quantitatively by several kinds of analysis of variance. We will present an overview of some selected findings. These results gave reason for a second way of examining the data. We were interested, if there were any qualitative differences in learning success between the students with regard to prior knowledge. To get further information about this question we checked out various probabilistic models, especially those based on latent class analysis. In this paper we would like to focus on this second way of data analysis and present the findings based on this method.

Latent class analysis examines qualitative differences between persons by their responses given in a questionnaire. The aim of the latent class analysis is to find a classification of the persons, which minimizes the difference between the subjects within a class and enlarges their differences between the classes at maximum. In this analysis we focussed on the differences between the subjects with regard to their knowledge about “The primary reactions of photosynthesis”. The number of latent classes in the model is determined by theoretical considerations. Therefore several latent class analyses were done with varying numbers of classes. Afterwards the best model was selected by a test on the validity of the model. Every person belongs to each latent class of the selected model with a certain probability. These probabilities of assignment of a class are the results of the latent class analysis. The persons are classified by the largest assignment probability.

To analyze learning increase in a pre-/posttest-design you have to ensure that the classes generated by the latent class analysis for the pretest and the posttest are the same. Therefore both tests were treated as one data collection and carried out a common analysis. The learning increase of a person can be seen by her change of the latent class from pretest to posttest, which is written down in cross tables.

4. Results

4.1. Results of Analysis of Variance (Summary)

Against our hypothesis 1 (see 3.2.) animations were not better than still images for the understanding of biological processes. In addition interactive animations (simulations) foster a deeper understanding of biological processes in comparison to pure animations as assumed in hypothesis 2 (see 3.2.), but this effect was not significant. As comparing animations with simulation 1 alone (with a limited amount of instructional support) we could only find a significant difference for the learning of factual knowledge. The difference between these two groups in understanding was not significant. Furthermore in contradiction to our hypothesis 3 (see 3.2.), further instructional aids (simulations 2 and 3) had no positive effect on better comprehension. Analyzing the importance of prior knowledge (facts) at learning with simulations, we found no significant differences between two prior knowledge groups (low and high) and the simulation treatments in understanding.

A closer examination of cognitive load revealed that there were no significant differences between the simulation treatments. In general, simulations with instructional aids led to a higher cognitive load. The comparison of the two prior knowledge groups (low vs. high) revealed no significant differences for cognitive load. However, persons with low prior knowledge had the tendency to feel more cognitively loaded. Finally, there was a significant negative correlation between cognitive load and increase of knowledge for persons who worked with simulations. Corresponding to this, persons with a low cognitive load got significantly better results in the knowledge test.

Due to these results we conclude, that most subjects mainly acquired knowledge of facts and less understanding in all treatments, even in the simulation groups. Reasons for this may be low prior knowledge in the topic in general and extraneous cognitive load by simulations with additional instructional aids, respectively. Cognitive load seemed to be harmful especially for the students with low prior knowledge. So we were interested in a closer examination of the qualitative differences between the subjects in learning success. We wanted to get more detailed information about the way of learning increase and its relation to the treatments. Therefore we did another data analysis based on probabilistic models, particularly Latent Class Analysis. These results are presented and discussed in the following.

4.2. Results of the Latent Class Analysis (LCA)

4.2.1 Learner profiles in the model with three latent classes (LCA3)

In this study a model with three latent classes proofed to be an adequate probabilistic model to describe qualitative differences between the students. In the following the learner profiles are presented diagrammatically and explained in detail. The profiles in Figure 1 show the probability to answer a single item correctly for each of the three latent classes of students. Items “fact1” to “fact7” asked for factual knowledge about the primary reactions of photosynthesis, items “underst1” to “underst8” asked for the understanding of the causal relations within these reactions.

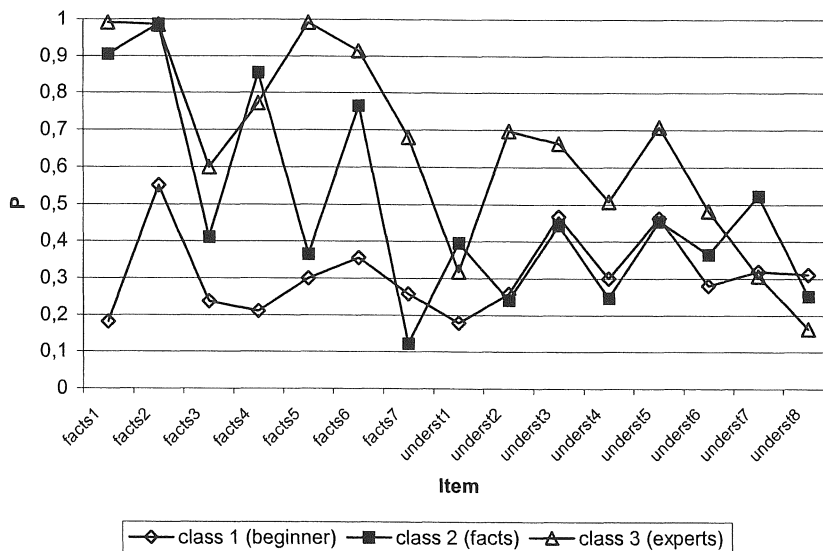


Figure 1. Learner profiles in the study primary reactions of photosynthesis

Individuals of class 1 (beginners) gave correct answers to any item with very low probabilities (Figure 1). Only for the item “facts 2” (a question about the products of the primary reactions of photosynthesis) the probability for a correct answer was near 50% ($p = 0,5$). For all the other items this probability was near 25% ($p = 0,25$), which is in accordance with the level of coincidence, because in the multiple choice test there was just one correct answer out of four (see 3.4.). So members of this class guessed most of the answers. From this it follows that they didn’t know much about the facts of primary reactions of photosynthesis (items “facts1” to “facts7”). Furthermore, there was no understanding of the causal relations within the processes at the thylakoide membrane in this group (items “underst1” to “underst8”). Therefore this class is called “beginners”.

Persons were classified under class 2, if they were able to answer selected items examining knowledge of facts (items facts 1 - 7). Due to this class 2 is called “facts”. Especially the items “facts 1”, “facts 2”, “facts 4” and “facts 6”, asking for educts, products, and the molecular formula of the primary reactions of photosynthesis were answered with a probability larger than 75%. A typical item which tested this factual knowledge is Item 1 (see also 3.4.):

The educts of the primary reactions of photosynthesis are:

- Water, Oxygen, ADP

- Carbon dioxide, $NADP^+$, ADP
- Water, $NADP^+$, ADP
- Water, $NADPH+H^+$, ATP

On the other hand individuals of class 2 knew less about spatial relations and the time sequence of events at the thylakoid membrane (facts 3, 5, 7). Item 3 is a good example (see also 3.4.) for this:

Which sequence of the electrone transport during the primary reactions of photosynthesis is correct?

- Photosystem I \rightarrow Photosystem II \rightarrow $NADP^+$
- Water \rightarrow Cytochrome-complex \rightarrow $NADP^+$
- Photosystem II \rightarrow Photosystem I \rightarrow Oxygen
- $NADPH+H^+$ \rightarrow Ubichinone \rightarrow Oxygen

A further characteristic of this class are low probabilities for the items examining understanding (underst 1 - 8), see Item 11 (3.4.)

In the dark, the pH-value in the stroma of the chloroplast decreases from 8,2 down to 7,2. This is due to the fact that

- $NADPH+H^+$ is synthesized in the stroma
- ATP is synthesized, until the proton gradient is completely diminished
- water is split at the photosystem II
- protons are transported into the thylakoid lumen at the cytochrome-complex

In this part the profile is very similar to that of class 1.

Class 3, in the following called "experts", has in general larger probabilities for giving right answers than the other two classes. All of the items testing facts were answered with probabilities larger than 60%. Furthermore the "experts" reached the highest probabilities for most of the items examining understanding of the causal relations within the processes of the primary reactions of photosynthesis. The average probability for a right answer in understanding comes to 48,1% in this class.

4.2.2 Analysis of learning gain for the whole sample

A change in students' knowledge is defined as a change between classes in the pre-/posttest-design. The transitions from the class based on pre-test results to the class based on post-test results are recorded in a cross table as shown in Table 2. Learning took place, if students changed from a class with low probabilities for correct answers to a class with higher probabilities.

Table 2. Cross table for the transitions between the three different classes from pre-test (before the treatment) to post-test (after the treatment). In the lines the classes based on the pre-test are recorded, the columns show the classes based on the post-test. In a cell of the cross table the absolute frequencies of persons are reported.

		Post-Test			Total
		Beginners	Facts	Experts	
Pre-Test	Beginners	46	33	37	116
	Facts	2	10	13	25
	Experts	1	0	8	9
Total		49	43	58	150

According to the definition above there are three groups having a learning success:
 22% changing from "beginners" to "facts" (33 persons absolute)
 24,7% changing from "beginners" to "experts" (37 persons absolute)
 8,7% changing from "facts" to "experts" (13 persons absolute)

8,7% changing from “facts” to “experts” (13 persons absolute)

All together 55,4% (83 Persons, N Total=150) had a learning gain (see Table 2). But what did these three groups learn in detail? This question can be answered by comparing the descriptions of the different classes as given above. As the first group carried out the transition from the class 1 “beginners” to the class 2 “facts”, students of this group had no prior knowledge (see the description of the learners’ profile of class 1, 4.2.1.) and acquired primarily knowledge of facts (see the description of the learners’ profile of class 2, 4.2.1.). According to the characteristics of class 2 this knowledge was primarily about educts, products, and the molecular formula of the primary reactions of photosynthesis, but not about spatial relations and the time sequence of events at the thylakoide membrane. There was no gain in understanding in this group. In contrast to this, the second group changing from “beginners” with no prior knowledge to “experts” obviously not only acquired more factual knowledge than the first group, but particularly could improve their understanding (see the description of the learners’ profile of class 3, 4.2.1.). The same is true of the third group changing from “facts” to “experts”. The main difference between group 2 and 3 lies in students’ prior knowledge. The third group started with knowledge of facts instead of no prior knowledge like the second group.

What were the chances for learning success for groups with different prior knowledge? There were 116 persons without prior knowledge (class “beginners” according to pre-test, see Table 2) and only 25 persons with prior knowledge (class “facts” according to pre-test, see Table 2). Accordingly, learning success can be described with regard to prior knowledge as follows:

28,4% of persons *without prior knowledge* learned *knowledge of facts* (educts, products, molecular formula); they changed from “beginners” to “facts” (33 of 116 persons)

31,9% of persons *without prior knowledge* learned knowledge of facts (educts, products, molecular formula plus spatial relations and time sequence of events at the thylakoide membrane) and *understanding* (causal relations); they changed from “beginners” to “experts” (37 of 116 persons)

52% of persons *with prior knowledge* acquired additional knowledge of facts (educts, products, molecular formula, plus spatial relations and time sequence of events at the thylakoide membrane) and *understanding* (causal relations); they changed from “facts” to “experts” (13 of 25 persons).

Table 3 summarizes these results.

Table 3. Summary of the relative frequencies for learning gains with regard to different prior knowledge

Learning Increase	Relative frequency
1. Factual knowledge (without prior knowledge)	28,4%
2. Understanding (without prior knowledge)	31,9%
3. Understanding (with prior knowledge)	52%

4.2.3 Effectiveness of the different learning environments (selected results)

What could different learning environments help with regard to students’ prior knowledge? The relative frequencies for the following comparisons were calculated as shown above. As can be seen from Table 4 for subjects without prior knowledge the learning environment “animation” supported the acquisition of factual knowledge better than “still images”, but not the acquisition of understanding. For subjects with prior knowledge “still images” foster understanding better than “animation”.

Table 4. Comparison of the relative frequencies for the treatments “still images” and “animation”

Learning Increase	Still images	Animation	Diff.
1. Factual knowledge (without prior knowledge)	14,3%	31,8%	17,5%
2. Understanding (without prior knowledge)	28,6%	22,7%	5,8%
3. Understanding (with prior knowledge)	60,0%	42,9%	17,1%

Table 5 shows the comparison between the learning environment “animation” and a compound group “simulations” in general. For this comparison “simulations” was created by pooling the three different “simulation”-groups (1-3) in one. For subjects without prior knowledge the difference between “animation” and “simulations” was almost the same in acquiring factual knowledge. However, the comparison revealed a superiority of the group “simulations” for increasing comprehension. This applied to subjects with and without prior knowledge.

Table 5. Comparison of the relative frequencies for the treatments “animation” and “simulations” in general. In this analysis all 3 simulation treatments were united to one group.

Learning Increase	Animation	„Simulations“	Diff.
1. Factual knowledge (without prior knowledge)	31,8%	31,5%	0,3%
2. Understanding (without prior knowledge)	22,7%	35,6%	12,9%
3. Understanding (with prior knowledge)	42,9%	53,8%	11,0%

At last the treatment of simulation 1 (with minimal instructional help) should be compared with the simulations 2 and 3 (with additional instructional help) to get further informations about the effectiveness of different kinds of instructional support. As can be seen from Table 6 additional instructional help like notes for the correct working order and additional information about the topic led to a larger relative frequency of persons acquiring factual knowledge within the group without prior knowledge. However, for an increase in understanding the learning environment “simulation with minimal instructional help” was favorable both for students with or without prior knowledge.

Table 6. Comparison of the relative frequencies for the treatments “simulation with minimal instructional help” and “simulations with additional instructional help”. For this analysis the two simulation treatments with additional instructional help were subsumed under one group.

Learning Increase	Simulation min. instruc.	„Simulations add. instruc.“	Diff.
1. Factual knowledge (without prior knowledge)	24,1%	36,4%	12,3%
2. Understanding (without prior knowledge)	44,8%	29,5%	15,3%
3. Understanding (with prior knowledge)	66,7%	50,0%	16,7%

In general more subjects with prior knowledge than subjects without prior knowledge reached an increase of understanding. This can be seen from Table 3 to Table 6, if the lines “2. Understanding (without prior knowledge)” and “3. Understanding (with prior knowledge)” are compared in each table.

5. Discussion

5.1. Analysis of Variance: Learning environment and learning increase

The quantitative analysis of our data revealed that students had low prior knowledge and acquired mainly factual knowledge and less understanding. Furthermore, the version of the learning environment didn't matter as much as we postulated in our hypotheses. Namely the animation missed to prove its superiority over still images for fostering comprehension. Simulations could foster a deeper understanding of biological processes better than animations, but this effect was not significant. Above all, any additional instructional aids going beyond tasks and questions couldn't diminish students' cognitive load or compensate for a lack in prior knowledge. Because prior knowledge proved to be poor and cognitive load had a major influence on the learning success, we were looking for more detailed information about the interactions of these factors on a qualitative level. Therefore we employed Latent Class Analysis as a further method.

5.2. Latent Class Analysis: Learner profiles and learning increase

Analyzing the data with latent class analysis we found qualitative differences in the learning success for the sample. The differences became apparent in three latent classes. The "beginners" did know almost nothing about the primary reactions of photosynthesis. They gave the right answers by chance. To be a member of this class due to the pre-test results means having almost no prior knowledge about the topic. The class "facts" had a special kind of factual knowledge, namely that dealing with educts, products and molecular formula of the primary reactions of photosynthesis. If a subject belongs to this class because of his pre-test results, this knowledge can be interpreted as prior knowledge. A change from class 1 according to the pre-test to class 2 according to the post-test after the treatment indicates a learning increase in factual knowledge, but not in understanding. The "experts" answered almost every item in factual knowledge and understanding with the highest probabilities compared with both other groups. In the pre-test only very few persons could be classified as "experts" on the basis of their pre-test results. Changing from pre-test "beginners" to post-test "experts" indicated an overall increase in factual knowledge and understanding. Changing from pre-test "facts" to post-test "experts" indicated the acquisition of additional factual knowledge about spatial relations and the time sequence of events at the thylakoid membrane and understanding of causal relations within these processes. Nevertheless, the probabilities for the items testing understanding are only on a medium level in contrast to the items testing factual knowledge. The latter are answered nearly surely. Therefore latent class analysis confirmed the observation that all subjects mainly acquired knowledge of facts. A second assumption was that there was just little prior knowledge in the sample. This could be confirmed, too. Only 16,7% of the whole sample were assigned to the class "facts" due to their pre-test results, even less (6%) to the class "experts". In contrast 77,3% of the sample belonged to the "beginners" according to the pre-test. So with regard to prior knowledge the sample was in large parts nearly homogeneous before the treatment.

5.3. Effectiveness of the treatments

Subjects equipped with prior knowledge reached nevertheless comprehension more frequently than those without prior knowledge. This effect can be observed for the whole sample and for the comparisons of the treatments. So the prior knowledge may have a greater influence on the quality and the quantity of learning success than the different treatments. This has to be kept in mind while discussing treatment effects.

The treatment "animation" fostered factual knowledge in subjects without prior knowledge instead of understanding. For comprehension the treatment "still images" was more

advantageous. Apart from the results in recent studies about multimedia learning, which report positive effects of animations for the understanding of processes (Mayer, 1997; Rieber & Kini, 1991), literature provides some empirical evidence that videos and animations in comparison to still images could diminish learners' attention (Salomon, 1984) or induce cognitive strategies less suited to initiate a deeper understanding (Lewalter, 1997a). As we have no indications for any differences in learners' attitudes or cognitive strategies these questions have to be kept in mind for further investigation.

Simulations improved understanding, especially the simulation with a minimal instructional support. This could be observed for subjects in spite of their prior knowledge. So our further helps like notes for the correct working order and additional information about the topic in both other simulations didn't lead to a deeper understanding of the primary reactions of photosynthesis. However, this kind of instructional support at least resulted in an increase of factual knowledge for persons without prior knowledge in this topic. All in all neither "animations" nor "simulations with additional instructional help" had a stimulating effect on deeper understanding for subjects without prior knowledge. So these hypothetical assumptions couldn't be verified on the basis of this sample.

Subsequently, there are two questions arising from the results of our study: (1) How can learners be supplied with adequate factual knowledge as an indispensable prerequisite for meaningful learning in cognitively demanding computer-based environments? (2) What kinds of instructional support are best suited for learners with different prior knowledge in these environments? From this instructional perspective the learning material itself could be less important for learning success.

6. Prospect

Our study revealed the great influence of prior knowledge on qualitative learning success. So our next study in this context will examine the treatment effects and their interaction with different states of a higher level of prior knowledge again. Therefore we are planning a further examination with biology students at different semesters at the university in Kiel, Germany. In this following sample there may be a larger deviation with respect to prior knowledge. Therefore we are optimistic to get some more information about our main interest - the optimal instructional support for learners with different prior knowledge in computer-based environments.

Moreover, in a further study we will investigate special kinds of instructional support. With these we want to elicit cognitive strategies that enable students to build up adequate mental representations of biological concepts.

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DIFFICULTIES IN THE USE OF QUANTITATIVE DATA IN UPPER SECONDARY BIOLOGY EDUCATION IN THE NETHERLANDS

Michiel van Eijck, Ton Ellermeijer and Martin Goedhart

Amsterdam Mathematics Science and Technology Education Laboratory, Universiteit van
Amsterdam (Amsterdam - The Netherlands)

meijck@science.uva.nl

Abstract

The ultimate aim of this study was to design learner-based teaching materials for upper advanced level of secondary biology education in the Netherlands in which microcomputer-based laboratories (MBL's) support pupils' obtainment and interpretation of quantitative data. The proximate aim of this study was therefore to identify difficulties in the use of quantitative data in upper secondary biology education. We quantitatively analysed the National Curriculum and seven National exams and students' average scores per National exam question and we identified domains where difficulties in the use of quantitative data may be apparent. Qualitative analysis of sections of textbooks covering one of these domains showed that representations and explanations of (patterns in) quantitative data can cause learning difficulties. A test of 48 students in three different schools on representations of quantitative data pointed to the existence of learning difficulties that may be due to the representation of quantitative data in textbooks. Finally, we discuss implications of this study for the design of teaching materials.

1. Introduction

1.1- Background

Since the 1960's there have been studies concerned with the use of quantitative data in biology education (reviewed by Marsh and Anderson 1989). In biological science curricula studies more attention has been paid to quantitative methods (see for example Biological Sciences Curriculum Study 1963). However, the implementation of quantitative methods in secondary biology education has been obstructed due to a lack of adequate teaching materials (Malpas 1973, Lenton and Stevens 1999). Moreover, at the upper advanced level of secondary biological education deep-rooted learning and teaching difficulties with the use of quantitative data have been reported (Paton 1996) and educators have frequently argued for a more elaborate use of quantitative data in pre-university biology curricula (e.g. Gross 1994, Phoenix 1999).

The ultimate aim of this study was to design learner-based teaching materials for the upper advanced level of secondary biology education in the Netherlands in which microcomputer-based laboratories (MBL's) support pupils' obtainment and interpretation of quantitative data. However, we wanted to get a better understanding of which content-specific domains and what educational practices with quantitative data such materials may actually be of benefit. Therefore, the proximate aim of this study was to identify difficulties in the use of quantitative data in upper secondary biology education.

1.2- Framework

In general, we agree with the idea that quantitative data do not exist apart from human beings. Rather, quantitative data are predicates which humans assign to objects and phenomena (Beth and Piaget 1966, Lakoff and Núñez 2000). More specifically, we study the use of quantitative data in science education from three different perspectives. First, we restrict the definition of quantitative data to data that can be counted, measured or calculated and for which mapping on an ordinal scale or expressing as quantities makes sense. This definition excludes the nominal use of quantitative data, which is applied, for example, when specimens are numbered in a zoological museum catalogue. Consequently, a set of quantitative data can be identified by the quantities or the ordinal scales involved. Second, from the perspective of communication we focus on the use of *representations* of sets of quantitative data, like written words, symbols, formulae, tables, graphs, and so on. Third, from the perspective of the praxis of both science and science education we focus on the *context* in which quantitative data are used.

Starting with the context, quantitative data can at first be used to describe objects and phenomena. However, especially in the experimental sciences, representing (patterns in) quantitative data is often bound up with causations that explain patterns in descriptive quantitative data. According to Mayr (1997), two kinds of explanations exist in biological science:

All the activities or processes involving instructions from a program are *proximate* causations. This means particularly the causation of physiological, developmental, and somatic programs. They are answers to "How?" questions. *Ultimate* or evolutionary causations are those that lead to the origin of new genetic programs or to the modification of existing ones - in other words, all causes leading to changes that occur during the process of evolution. They are past events or processes that changed the genotype. They cannot be investigated by the methods of chemistry or physics but must be reconstructed by historical inferences - by the testing of historical narratives. They are usually the answer to "Why?" questions. (Mayr 1997, pp. 67)

Hence, in biology representations of sets of quantitative data are most often bound up with proximate explanations. However, proximate explanations can stand in a twofold relationship to sets of quantitative data (Kuhn 1961). On one hand, a proximate explanation can be formalised as a mathematical model. Such a model may consist partly of a set of non-empirical quantitative 'data', which can be represented by, for example, a formula or a graph. On the other hand, a proximate explanation can explain a pattern in a set of empirical quantitative data that is obtained with one or more measurements and which can be represented by, for example, a table or a graph. We think this dual relationship of proximate explanations for different sets of quantitative data can be confusing for pupils when the purposes for which each of the quantitative data sets are constructed are not made clear to them.

In our opinion, science education should make proximate explanations and their relationship to (representations of) quantitative data comprehensible to pupils. Findings of Abrams *et al.* (2001) suggest that this may be complicated. They asked 96 secondary school pupils from different grades *how* certain daily-life phenomena occurred, like for example the phenomenon that a bean plant grows towards the light. They found that 42% of the students were not able to explain such phenomena proximately. Moreover, 31% of the students spontaneously gave an answer as if they had been asked a *why*-question. For example, to the question *how* does it happen that a plant grows towards the light a pupil gave the answer: "*because* you [the plant] need(s) light to grow, so it grows that way". These results suggest that pupils had difficulties with constructing proximate explanations and that they tended to explain biological phenomena as if they had been asked a *why*-question. Abrams *et al.* (2001) suggested that pupils' tendency to answer as if they had been asked a *why*-question is due to their unfamiliarity with causal mechanisms. In addition we think it may be also due to pupils' difficulties with proximate explanations. When pupils are taught to construct proximate explanations during biology lessons they are usually confronted with representations of quantitative data in their textbooks (graphs, tables, formulae) that are bound up with proximate explanations in texts. As said before, the relationship between proximate explanations and representations of sets of quantitative data may be complicated for pupils. Therefore, focussing on the use of such representations in textbooks may provide more understanding of how pupils' difficulties with proximate explanations emerge.

Roth *et al.* (1999) studied in detail the use of representations of quantitative data in both scientific ecology journals and sections on ecology in high school biology textbooks. In particular, they focused on *graphing resources* which are aspects of Cartesian graphs that "constitute resources for making sense of the primary curve that traces the functional relationship between two sets of corresponding measurements" (Roth *et al.* 1999). One of their findings was that graphing resources in scientific ecology journals are used abundantly, such that they contribute to inferences made according to the quantitative data represented by the graph. In contrast, they found that graphing resources of graphs in sections on ecology in high school biology textbooks are often lacking or that they are used such a way that they obstruct reading and interpreting of the graph. For example, Roth *et al.* (1999) repeatedly encountered graphs in schoolbooks without labels, scales, quantities or units. They called these *graphical models*. Such graphs are representations of functional relationship between quantities but due to the way the quantitative data are (not) represented by the graph, it remains unclear to the reader how that relationship is related to quantitative data obtained by, for example, measurements or calculations. Besides many graphical models, they frequently found cases in which inferences in main texts and captions were not justified by the graph at all. The findings of Roth *et al.* (1999) suggest that the

use of graphs in textbooks obstructs rather than supports pupils' construction of proximate explanations. This may explain pupils' failure to construct proximate explanations as well as their tendency to answer as if they had been asked a *why*-question.

1.3- Research questions

The proximate aim of this study was to find difficulties in the use of quantitative data in upper secondary biology education in The Netherlands. To reach this aim we first identified content-specific domains in which the use of quantitative data was extensive as well as being associated with the occurrence of learning difficulties. Next, we choose a representative domain for a case study in which we draw a detailed picture of pupils' learning difficulties associated with the use of quantitative data in current teaching materials. This approach took into account different curricular levels (see Goodlad 1979 for a detailed description of curricular levels) and thus our research questions followed from this. For each content-specific domain, to what extent do quantitative data appear in the National Curriculum and the National exams and, hence, to what extent can we expect difficulties with the use of quantitative data (formal curriculum)? For the domain of choice, what difficulties with representations of quantitative data and related explanations can we observe in textbooks (formal curriculum)? For the same domain, what difficulties do pupils have with representations of quantitative data and related explanations (experiential curriculum)?

The methodology and results involved with answering these research questions will be respectively explained and shown in detail in sections 2 through 4. In section 5 we summarise the conclusions we derive from the results. The reader of this paper may experience that parallel with our 'descent' from the formal curriculum towards the experiential curriculum, we 'descend' from a quantitative study towards a more detailed qualitative case study. This is due to the ultimate aim of this study, namely the design of learner-based teaching materials for secondary biology education in the Netherlands in which microcomputer based laboratories (MBL's) support pupils' obtainment and interpretation of quantitative data. We discuss our conclusions and this ultimate aim in section 6.

2. The use of quantitative data in the National Curriculum and the National exams

2.1- Domains in which difficulties in the use of quantitative data can be expected

To determine the extent to which quantitative data appear in certain domains of the National Curriculum and the National exams, we focused on quantities as identifiers of sets of quantitative data. That meant that quantities mentioned, for example, as symbols or as words in texts, graphs, tables, diagrams, and formulae were all instances of quantitative data. In the current National Curriculum for the upper level of secondary biology education in the Netherlands (Ministerie van Onderwijs, Cultuur en Wetenschappen 1998), we counted the number of objectives mentioning quantities and the number of different quantities mentioned in the objectives. In seven National exams for the advanced upper level (*tweede fase VWO*) of secondary biology education in the Netherlands of the period 1995-2001, we counted the number of questions where students were meant to use quantitative data and the number of different quantities mentioned in each question. We counted 140 different quantities in 62 of the 216 domain-specific objectives of the National Curriculum. The extent to which quantitative data play a role in the National exams in the period from 1995 to 2001 is shown in Table 1.

Table 1. The number of questions containing quantitative data and the number of different quantities per exam in the National exams of the years 1995-2001.

Exam	Questions per exam	Questions containing QD per exam	Different quantities per exam
1995	43	21 (49%)	53
1996	44	25 (57%)	44
1997	46	26 (57%)	36
1998	44	21 (48%)	52
1999	41	15 (37%)	16
2000	44	28 (64%)	43
2001	40	23 (58%)	36

Note. QD = quantitative data.

We refined the analysis to each single content-specific domain of the National curriculum (see Table 2) to find domain(s) of biology in which difficulties with the use of quantitative data may be expected.

Table 2. Content-specific domains of the current Dutch National Curriculum (Ministerie van Onderwijs, Cultuur en Wetenschappen 1998).

<i>B: Structures</i> B1: Structures of ecosystems B2: Structures of species and population B3: Structures of organisms B4: Structures of cells	<i>C: Lifecycle</i> C1: Lifecycle and genetic information C2: Human lifecycle C3: Lifecycle of cells
<i>D: Metabolism</i> D1: Energy and matter D2: Plant metabolism D3: Human metabolism D4: Dissimilation and assimilation D5: Protein synthesis	<i>E: Dynamics and homeostasis</i> E1: Dynamics in ecosystems E2: Emergence and maintenance of variety E3: Influence of humans on ecosystems E4: Ethology E5: Homeostasis E6: Protection of internal environment

Note. Domain A contained general skills instead of content-specific objectives.

We defined five different parameters that may be associated with difficulties with the use of quantitative data: 1) the number of objectives containing one or more quantitative data; 2) the number of exam questions containing one or more quantitative data; 3) the number of different quantities in objectives containing quantitative data; 4) the number of different quantities in questions containing quantitative data; and 5) the number of difficult as well as reliable exam questions containing one or more quantitative data. The difficulty of a question is defined in terms of the fraction of candidates that gave the wrong answer on this question (Van Berkel 1999). However, exam question can be difficult due to improper construction by exam developers. Such questions are also likely to be unreliable, which results in high-scorers to score low on such questions. Thus, we also decided to take into account the rest-item correlation (R_{ir}) of each question, which is defined as the correlation between examinees' scores on the question and the average scores on the remaining questions (Van Berkel 1999). The difficulty (p) and the rest-item correlation (R_{ir}) for each question were obtained from the *Test and Item Analysis* (TIA) of the National exams, produced in the Netherlands by the *Central Institute of Test Development* (CITO). The sample size of a given TIA for a given exam is equal to the number of all candidates doing that exam (in our case $N \gg 1000$). We assigned questions on which 70% or less of the pupils found the right answer as 'difficult' and questions with $R_{ir} < 0.15$ as 'unreliable' (according to Van Berkel 1999). Thus, for each domain we determined the fraction of difficult and reliable exam questions of the total number of exam questions with quantitative data. Table 3

shows for each content-specific domain of the National Curriculum the value of the five parameters that indicate difficulties with the use of quantitative data.

Table 3. *Parameters indicating difficulties with the use of quantitative data*

Domain	Objectives	Objectives with QD	Different quantities in objectives	Exam questions with QD	Different quantities in exam questions	Difficult and reliable exam questions with QD ¹ (%)
B1	6	2	11	11	20	18
B2	7	1	1	0	0	0
B3	4	0	0	2	3	100
B4	9	0	0	4	5	75
C1	14	4	6	11	6	36
C2	19	2	6	1	1	0
C3	9	0	0	4	3	100
D1	15	6	10	14	24	57
D2	13	6	13	4	18	50
D3	26	8	39	33	59	45
D4	13	6	14	9	17	67
D5	17	2	6	7	16	71
E1	8	6	19	13	15	38
E2	6	4	9	11	9	73
E3	2	2	12	13	10	31
E4	13	3	9	7	18	43
E5	22	10	18	11	12	64
E6	13	0	0	4	18	0

Note. The total number of objectives is given to allow comparison with the number of objectives with quantitative data. QD = quantitative data. ¹ The number of difficult and reliable exam questions with quantitative data is shown as the fraction of the total number of exam questions with quantitative data within the content-specific domain.

2.2- Choice of domain

Domain D3 (human metabolism) was determined to have an exceptional high number of different quantities in objectives as well as in exam questions. Furthermore, sections of textbooks covering this domain seem to contain many graphs, and the physical-chemical research tradition in which proximate explanations dominate is characteristic for this domain (Mayr 1997). Thus, this domain seemed to be very appropriate to investigate pupils' ability to construct proximate explanations in relation to the use of quantitative data represented by graphs. Moreover, the domain offered opportunities to design learner-based teaching materials in which pupils apply microcomputer-based laboratories (MBL's) to study daily-life phenomena.

3. Difficulties in the use of graphs on the cardiovascular system: a case study

To investigate the use of quantitative data in textbooks we focused on representations of quantitative data and on the context in which such representations are used. We selected the use of graphs for three reasons. First, this case study was done in preparation for the design of learner-based teaching materials in which ICT-based learning environments for obtaining and interpreting data are applied. Such learning environments often automatically represent quantitative data as graphs. Second, producing, reading and criticising graphs is one of the seven most important skills of the professional biologist (Schank 1994). So, graphing is a representative

use of quantitative data in biology education. And third, part of our framework about the use of representations of quantitative data is based on graphing practices in high school biology textbooks (Roth *et al.* 1999, see also section 1).

Our database of graphs is derived from the two textbooks most commonly used in the Netherlands, together by at least 40% of the Dutch biology teachers. These are *Biologie voor Jou* (Smits and Waas 2001) and *Nectar* (Maier and van Wijk 1999). In the chosen domain (i.e. Human metabolism, see section 2.2) we selected all graphs from a section in which graphs were abundant in each of both textbooks (i.e. Cardiovascular system). We started our case study with three types of graphs that appeared each in both textbooks to get a detailed picture of the use of these graphs and to get ourselves familiar with the analysis method used. Finally, we classified all graphs according the ontology of graphs described Roth *et al.* (1999).

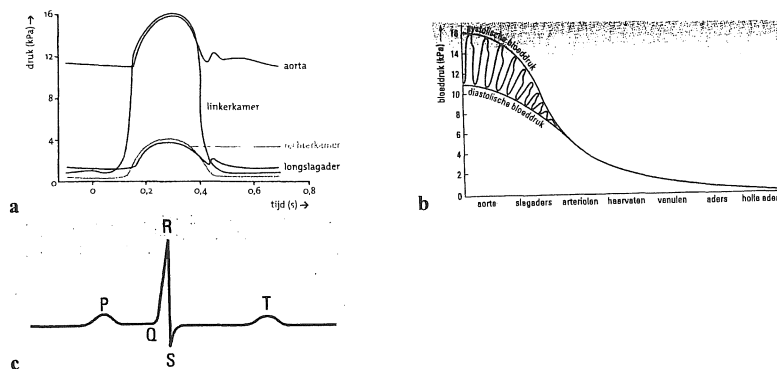


Figure 1. Three characteristic Cartesian graphs about the cardiovascular system from textbooks. a) *Wiggers* diagram (Smits and Waas 2001, pp. 165). b) Graph showing course of blood pressure in different parts of the greater circulation (Maier and Van Wijk 1999, pp. 108). c) Graph of an electrocardiogram (Maier and Van Wijk 1999, pp. 109). *Note.* Because of limited space graphs are depicted without caption and the main text that refers to the graph.

In Figure 1 we give three examples of graphs we classified (these examples are discussed in the following sections as well). According to our analysis framework, we classified the graph in figure 1a as a *graph of a mathematical model* because all axes have quantities, units and scales but no data points are visible. We classified the graph in Figure 1b as a *graphical model* because the space set out on the horizontal axis is labelled only qualitatively and units neither quantities are visible. The graph in Figure 1c was also classified as a *graphical model* because the curve of the graph is given without axes, scales, labels for quantities, or units respectively. Next, for each graph we analysed the nature of the reasoning in the caption and the main text. First, for each graph we analysed whether an explanation was given in either the caption or the main text, in which the author referred to the graph. We categorised each explanation as being ultimate or proximate. Second, for a given proximate explanation we analysed the use of quantities in both the proximate explanation and the graph. We analysed whether quantities were mentioned in the graph and/or in the proximate explanation. Furthermore, if quantities were mentioned in both the proximate explanation and the graph we analysed whether or not they were the same. For example, the author gave in the main text a proximate explanation for the graph in Figure 1a but not all quantities in the graph were mentioned in the proximate explanation in the main text. This

is categorised as ‘quantities in both graph and explanation, no fit’. This was more or less the case with the graph in Figure 1b. The author gave a proximate explanation in which a quantity was mentioned vaguely (i.e. ‘blood streams more regular’) but which does not fit with the quantity in the graph (i.e. ‘blood pressure’). With the graph in Figure 1c a proximate explanation was given in which quantities were mentioned (i.e. ‘electrical activity’) while no quantities were mentioned in the graph. We categorised this as ‘quantities in explanation, no quantities in graph’.

Table 4. Analysis of graphs and accompanying explanations in sections on the cardiovascular system in two biology textbooks in the Netherlands

Elements of analysis	Frequency	
	<i>Biologie voor Jou</i> ¹	<i>Nectar</i> ²
Cartesian graphs	16	21
With data from actual experiments or with data points visible	0	0
Representing mathematical model	4	5
With missing scales or units (‘graphical model’)	12	16
Explanation in main text for patterns in Cartesian graphs	5	6
ultimate explanation only	0	0
proximate explanation only	4	5
proximate explanation and ultimate explanation	1	1
quantities in both graph and proximate explanation, fit	2	0
quantities in both graph and proximate explanation, no fit	2	5
quantities in graph, no quantities in proximate explanation	0	0
quantities in proximate explanation, no quantities in graph	1	1
No explanation in main text for patterns in Cartesian graphs	11	15
explanation for pattern in Cartesian graphs asked in task	11	8
explanation plays no role at all	0	7

Note. ¹Smits and Waas (2001); ²Maier and Van Wijk (1999).

Table 4 shows the outcome of our analysis of graphs and related explanations in sections on the cardiovascular system in two biology textbooks in the Netherlands (Smits and Waas 2001, Maier and Van Wijk 1999). In both textbooks, the high number of graphical models and graphs of mathematical models are in contrast with the lack of graphs from actual experiments. Moreover, only 5 and 6 graphs, in each textbook respectively, are explained while in 11 and 8 instances, respectively, pupils are asked to give such explanations in tasks. In most cases, the quantities mentioned in the graphs differed from quantities mentioned in explanations in the main text referring to the graph.

4. Pupils’ difficulties in the use of graphs on the cardiovascular system

To investigate the experiential use of quantitative data we focused again on representations of quantitative data in textbooks and on the context in which such representations were used. We designed a test for pupils based on the graphs shown in Figure 1. These graphs were identified in the textbook analysis as possibly causing difficulties in either the use of the graph or in the related explanation. Each of the three types of graphs appeared in both textbooks. In the test, the graphs were each depicted with a caption and the part of the main text in which the author referred to the graph. For each graph we designed a series of questions to probe pupils’

difficulties related to graphing difficulties indicated by the textbook analysis. 48 pupils (age 16 to 18) from three different urban schools following the advanced upper level of secondary biology education took the test. The pupils used one of the two textbooks analysed (see section 3), and they had all followed a course covering the specific domain. The teachers had teaching experience of at least five years.

4.1- Pupils identifying the nature of the Cartesian plane of the graphs

We asked pupils to identify the nature of the Cartesian plane of the graph of Figure 1c. That is, we asked which quantities were measured and in which units these quantities were measured, and thus, which quantities and units should be noted on the horizontal and the vertical axes. The compactness of pupils' answers permits us to show them all in table 5.

Table 5. Pupils' answers (N=44) on the question to identify the nature of the Cartesian plane of a graph without axes, quantities and units

	on horizontal axis		on vertical axis	
quantities	<i>time</i>	38	<i>potential difference</i>	1
	no answer or ?	6	<i>voltage</i>	6
			<i>electric activity (of heart)</i>	17
			<i>electric signals</i>	1
			<i>pressure</i>	5
			<i>current</i>	4
			<i>electricity</i>	3
			<i>impulses</i>	1
			<i>P, Q, R, S, T</i>	1
			no answer or ?	6
units	<i>ms</i>	7	<i>mV</i>	4
	<i>s</i>	22	<i>V</i>	6
	<i>MS</i>	1	<i>μV</i>	1
	<i>tenths of seconds</i>	1	<i>ΔV</i>	1
	no answer or ?	16	<i>Ma</i>	1
			<i>mA</i>	4
			<i>a</i>	1
			<i>A</i>	1
			<i>N</i>	1
			<i>joule or watt</i>	1
			<i>Pascal</i>	1
			<i>kPa</i>	1
		no answer or ?	21	

Note. Only 44 pupils of the 48 pupils finished the test.

Most pupils correctly identified the nature of the horizontal axis, although 16 pupils did not indicate which unit is used for time measurements. Pupils mentioned many different quantities and units, especially with respect to the vertical axis. 17 pupils mentioned the quantity 'electric activity', which is mentioned in the main text of the textbook where the author referred to the graph. This indicates that pupils actually used the main text to interpret the graph. The answer "P, Q, R, S, T" indicates that this pupil actually used the depicted labels for interpreting the graph. Interestingly, five pupils mentioned 'pressure' as quantity on the vertical axis. This suggests that they actually tried to place the graph in a context related to blood circulation.

4.2- Pupils' epistemological notions of the graphs

We asked pupils how the graphs in both Figures 1a and 1b 'emerged'. By design we asked not for experiments, activities or persons, or something similar because we wanted to know to what extent pupils could up with such ideas by themselves. We made a categorisation scheme according to the epistemological notion of pupils' answers. For example, the Wiggers' diagram in Figure 1a is a graph of a mathematical model based on various data. These data were obtained by many different researchers of which the researcher Carl J. Wiggers (1883-1962) was apparently very productive and successful (Reeves 1998). Thus, we categorised pupils' answers as showing an *epistemological notion* when one or more comments were made about either: 1) the long time span; 2) the different researchers that worked on it; 3) the different activities involved; or 4) the various combined sets of data that are required for such a graph (which requires at least multiple experiments). For example, the following answer shows an epistemological notion: "One has done research for years on the heart and the blood circulation. One of the results is this graph". Other pupils' answers showed no epistemological notion but consisted of an *explanation* for patterns in the graph, like: "The blood pressure in the ventricles is higher at the moment that the crescent-shaped valves are opening, because of that higher pressure they are opening." Another type of answer pointed to an idea of a single *measurement* or *experiment* without further explanation, like for example: "Someone has measured these values and plotted in a graph." We also found combinations like, for example, explanations with an epistemological notion. The types of answers pupils gave to the questions on the graphs of Figures 1a and 1b are summarised in Table 6. Most pupils gave an explanation for patterns in the graph, or mentioned that measurements or experiments were carried out from which the results were directly drawn in a graph. However, only seven pupils' answers show epistemological notion in their explanations for the emergence of the graph.

Table 6. Pupils' answers (N=48) on the question how graphs emerged

Answer	Graph 1a	Graph 1b
No (substantial) answer	2	3
Epistemological notion	5	0
Explanation with epistemological notion	2	0
Explanation without epistemological notion	7	11
Measurement or experiment	32	34

4.3- Pupils' explanations in relation with the graphs

Depending of the content of the graphs we asked a series of questions to probe how pupils explained patterns in the graphs (see Table 7). In some instances we did not want to stress any one type of explanation so we just asked pupils to explain patterns (i.e. question 1 for both graphs in Figures 1a and 1b). In other instances we 'pushed' pupils towards proximate explanations by using a *how*-question (i.e. question 2 and 3 on the graphs of Figures 1a and 1b and question 1 on the graph of Figure 1c). Both questions 1 and 2 on graph 1b can be answered with the same proximate explanation. However, in the first question the attention of the pupils is primarily directed to the graph, and the answer depends on graph reading. In the second question the answer of the pupils is not dependent on graph reading ability. This twofold questioning for the same explanation gives information on whether pupils' graph reading skills influences their answers.

Table 7. Questions in the test dealing with explanations

Graph	Question
1a	<ol style="list-style-type: none"> 1. Explain the pattern of the graph of the left ventricle. 2. Explain what causes¹ the curve of the left ventricle to lie partly above the curve of the aorta. 3. Explain what causes¹ the curve of the lung artery to lie much lower than the curve of the aorta.
1b	<ol style="list-style-type: none"> 1. Explain the pattern of the upper line in the graph (systolic blood pressure) from the aorta to and including the venae cava (thus the whole line, from the beginning to the end). 2. Explain what causes¹ the blood pressure in the aorta to be higher than in the capillaries. 3. Explain what causes¹ the blood pressure to vary between the systolic and the diastolic blood pressures.
1c	<ol style="list-style-type: none"> 1. How does the 'electrical activity' of the heart emerge?

¹ In the original Dutch questions the part "what causes" reflects a proximate nature better because in Dutch it can be formulated as (literally): "how does it come". Due to the word *how* such a question asks for a certain functional mechanism. However, such an expression does not exist in English. Although the word *how* is omitted we think that the translation to "what causes that" best approaches the original Dutch expression.

We categorised pupils' explanations as *proximate* or *ultimate-like*. Furthermore, we categorised pupils' proximate explanations as *sound* or *not sound*. An explanation was assigned as *proximate* when it only referred to physical causal mechanisms inside the human body. For example, according to the question what causes the blood pressure in the aorta to be higher than in the capillaries (see the graph of Figure 1b, question 2) pupils' explanation "*closer to pumping heart*" refers to a physical causal mechanism (pumping heart). Pupils' proximate explanations were categorised as *sound* when, from a scientific point of view, the causal mechanism correctly explained the phenomena. Thus, although the explanation in the above example is proximate, it is *not sound*. In contrast, the explanation "*the total surface area of the capillaries is bigger than that of the aorta*" is categorised as *sound*. We categorised pupils' explanations as *ultimate-like* when they referred to causes other than physical mechanisms inside the human body. We preferred the term 'ultimate-like' instead of 'ultimate' because pupils' explanations were teleological rather than truly ultimate (as defined by Mayr 1997, pp. 67). That is, in their explanations pupils assigned a purpose or a function to a pattern in the graph but they did not provide also an evolutionary explanation making the assigned purpose or function plausible, like in, for example, the following answer (to the same question as before): "*The capillaries are very narrow and less important, with too much pressure in the capillaries one would be covered with bruises.*" Some answers consisted of proximate as well as ultimate elements, like, for example, the following answer (also to the same question as before): "*It is just pumped away in the aorta and it must through the whole body. Big force = big pressure. the capillaries are small vessels that won't appreciate high pressure.*" Although this answer describes physical mechanisms ("*just pumped away*" and "*Big force = big pressure*") the teleological causes ("*must through the whole body*" and "*won't appreciate high pressure*") actually account for the phenomenon being explained (difference in pressure between the aorta and the capillaries). Therefore, this answer was categorised as ultimate-like.

Table 8 summarises pupils' types of answers to questions addressing explanations for (patterns in) graphs. On questions about the graph of Figure 1a, a relatively high number of pupils gave an ultimate-like or an unsound proximate explanation. Note that 28 pupils gave an ultimate-like explanation to question 3 of the graph of Figure 1a, although it was actually a *how*-question. Moreover, although few pupils gave ultimate-like answers to the questions on both the graphs in Figures 1b and 1c most of pupils' proximate explanations were unsound. Note also that there was little difference between the nature of the answers on the first and second question of graph 1b. This suggests that pupils' answers were not influenced by graph reading skills.

Table 8. Pupils' answers ($N = 48$) to questions addressing explanations for (patterns) in graphs

Graph	Question	Answer			
		not explanatory	ultimate-like	proximate	
				sound	not sound
1a	1	12	11	10	15
	2	20	13	6	9
	3	8	28	5	7
1b	1	13	2	4	29
	2	5	3	7	33
	3	12	1	0	35
1c	1	9	0	19	20

5. Conclusions

The proximate aim of this study was to find and describe difficulties in the use of quantitative data in upper secondary biology education in The Netherlands. Indeed, we found that the extensive use of quantitative data in the National Curriculum as well as the National exams is biased to certain domains. According to the results of the National exams, difficulties with the use of quantitative data can be expected in particular in the domains *Energy and matter*, *Human metabolism*, *Dissimilation and assimilation*, and *Homeostasis*. These domains are on topics in which, from a historical point of view, mathematics, physics and chemistry play a dominant role.

To study difficulties with quantitative data in textbooks we have chosen *Human metabolism* as a representative domain and graphs as representative representations of quantitative data. In sections covering this domain, it appeared that no one graph represented quantitative data which were from actual experiments, and that the graphs studied were often lacking *graphing resources*. In the texts accompanying the graphs, explanations were often absent or were such that quantities mentioned in the explanations and the graph did not fit at all.

By means of a test using problematic graphs from our earlier analysis of textbooks, we studied pupils' difficulties with graphs which appeared to be problematic in light of the textbook analysis. We observed that pupils had difficulties in identifying the nature of the plane of a graph. Furthermore, when pupils were asked to construct proximate explanations related to patterns in graphs (by means of *how*-questions), they had difficulties in formulating, from a scientific point of view, sound answers of a proximate nature, or they tended to give ultimate-like explanations. Finally, pupils showed little or no epistemological notions of graphs.

6. Discussion

The proximate aim of this study was to find difficulties in the use of quantitative data in upper secondary biology education in The Netherlands. The detail with which we have described some of pupils' difficulties with graphs also permits us to construct possible causes for these difficulties.

We have observed that pupils actually used graphing resources and read the accompanying texts when they tried to interpret a graph and when they attempted to construct proximate explanations. However, most of the graphs studied in textbooks were not provided with sufficient graphing resources. Therefore, pupils' difficulties to identify the nature of the Cartesian plane of the graph might be caused by a high 'interpretative flexibility' allowed by absence of graphing resources (Roth *et al.* 1999). Furthermore, textual explanations for patterns in graphs were often lacking, or quantities mentioned in the graph differed from quantities mentioned in the textual explanations. Moreover, pupils frequently failed to construct proximate explanations that fitted with quantitative data represented in the graph. The results therefore suggest that the use of quantitative data in textbooks obstructed pupils from making sense of proximate explanations.

Pupils' explanations on *how*-questions were often ultimate-like. That is, they assigned a purpose or a function to a pattern in the graph but they did not provide also an evolutionary explanation making the assigned purpose or function plausible. This teleological-functional tendency to view objects and events as 'designed for a purpose' can be observed with adults as well as children, and is a feature of intuitive theory building (Kelemen 1999). Moreover, ultimate-like explanations are not bound up as tightly as proximate explanations with the functional relationship between quantities represented by the graph. It is therefore likely that pupils relied on the construction of ultimate-like explanations because the graphing resources and the textual information provided were insufficient to let pupils make sense of the quantitative concepts necessary to construct proximate explanations.

When experts read graphs with few graphing resources, they are able to interpret these graphs properly and to construct sound proximate explanations. This is because they fill in the lack of graphing resources with domain-specific epistemological knowledge (Bowen *et al.* 1999). In our study of graph reading, pupils seemed to have little domain-specific epistemological knowledge of common graphs in their textbooks (like for example the *Wiggers* diagram). This may also explain pupils' difficulties with interpreting graphs.

Due to the explorative character of this study we did not *prove* that pupils' difficulties we observed are due to inconsistencies in textbooks. Nor did we thoroughly disprove that such difficulties are due to shortcomings in pupils' skills in reading and interpreting graphs (as suggested for example by Berg & Philips 1994). However, to extend our study in such directions would not bring us closer to the ultimate aim, which is to design learner-based teaching materials in which microcomputer based laboratories (MBL's) support pupils' obtainment and interpretation of quantitative data. Based on our enriched understanding of difficulties with the use of quantitative data, we are already able to formulate requirements such teaching materials should meet.

We want to design teaching materials in which pupils are not obstructed from making sense of representations of sets of quantitative data. In general, our aim for such lesson materials is that pupils should understand the 'line' between, on one hand, actual measurements in which quantitative data are obtained and represented by graphs, and on the other hand, proximate explanations that explain empirical data and that may be also (partly) formalised in mathematical models and represented by graphs. Therefore, the phenomena to be explained should at first make sense to pupils. Also, the proximate explanations for the phenomena should make sense to pupils and thus, pupils should be able to handle the concepts with which such proximate explanations

are constructed. However, to make sense of sets of quantitative data, pupils should be able to construct proximate explanations with concepts that are bound up with quantifying the phenomena, like for example quantities, units and scales. Consequently, pupils should use such 'quantitative' concepts meaningfully.

In our design we shall apply some strategies and ideas which we think support the teaching materials to meet the requirements. To ensure that pupils are able to handle the concepts with which they construct proximate explanations that make, finally, sense to them, we apply the problem-posing approach of teaching science topics, developed by Lijnse and co-workers (see for an overview Lijnse 2000). Both requirements, that pupils should be able to construct proximate explanations with concepts that are bound up with quantifying the phenomena and the phenomena to be explained should make sense to pupils, can be met by allowing pupils to take their own measurements in the classroom. The topic of choice for the teaching materials will be the same as the one for which we have done our proximate study, namely the cardiovascular system, because studying phenomena within the domain of the human body often make sense to pupils. Furthermore, in this domain we can apply MBL's, which automates both measuring data and drawing graphs of those data. This enables pupils to take multiple measurements of each different phenomenon as well as to interpret the results of their measurements, all in a relatively short time. Moreover, by comparing graphs of actual measurements and corresponding graphs in their textbooks, pupils can also acquire epistemological knowledge of common graphs in the cardiovascular domain. In such a manner we expect to enable pupils to make sense of the use of quantitative data in the construction of proximate explanations for biological phenomena.

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LEARNING AND TEACHING CELL BIOLOGY FROM A SYSTEMS THEORY PERSPECTIVE – AN INTERIM REPORT OF A DEVELOPMENTAL RESEARCH PROJECT

Roald Verhoeff, Arend Jan Waarlo and Kerst Boersma

Centre for Science and Mathematics Education, Department of Biological Education,
Universiteit Utrecht (Utrecht - The Netherlands).

r.p.verhoeff@phys.uu.nl

Abstract

This study aims to develop a learning and teaching theory concerning cell biology in upper-secondary biology education based on systems theoretical notions. Our research approach can be characterised as ‘developmental research’ in which a learning and teaching strategy is designed, developed and field-tested in co-operation with experienced biology teachers and in successive cycles.

Initial research activities focused on defining design criteria and included literature review, explorative classroom activities, interviews with teachers and students, and conceptual analysis of cell biology. These activities resulted in a selection and sequence of learning activities in which two key issues were addressed, i.e. introduction of a systems model starting with the basic properties of life and application of this model to the cell as a basic and functional unit of the organism.

A preliminary educational strategy was tested in two case studies in October 2001. Research data were collected through: classroom observations, interviews with teacher and students, audio-taped oral discussions, completed worksheets, written tests and questionnaires. The research findings were reflected on and the educational strategy was subsequently reshaped and tested in a third case study in March 2002. The revised strategy will be presented together with the preliminary results of the last case study.

1. Introduction

A basic understanding of the functioning of the cell is assumed to be essential for sound understanding of the functioning of the multicellular organism. Students are taught a large variety of life structures and processes at the cellular level. The concepts used to describe them are mainly drawn from the sub-cellular level, but this knowledge seems to be fragmentary if its integration at the cellular and organismic level remains undone. As a consequence, many students fail to acquire coherent conceptual understanding of the cell as a basic unit of the organism (Dreyfus & Jungwirth, 1989). In addition, conceptual problems associated with a lack of relating these levels of biological organisation arise when studying other biological topics as well (Núñez & Banet, 1997; Roebertsen, 1996; Songer and Mintzes, 1994).

Douvdevany *et al.* (1997) showed in their study that even the knowledge of junior high school teachers about cellular processes lacked coherence, although they had enough specific declarative knowledge. Interviews with Dutch upper-secondary biology teachers and explorative content analysis of schoolbooks showed difficulties similar to those identified in the research papers mentioned. In Dutch schoolbooks the cell takes an important but very isolated place and is one of the first subjects dealt with in upper-secondary education.

In this PhD project the focus is on a synthetic approach to cell biology in upper-secondary biology education. To enhance the coherence in learning and teaching (cell) biology we introduce systems thinking as a key competence. A competence is the combined action of attitude, knowledge and skills that enable to perform a task adequately. So systems thinking competence is the ability and willingness to link different levels of biological organisation from the perspective that natural wholes, such as organisms, are complex and composite, consisting of many parts in active relation and interaction of one kind or another and that the parts may be themselves lesser wholes, such as cells in an organism (Mayr, 1997). Our hypothesis is that purposeful application of a systems perspective leads up to more coherence in learning and teaching of cell biology. Research biologists also state that studying biological problems can be seen as studying biological systems and that this approach does not depend on the level of biological organisation on which the problem is studied. This has resulted in a strong integration of biological knowledge by now (Biological Council of the Royal Netherlands Academy of Arts and Science, 1997). Although the Dutch examination syllabus underlines the importance of systems thinking in biology education, the implementation of systems thinking in classroom practice falls short of expectations.

Based on the preceding considerations this study aims at answering the following overall research question:

What learning and teaching strategy based on systems thinking results in an adequate and coherent understanding of the cell as a basic and functional unit of the organism?

This problem statement gave rise to four specific research questions as listed below. These correspond with the different stages of developmental research, which will be elaborated in the section 3 'Research design'.

- In what way could the intended learning and teaching strategy be shaped?
- What learning outcomes arise from the executed learning and teaching strategy and what learning processes constituted these learning outcomes?
- What indications can be derived from the observed learning outcomes and processes for revising the learning and teaching strategy?
- Does the revised strategy lead to a further improvement of the learning outcomes and processes in terms of expectations laid down in the strategy?

2. View on learning and doing research

This PhD study is part of a research programme of the Department of Biological Education aimed at promoting systems thinking in biology education. The Department belongs to the Centre for Science and Mathematics Education in Utrecht University. Research at this centre is being carried out from a *social constructivist perspective*. This means that active involvement of students in individual, group and classroom activities is considered as a prerequisite for learning, and that emphasis is on connecting scientific knowledge to students' prior ideas. These content related activities are meant to alternately raise and answer questions, so as to provide motives for learning. This so-called *problem posing approach* (Klaassen, 1995) has been applied to a large number of topics, such as the particle model (Vollebregt, 1998), immunology (Janssen, 1999), genetics (Knippels, 2002) and decision making about packaging waste (Kortland, 2001).

In choosing a *developmental research approach* the aims of improving educational practice and developing domain specific theories, i.e. learning and teaching strategies, seem to be compatible (Lijnse, 1995; Boersma, 1998). Ultimately, our research will give more insight into dealing effectively with the problems in cell biology education and could also provide some indications about how to proceed in designing biology education from a systems perspective.

3. Research design

The central problem of this study is being tackled by means of 'developmental research'. In developmental research theory driven, creative and practicable solutions to learning and teaching problems are designed. For that reason learning and teaching are treated as closely connected. In addition, iterative consultation with a limited number of experienced biology teachers takes place and researchers and teachers also co-operate in testing and reflecting on the developed learning activities in classroom settings (Lijnse, 1995).

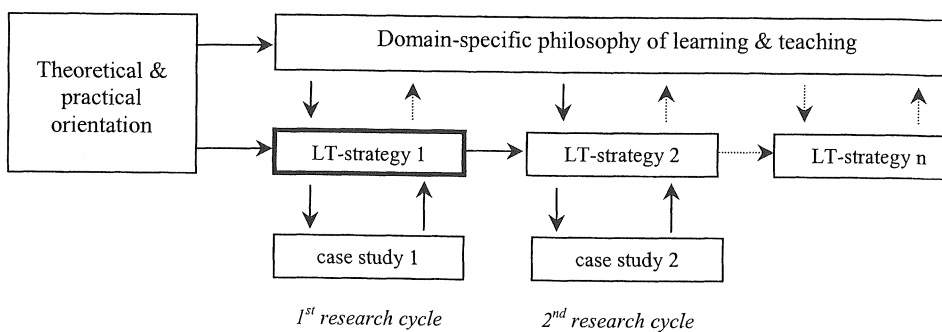
The process of developmental research is cyclic in nature and comprises the following stages:

- theoretical reflections and empirical explorations, resulting in design criteria and a prototype of the learning and teaching strategy
- first test cycle of the designed learning and teaching strategy
- revision of the strategy
- second test cycle and further extraction of theoretical implications

The different stages can be categorized in an explorative phase and a cyclic research phase as depicted in figure 1.

In this study, each stage was guided by a research question formulated in the introduction. In the explorative phase (see figure 1), the general characteristics and structure of the (supposedly effective) teaching and learning process for cell biology from a systems theoretical perspective were identified. In this stage the research literature on cell biology education was studied and teachers and students were interviewed. Furthermore, an explorative case study concerning lessons on endocrine regulation was carried out. Emphasis was on relating students' prior cell biology knowledge to higher levels of organisation (Verhoeff, in press).

Another exploration focused on computer-assisted development of a system model of digestion in humans and applying this model to different levels of biological organisation. During this explorative phase, a specific sequence of interrelated learning activities and guidelines for teaching these activities gradually emerged. For example, the computer



Explorative phase

Cyclic research phase

Figure 1. Design of developmental research (Boersma, 2002). Consisting of an explorative phase and a research phase in which a learning and teaching (LT) strategy is tested in successive cycles resulting in a domain-specific educational theory (n). LT-strategy 1 is elaborated on in this paper.

learning tool was integrated with the designed learning and teaching strategy to be tested in the first case study.

During the first case study, qualitative data were collected through classroom observations, audio-taped classroom and group discussions, completed worksheets, tests and interviews with students and teachers. The data of the first case study were analysed and evaluation of LT-strategy 1 took place by comparing the expected and observed learning and teaching process and outcomes. Reflection on discrepancies provided guidelines for adjustment of the strategy. In the second test cycle the theoretical notions about the designed learning and teaching process should get a more solid empirical basis and lead to a domain-specific educational theory. The second case study is now being analysed. In this paper we will elaborate on the first case study resulting in LT-strategy 2.

4. Towards an adequate learning and teaching strategy

Two features of the intended LT-strategy are integrating cell biology with systems thinking (Verhoeff *et al.*, 2001) and providing content specific learning motives through a problem posing approach (Klaassen, 1995). The first one aims to acquire a view of the cell as a system, and the second one aims to actively involve students in systems thinking. Both aim at acquiring systems thinking competence. Section 4.1 and 4.2 will go more deeply into 'the cell as a system' and into 'motives for systems thinking'.

4.1 'The cell as a system'

In biology we can differentiate between three systems theories, which cover different aspects of living systems (Verhoeff *et al.*, 2000). Together they cover the whole scope of biology and offer a coherent structure for biology education. The 'General Systems Theory' (Von Bertalanffy, 1968) mainly covers the structure of living systems. 'Cybernetics' addresses the regulatory aspects of life, while 'chaos theory' deals with developmental and evolutionary aspects. Because of the abstract and theoretical character of many ideas of the different systems theories, these ideas should be introduced carefully, i.e. adequately sequenced. Because cybernetics and chaos theory require some basic understanding of the General Systems Theory and students are not acquainted with systems thinking, it seems appropriate to start with the General Systems Theory, which mainly refers to the structural organisation of

organisms. Von Bertalanffy was among the first to articulate a systems approach to the study of life and was interested to overcome fragmentation between the various disciplines within biology. Some central ideas of his theory with relevance to (cell) biology education can be distinguished:

- Biological objects can be seen as systems with an internal and external environment separated by a systems boundary.
- Living systems are hierarchical; several levels of organisation can be distinguished.
- At each level of organisation, living systems can be distinguished that are functional to the system at a higher level of organisation where they are part of.
- Living systems are open systems with a continuous exchange of material, energy and information with the environment.

Understanding a systems concept, derived from the description above, requires understanding of the concept 'level of organisation'. The latter requires some knowledge about the structures and processes on different levels of organisation. So, acquiring a meaningful systems concept should start with (implicitly) exploring some levels of organisation. Because students' prior knowledge mainly relates to the level of the organism, it seems desirable to start an LT-strategy on the organismic level and to descend next to the cellular level. This is supported by Knippels (2002) who designed an LT-strategy for genetics. Her so-called yo-yo strategy shows that students can develop coherent knowledge about genetics when (a) concepts of reproduction and genetics are classified by the levels of biological organisation, (b) students descend gradually from the organismic to the cellular and molecular level and (c) the concepts of these levels are related to concepts at the level of the organism (ascending).

In this study, the central problem is to integrate the development of the essential cell biological knowledge along with the basic concepts of the General Systems Theory. An essential idea in cell biology is the distinction between autonomous cells or unicellular organisms and functional cells that are part of a multicellular organism (Verhoeff *et al.*, 2001*). The system characteristics of the General Systems Theory can be seen as abstractions from the basic functions of life: metabolism, growth and development, and responding to environmental stimuli (metabolism for example requires that a living system exchanges matter with its surroundings). Therefore the strategy for the cell as a system started with free-living cells, which can be observed through a microscope. By implication, acquiring a systems concept started at the cellular level as well, followed by its application to other organisational levels. When students view the cell both as an autonomous system and as a functional part of a larger whole, distinguishing the levels of organelles (as functional parts of the cell) and organs (as structural organisation of functioning cells) seems logic (Dreyfus & Jungwirth, 1980; Verhoeff, in press). Figure 2 shows in which order the different forms of the cell 'as basic unit of life' are presented in the LT-strategy. Figure 2 also shows that a right understanding of the cell as a functional unit requires a final step in the LT-strategy: interrelating the different levels of organisation.

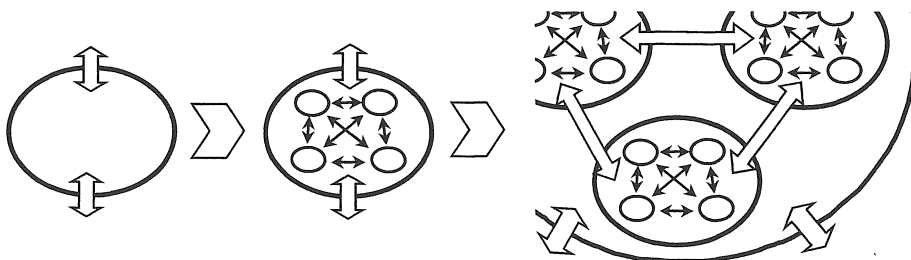


Figure 2. The cell as autonomous, complex and functional system in order of appearance in the LT-strategy.

4.2 Motives for systems thinking

The problem posing approach implies that learning activities should be inherently motivating. This can be established through eliciting meaningful content-related questions and answers in a well thought out sequence.

Developing a motive for learning cell biology doesn't seem to be problematic. By presenting a problem at the level of the organism and by asking for an explanation, students will try to find answers by descending to lower levels of organisation. However, developing motives for systems thinking will likely take some doing. Why making use of abstract concepts like system and level of organisation when more familiar concepts like organism and cell are satisfactory? The General Systems Theory distinguishes some general characteristics, which apply to all living systems at different levels of organisation. So what? The added value is not self-explaining. Anyhow, students could start to find out some general characteristics of organisms, organs and cells. When they do so, the systems concept becomes functional because it provides a general label for the set of characteristics. A computer learning tool was developed and tested to address this problem, i.e. through exploring the process of digestion in humans from the organismic up to and including the cellular level. This program has been embedded in the LT-strategy, which will be elaborated in the next section. Figure 3 shows the content structure of the program. The generalisation of systems characteristics parallels the exploration of the process of digestion. So, exploration of the process of digestion provides a learning motivation and systems thinking joins in.

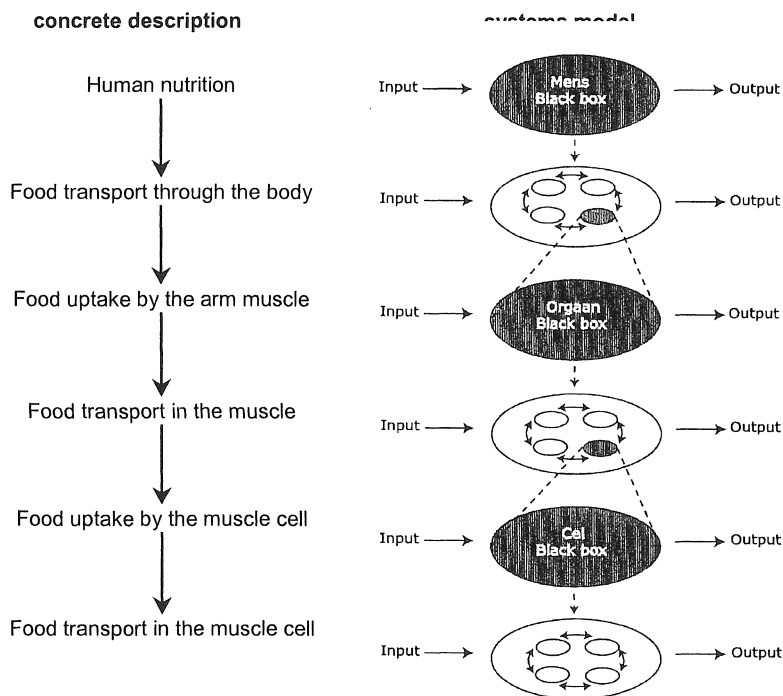


Figure 3. Content structure of the computer aided learning program ('Mens' = 'Human', 'orgaan' = 'organ' & 'cel' is 'cell').

4.3 The preliminary strategy

During the explorative phase of our research promising learning activities and options for sequencing them emerged. These were transformed into a preliminary strategy for learning and teaching cell biology from a systems perspective. Table 1 shows the most important steps of the preliminary strategy, which was tested in the first case study.

Table 1. Preliminary strategy for the cell as a system.

Sequence of problems	Learning activities
How can we explain a biological phenomenon?	<p><i>Global orientation on cell biology (1 lesson)</i></p> <ul style="list-style-type: none"> • Cell biology is essential for understanding biological phenomena
Do the basic functions of multicellular organisms also apply to unicellular organisms?	<p><i>Introduction of free living cells (3 lessons)</i></p> <ul style="list-style-type: none"> • Eliciting prior knowledge on the basic functions of life and applying this to unicellular organisms • Comparing unicellular and multicellular organisms within the context of digestion, resulting in: • A general model of organisms
How do organisms including free-living cells fulfil the basic functions of life?	<p><i>Explication of systems thinking (1 lesson)</i></p> <ul style="list-style-type: none"> • Exploring the process of digestion on different levels of organisation • Reflection, including explication of the levels of organisation and the general characteristics of living systems.
Does the general model, which applies to free living cells, also apply to cells that are part of an organism?	<p><i>Application of the systems model to the cell as a functional unit (2 lessons)</i></p> <ul style="list-style-type: none"> • Exploring the cell and its organelles on the basis of the systems model • Relating the organelles and their cellular function
How do cells that are part of an organism fulfil the basic functions of life?	<p><i>Interrelating the different levels of organisation (1 lesson)</i></p> <ul style="list-style-type: none"> • Explication of the functional relation between the cell, organ and organism.
To what extent is the cell as functional unit, autonomous?	

5. Results of the first case study

The preliminary strategy was elaborated into a scenario and tried out in a first case study. A scenario is a more explicit, context-specific description and justification of the expected learning and teaching processes, including learning and teaching activities and intended learning outcomes. In testing the adequacy of the LT-strategy the scenario guides the analysis of the actual learning and teaching process in the classroom practice. As described in section 3, extensive data sets were collected through various methods in order to get insight into the actual learning and teaching processes. Section 5.1, 5.2 and 5.3 describe the main results of the first case study, which gave indications for revision of the learning and teaching strategy. This revised strategy is presented in the section 6.

5.1 Global orientation and introduction of free-living cells.

The purpose of the global orientation was to give students a content related motive to participate in the cell biology course. Furthermore, this global motive should guide students through the rest of the course. As mentioned in section 4.2, finding an explanation for a phenomenon at the level of the organism would provide a motive to descend to the cellular level. As an example of such a phenomenon, regeneration of a salamander limb was selected and presented to students in a class discussion. When the teacher asked the students who had

heard of regeneration before, one student directly related the process to cells: *“That is when cells are regrouping again and form a new body. But not all organisms are able to do it (...)”*

In the specific case of regeneration of the salamander limb the students engaged in a discussion that dealt with ‘cells’ when being asked how the process of regeneration could be accomplished:

- Teacher: (...) A salamander limb is made of bones, blood vessels, skin and things just like my arm, but how is it possible that it all regenerates?*
- Sanne: Maybe that the cell has information what the cells next to it must do and can thus take over its function ...eh like it can make the cell next to him*
- Teacher: Nice theory, so cells are capable of telling the cells around them what to do. Very thoughtful, why not*
- Edwin: But cells have to know what to do themselves, don't they?*
- Teacher: You mean, a cell has to know for itself what to do?*
- Edwin: Yeah that's in the chromosomes or something*
- Teacher: But Sanne just said that a cell could tell other cells what to do*
- Edwin: But that means there are like smart cells and stupid cells (laughing)*
- Teacher: No, it means there is communication between cells, okay?*

The context of growth and development stimulated students to descend to the cellular level as expected. Many students engaged actively in the class discussion and especially wondered to what extent cells are autonomous or dependent on getting information from outside. As a consequence, reflecting on the class discussion, which presented cell biology as essential for understanding biological phenomena in general, could provide a global motivation for cell biology.

The next learning activity focused at the basic functions of the multicellular and unicellular organism respectively. As expected the basic functions of life provided a meaningful starting point. According to the teacher it provided a much needed and useful perspective when looking at free-living cells through the microscope. Moreover, not being able to see the functions clearly under the microscope, gave the students a motive to look at a more schematic picture of free living cells in the next activity. Although a meaningful introduction of free-living cells succeeded, students didn't quite see the point of thinking about the basic functions of multicellular organisms first, before looking through the microscope. After the lesson many students mentioned that they already knew the functions and didn't learn much. As a consequence, the students were less motivated.

Another unexpected problem arose during the comparison of schematic representations of the unicellular and multicellular organism within the context of digestion, resulting in a general model of organisms. Students' prior knowledge about the functions of different organs in the human body and their interrelations was less developed than expected. Therefore students couldn't use this knowledge in order to arrive at a deeper understanding of the cell as an autonomous functioning unit.

In the plenary reflection, however, a comparison of the unicellular and multicellular organism on a more general level was promising. After drawing the general model on the black board, the students were able to explain the meaning of the different characteristics in the context of the multicellular organism. Subsequently, the class discussion dealt with the application of the model to free living cells:

- Teacher: Does this model apply to unicellular organisms Barbara?*
- Barbara: I don't think so*
- Peter: I think so*

- Teacher: *Firstly, why not?*
 Barbara: *Because it's a little weird for a one cell ... organs are made out of cells, aren't they?*
 Teacher: *That's right and my organs are made of cells and a unicellular organism has just one cell, how can there be something in just one cell?*
 Barbara: *Well, there can be something in it, but...*
 Sanne: *It must fulfill the same basic functions, so I think it works the same more or less.*
 Edwin: *Yeah, it has no organs, but it does have organelles*
 Teacher: *Thanks, very good*

Hereafter, the class discussion focused on reflection on the observations through the microscope and the schematic representation of the unicellular organism. To structure the discussion, the teacher referred explicitly and repeatedly to the general model of the organism. This way all the general characteristics of 'the cell as autonomous system' were dealt with.

Based on the deficiencies of the LT-strategy so far, some clues for revising the strategy were defined:

- The global orientation needs to be directed to the cellular level more explicitly in order to be able to make the subsequent step to free living cells. Growth and development provides a meaningful context in which the step to free living cells can be guided by the question to what extent cells in our body resemble or differ from autonomous living cells.
- The unicellular organism provides a meaningful starting point for developing a general model of organisms. On a general level the comparison of unicellular and multicellular organisms can be helpful, for example in distinguishing the functional units (i.e. organs and organelles) and explicating their functional interrelations.

5.2 Explication of systems thinking

As described in section 4.2 the process of digestion in humans was explored at different levels by means of a computer-aided program. The aim of the learning activity, in which the program was embedded, was to provide students with a content-related motive for explication of the levels of organisation and the general characteristics of living systems. The computer-aided program was designed and tested in an explorative study (Verhoeff, in press) and proved to be adequate, albeit that a plenary reflection should be added. The interactive nature of the program stimulated students to explore the human digestive system on the different levels of organisation. On being asked, most students concluded that the schematic (systems) representation was helpful to them because it provided a clear overview. This insight was mentioned after descending to the level of the organs and cells respectively. In the plenary reflection Kim summarised the schematic presentation as follows:

A body is made of organs and organs are made of cells, and actually the organs and organelles have the same kind of eh... function. Only organs are for the body and organelles are for cells...and they all have (...) the same models.

Although Kim's description meets the intended learning outcome, audio recordings of discussions between individual students showed that some students persisted in describing the cells and organs in the schematic model as 'things'. Thus, showing a need for the right vocabulary. This provides a basis for introducing concepts like organisational level and system. However, due to a lack of time the levels of organisation and the general characteristics were not explicated in a reflection on the computer-aided program. This learning outcome should be stressed in revising the strategy and in informing the teacher.

5.3 The cell as functional unit of the organism

In the strategy so far, a systems model was introduced at the level of the organism. In the next step the systems model was used to develop a coherent understanding of the cell as a functional unit. First by exploring the cell and its organelles guided by the systems model, and second by explication of the relation between the cell and higher levels of organisation (organ and organism).

The class was divided in groups of three students and each group explored one organelle guided by the basic system characteristics. Students could use various information sources, such as biology textbooks and a specific website. Afterwards students presented the different characteristics of ‘their’ organelle. These presentations were combined in a plenary reflection, resulting in a drawing of the cell as a functional unit of the organism, on the blackboard.

Application of the systems model to the cell as a functional unit seemed an obvious step to most students ‘*Well, cells in our body are living units too, so they have to fulfil the basic functions as well*’. In the group discussions students explicitly referred to the system model and some system concepts when exploring their model: ‘*I cannot find what the output of the nucleus is*’ and ‘*How is it (nucleus) related to other organelles?*’ So students tried to answer the right questions. This is shown for example by students who studied the Golgi-apparatus:

Lotte: Our presentation is about the Golgi-apparatus. It's an apparatus in the cell that looks very strange. It was already discovered in 1898 by Mericus Golgi and that's why it's called Golgi-apparatus. He found it in brain cells of the owl and later in the nerve cells of a cat.

Linda: The electron microscope showed that it is in almost every cell and people think the Golgi-apparatus collects and packs proteins that are built by the cell. Proteins that are produced by the Endoplasmic Reticulum go to the Golgi-apparatus and are stacked in its hollow spaces (...) The function of the ER is transportation of the proteins.

Lotte: The Golgi apparatus exists of stacked hollow bubbles surrounded by a membrane. It looks like this (points at a picture in her text book). The input of the Golgi are proteins, because they collect them. The output of the Golgi are proteins in an altered form....

However, the classroom presentations of the organelles showed difficulties in developing a coherent picture of the cell only on the basis of the system model and their textbooks. This was mostly due to the fact that students descended quickly to the molecular level when searching for answers and lost the overall picture of the cell as a whole. For example students who studied the nucleus in their textbook were confronted with many concepts on the molecular level. Instead of focusing on the organelle in the context of the cell as a whole, they tried to understand DNA and RNA.

The plenary reflection resulted in a general picture of the cell as a functional unit of the organism. Subsequently, the class discussion focused on the difference between various cell types. Functional considerations about these differences motivated students to make the transition to higher levels of organisation, i.e. the organ and the organism. After an individual assignment in which the similarities and differences between the cell as an autonomous and as a functional system were explicated, there was a final plenary reflection on the functional relation between the cell and the organism.

Analysing the problems of students in this last phase of the LT-strategy showed a lack of competence in using the systems model as a ‘tool’ to explore the cell as a functional unit of the organism. To solve this problem it was proposed to engage students more actively in the development of the model itself. Modelling cells needs to be a central activity in the LT-strategy in which the complex character and microscopic scale of cells could function as a motive. In the next section the revised LT-strategy, based on the results of the first case study is presented.

6. Revised strategy for the 'cell as a system'

Table 2. Revised strategy for the cell as a system.

Sequence of problems	Learning activities
To what extent do our body cells function autonomously	<p><i>Global orientation on cell biology (1 lesson)</i></p> <ul style="list-style-type: none"> • Introduction and orientation on the cell as a basic unit of the organism within the context of growth and development. • Introduction of unicellular organisms as autonomous living cells.
What are the general characteristics of unicellular organisms?	<p><i>Investigating free-living cells (2 lessons)</i></p> <ul style="list-style-type: none"> • Application of the basic functions of life to unicellular organisms resulting in a schematic presentation of the cell as an organism. • Reflection on the students' observations and schematic representations • Exploration of the process of nutrition in a unicellular organism resulting in a final general model of free living cells
How do unicellular organisms fulfil the basic functions of life?	
Does the general model of free-living cells, also apply to cells that are part of an organism?	<p><i>Investigating cells as part of an organism (2 lessons)</i></p> <ul style="list-style-type: none"> • Studying the characteristics of animal and plant cells through the microscope, guided by the general model of free-living cells. • Introduction of electron microscopic photos to study plant and animal cells resulting in a schematic representation of the cell. • Reflection on the cell as a complex and functional unit, and explication of the process of modelling cells.
What is the function of a cell model?	
How does the cell as a functional unit of an organism fulfil the basic functions of life?	<p><i>Building a model of a plant cell (1 lesson)</i></p> <ul style="list-style-type: none"> • Exploring the different organelles and their functions. Students are divided in groups to build a 3-D model of one specific organelle. • Reflection, including placement of the 3-D organelles in a 3-D model of a plant cell, relating the organelles and explaining their cellular functions.
How do cells as functional units fulfil their functions?	<p><i>Explication of systems thinking (1 lesson)</i></p> <ul style="list-style-type: none"> • Orientation on the functional relation between the cell and the organism • Exploration of the process of digestion at different levels of organisation • Reflection, including explication of the levels of organisation and the general characteristics of living systems
How are multicellular organisms organised?	
What is the function of a systems model?	<p><i>Application of the systems model (1 lesson)</i></p> <ul style="list-style-type: none"> • Application of the general systems model and interrelating the different levels of organisation within the context of a specific biological phenomenon (a nursing mother). • Reflection and rehearsal of the main points.

In table 2 the revised LT-strategy is shown, based on the results of the first case study. In the first case study, the basic functions of life proved to provide a meaningful starting point for both cell biology and systems thinking. The systems model also stimulated students to ask appropriate questions during their learning process, i.e. questions about the coherence of structures on the cellular level and questions concerning the relations between the cell and the organism. However, students showed a lack of competence in using the systems model as a tool in acquiring a coherent understanding of the cell as basic unit of life. To solve this problem, the revised LT-strategy focused on engaging students more actively in the development of a systems model. This major revision went hand in hand with a more specific definition of the intended leaning outcome of the strategy as a competence, i.e. students should be able to distinguish the levels of biological organisation and to interrelate

those levels within the organism. Moreover, systems thinking can be described as being able to think back and forth between real biological phenomena and a general systems model of these phenomena at different levels of organisation. In order to achieve the intended learning outcome, modelling (as described at the end of section 5.3) became an important learning activity in the revised LT-strategy. Moreover, the final learning activity, focused on using the systems model to acquire coherent understanding of a biological phenomenon that transects several biological organisation levels.

Recently, the second LT-strategy has been tested in a second case study. Based on the insights and the evaluation of the first case study, it is reasonable to expect that the second case study will provide us more insight into the characteristics of an adequate learning and teaching strategy for cell biology based on systems thinking.

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STUDENT DIFFICULTIES WITH THE USE OF ARROW SYMBOLISM IN BIOLOGICAL DIAGRAMS

Lynn du Plessis¹, Trevor R. Anderson¹, Diane J. Grayson²
University of Natal¹, University of South Africa², South Africa
anderson@nu.ac.za

Abstract

Students experience difficulties with the interpretation of arrow symbolism in biology diagrams. The source of difficulties could be attributed to the misleading use of graphic principles in presentations or to student difficulties with the interpretation and intention of the symbolism. To investigate the extent of the problem, a content analysis of six popular South African biology textbooks was undertaken to ascertain the prevalence of visual presentations, of each type of visual presentation (realistic, stylised and abstract) and of arrow symbolism within each visual type. The styles and purposes of arrow symbolism in the textbooks were categorised and a set of criteria developed by which to critically evaluate the presentation of arrow symbolism in visual displays. Several areas of potentially confusing presentations were revealed. A series of probes and interviews, using stylised and abstract diagrams, were designed and the results analysed to expose difficulties experienced by students in the interpretation of arrow symbolism. Several perceptual, reasoning and conceptual difficulties were revealed and classified at level 3 on the framework of Grayson *et al.* (2001). Presentation of arrow symbolism in diagrams that was contrary to the principles of graphic design contributed to difficulties.

1. Introduction

Textbooks are used in most schools as a source of visual displays (presentations). Visual displays are divided into realistic representations and stylised or abstract diagrams, all of which play important roles in the teaching and learning of science including biology. In general terms, realistic representations show structure while stylised and abstract diagrams enhance aspects of structure or function and emphasise relationships between elements of the diagram. To accomplish their particular focus, graphic devices such as arrows are used.

Extensive research on stylised and abstract science diagrams, has shown that they can improve student understanding of scientific concepts (e.g. Mayer & Gallini, 1990; Mayer, *et al.*, 1995; Winn, *et al.*, 1991; Sterner, 1998; Phillips & Quinn, 1993; Moore, *et al.*, 1993). However, to be instructively effective, the construction of the diagram should comply with graphic (design) principles (Kosslyn, 1989), and be relevant to the representation of the information or content and to the task. A shortfall in one or more of these areas may result in students showing difficulties with the interpretation of the diagram (e.g. Henderson, 1999; Wheeler and Hill, 1990; Reid, 1990; Hill, 1988; Lowe, 1993; Fleming, 1987).

Arrows, like many other symbolic representations, can be presented in a variety of patterns, take many styles and have a wide range of functions and meaning (Schollum, 1983; Henderson, 1999; Hardin, 1993; Geva, 1983). Lack of objective during the interpretive process or a misunderstanding of the intention of the symbolism relative to the context of the diagram could generate confusion or misinterpretation. To aid interpretation of diagrams, students should therefore be instructed in the relevant content knowledge, in the process of interpretation of diagrams (Kindfield, 1994; Lowe, 1996) and in the conventions and symbolism, including graphic devices such as arrows, used in diagrams (Henderson, 1999; Kress & van Leeuwen, 1996). An understanding of potential difficulties would allow appropriate strategies for such training to be designed.

Various general articles have been written on difficulties with arrow symbolism, mostly in the fields of physics and chemistry (Schollum, 1983; Jiminez-Valdares & Perales-Palacios, 2001; Amettler & Pinto, 2002). However, despite their significance as specifiers of function and relationships and their integral role in directing meaning, there appears to be no rigorous study reported on the evaluation of the use of, presentation of, and difficulties with, arrows in scientific diagrams per se, let alone in biology diagrams, the focus of the present study.

2. Aims of research

The aims of this study were two-fold:

- a) To investigate the prevalence, and appropriate or misleading use of arrow symbolism in textbooks currently used for Grade 11 and 12 biology studies in South African schools.
- b) To assess students' skills with the interpretation of arrow symbolism in biology diagrams in order to investigate students' understanding and identify difficulties.

3. Research design and Method

The above aims were respectively addressed according to the methods described in sections 3.1 and 3.2 below.

3.1 Prevalence of arrow symbolism and the quality of its presentation.

3.1.1 Information obtained from a convenient survey of 50 teachers in 35 schools was used to select three popular series of South African textbooks, from three different publishing houses, that are currently being used to teach Grade 11 and 12 biology in schools in the KwaZulu-Natal region of South Africa. Each series consisted of two books, one for Grade 11 and one for Grade 12 pupils (Ayerst, *et al.*, 2000a and 2000b; Ashwell, *et al.*, 1999a and 1999b; Degenaar, *et al.*, 1999 and 2000). These six books were then subjected to content analysis (Cohen, *et al.*, 2000; Bell, 2001) to obtain the following information:

- a) The prevalence of visual displays in each of the six textbooks;
- b) The categorisation of visual displays into realistic representations, and stylised and abstract diagram types (modified from Alesandrini, 1987; Hunter, *et al.*, 1987);
- c) The occurrence, and prevalence, of arrow symbolism in visual displays and in each type of visual display; and,
- d) The classification of the arrow symbols, used in the selected textbooks, according to differences in arrow style and purpose (Schollum, 1983; Kress and van Leeuwen, 1996).

3.1.2 A set of 12 criteria (Table 1), based on the work of previous researchers (Kosslyn, 1989; Kress and van Leeuwen, 1996; Goldsmith, 1987; MacEachren, 1995), was developed for evaluating the use and presentation of arrow symbolism in the realistic, stylised and abstract displays. The criteria were applied to 614 displays in the six selected Grade 11 and 12 biology textbooks. Possible areas of difficulty with interpretation of the displays were identified and used to inform the design of probes for student understanding and difficulties (See 3.2.1).

3.2 Identification of student difficulties with arrow symbolism.

The study was performed, post-instruction, on three populations (average number 50) of Grade 11 and 12 biology students. For investigating student difficulties, a stylised diagram (Fig. 1) of the cardiac cycle (Wright, 1989) and an abstract diagram of a flow chart (Fig. 2) of Thermoregulation

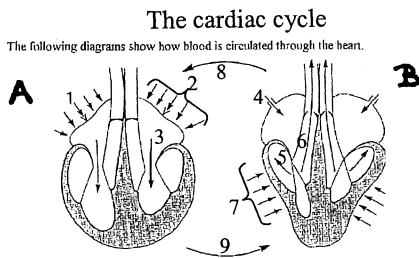


Figure 1. A stylised diagram of the cardiac cycle (Wright, 1989 p55).

The flow chart below shows the effect of many different factors on the reflex control of body temperature in a mammal. Answer the following questions about temperature control in a human using the flow chart to help you.

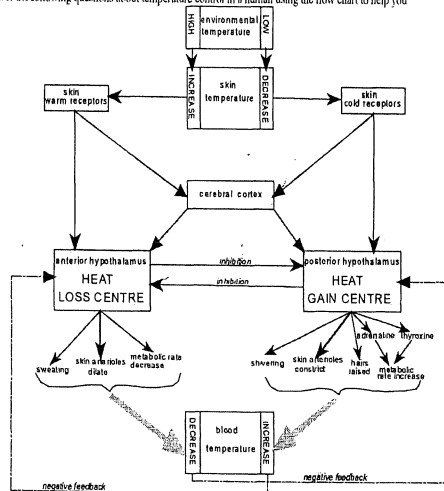


Figure 2. An abstract diagram of a flow chart showing the process of thermoregulation (Independent Examination Board, South Africa, Senior Certificate examination paper 1994).

the thermoregulation process (Independent Examinations Board, South Africa, Senior Certificate examination paper, 1994) were selected as being typical of what South African educators expect Grade 11 and 12 students to be able to understand and use for learning. These diagrams were also selected for their different styles (stylised and abstract) and the following range of visual cues that they possess:

- a) Arrows indicating sequence and/or direction;
- b) Single, diverging, converging and groups of arrows;
- c) Vertical, horizontal and opposite foci;
- d) Repetition; and,
- e) Arrow style: Fig. 1, showing the cardiac cycle has one style of arrow, and Fig. 2 has several styles of arrow, representing different concepts.

3.2.1 The presentation of arrow symbolism in each diagram (Figs. 1 & 2) was analysed according to the design criteria in Table 1, from which possible student difficulties were identified. This information was used to inform the design of free-response, multiple-choice with justification (Haslam & Treagust, 1987; Treagust, *et al.*, 1988) and interview questions (Posner and Gertzog, 1982; Cohen, *et al.*, 2000; White & Gunstone, 2000) to establish whether these possible difficulties actually occurred among the students. Examples of typical probes are included in the appendix.

The multiple-choice probes (see examples in the appendix), included a correct answer (or propositional knowledge statement), several distractors and, in some instances, a possibility for students' suggestions. Justifications allowed clarification of students' perceptual and reasoning skills and conceptual understanding. Answers to related questions in probes were compared for constancy of interpretation. For the interviews, a series of questions from general, free-response questions at a superficial level to more specific and targeted questions at a deeper level, was designed to lay the foundation of, and guide the interview. However, flexibility allowed deeper investigation into difficulties specific to individual students. Respondents were encouraged to think aloud and point out features of the diagram being discussed, and where appropriate, draw markings on the diagram. In addition to notes made by the interviewer, the interviews were also audio-, and, in some cases, video-taped, and transcribed. To allow for any aberrant or 'invented' answers given on the spur of the moment (Hills, 1989), difficulties with incidences of less than 8% were disregarded. Incidences of related questions, designed to probe the same difficulty, were combined and averaged.

3.2.2 Inductive analysis (McMillan and Schumacher, 1993; Johnson & Gott, 1996) of the student responses to written and interview questions allowed the categories of difficulties to emerge. The identity, nature and description of each difficulty was honed by:

- a) Comparing student responses with propositional knowledge statements based on scientifically acceptable answers to the questions and sound graphic principles (Kosslyn, 1989); and,
- b) Using the 4-level framework of Grayson *et al.*, (2001) to guide the process of progressively gaining greater insight into the nature of each difficulty. Using this framework, difficulties emerging unexpectedly from free-response probes were classified on the framework at level 1, while difficulties suspected on the basis of teaching experience or following analysis of the diagrams according to the above criteria (section 3.2.1), were classified at level 2. More specific probing into the nature of the level 1 and 2 difficulties, including with interviews, yielded greater insight into the nature of the difficulties, allowing them to be classified at higher levels on the framework, namely at level 3 (partially established) or level 4 (fully

established), at which stage stable descriptions of the difficulties were obtained. Only difficulties established at level 3 are reported in this paper (Table 2).

4. Results and Discussion

4.1 Prevalence of arrow symbolism and the quality of its presentation.

4.1.1 The prevalence of visual displays in the selected biology textbooks range from a minimum average of 0,57 visual displays per page (or 49% of pages with displays) in Degenaar, *et al.*, (2000) to a maximum average of 1,31 visual displays per page (or 84% pages with displays) in Ashwell, *et al.*, (1999a), with an overall average of 0,86 displays per page or 66%. These findings are consistent with the findings of other researchers (Reid and Miller, 1980). Visual presentations are, therefore, an important consideration in using textbooks. The results also indicate a predominance of stylised diagrams (58%) over realistic (27%) and abstract (15%) visual types, with a shift in emphasis from Grade 11 to Grade 12, of realistic representations to stylised and abstract diagrams. Presumably, this also indicates a shift in emphasis from structure to more cognitively-demanding considerations of process and explanation. This in turn presupposes a shift toward the greater use of symbolism.

The results of the analysis for arrow symbolism indicate that between 17% and 50% (with an average of 33%) of visual displays have arrow symbolism, and also bears out the expected shift in emphasis from Grade 11 to Grade 12. The average percentage increases to 45% if realistic representations, which seldom use arrow symbolism, are disregarded. Arrows are used in, on average, 67% of abstract diagrams and 38% of stylised diagrams. These results indicate the widespread use of arrow symbolism in diagrams and highlight the importance of a clear understanding of arrow symbolism for both presentation and interpretation.

Not only were arrows used in different types of displays over a wide range of contexts but the presentational style and purpose of the arrows varied considerably, both between and within diagram types. Eight categories of style, presented in a variety of groupings and pattern formations, and 26 categories of arrow purpose, were identified. The meaning of the arrow was in many cases specific to, and governed by, the context of the diagram, the position of the arrow/s in the diagram and the relative connections. The wide range of styles and purpose of the arrow symbolism required that the intended meaning of every arrow in a diagram be determined in context. This diversity of presentation could be perceived as confusing, but not necessarily misleading. However, since inconsistent or inappropriate presentation of arrow symbolism could have a negative impact on interpretation this was further evaluated.

4.1.2 The presentation of arrow symbolism in the selected textbooks was evaluated using twelve devised criteria (Table 1). The results revealed that, on average, 30% of diagrams were potentially confusing or misleading, particularly to students unfamiliar with the context or visual style. Incorrect interpretation could ensue. In view of limited space we will illustrate the results in Table 1 using selected examples of diagrams (see Fig. 3 and 4).

Perceptual skills are required to search for, detect, select and organise relevant features and related elements in diagrams (Winn, 1993). Perceptual difficulties can result if arrows are small relative to the proportions of the diagram, too small to be readily discernable, or inappropriately grouped. In fourteen percent of diagrams (Table 1; Criterion 2), interpretation was compromised as arrows were too small to be readily detected. Inappropriate pattern formation or grouping of arrows (Criterion 3) can inhibit the formation of perceptual units

(groups) or lead the eye in unintended directions (e.g. in Fig 3 diagram B, the horizontal arrows imply a linear link between ATP and H, thus minimising their association with glucose-phosphate. Such illusionary or distortion effects, noted in nine percent of diagrams (Criterion 3c), could lead to poor student mental models of the metabolic pathway chemistry.

Table 1. Evaluation of inappropriate presentation of arrow symbolism in visual presentations of six selected textbooks. The results for each criterion are expressed as the total number and percentage of diagrams showing some form of inappropriate use of arrow symbolism.

CRITERIA FOR ANALYSIS OF ARROW SYMBOLISM	Inapprop. Presentation	
	Total /614	Av %
1. Spatial organisation of arrows in diagram including 3 categories of effective diagram type, spatial frequency and conventional read	33	2
2. Size of arrow features proportionate to diagram	89	14
3. Pattern formation of arrows (Grouping, positioning, connecting)		
a. Grouping/unit binding (explicit, implicit boundaries & emergent properties)	71	12
b. Grouping for continuity, proximity, similarity, frequency (4 categories)	176	7
c. Presentation of arrows to avoid illusion or distortion effect	57	9
d. Positioning of individual arrows within elements:		
i) relevant connections for interpretation of data	54	9
ii) optimal positioning for meaning within diagram	102	17
iii) suitable positioning for visibility, distinct from background	91	15
e. Precise connections including origin, pathway & point (3 categories)	247	13
f. Appropriate connections between merging arrows	40	6
4. Number of arrows in diagram for effective processing		
a. Suitable number of arrows/groups of arrows (no gaps/no extras)	144	12
b. Suitability for information processing (meaning) at relevant level (no overload)	24	4
c. Consistent number in repeated group intending similar interpretation	5	1
5. Style of arrow		
a. Suitable style for intended meaning (12 categories)	352	5
b. Variation/consistency in style, for different/within purpose (3 categories)	124	7
c. Suitability of arrow style for the focus of diagram	104	17
d. Correct use of arrow 'conventions' (where applicable)	65	11
6. Clarity of meaning of arrow/s		
a. Unambiguous interpretation of individual/groups of arrows	135	22
b. Method/position/consistency of labelling for interpretation (2 categories)	191	16
c. Suitable key (where necessary)	100	16
7. Goal of search defined/clear for appropriate interpretation of arrows	106	17
8. Conformity of arrow style within diagrams, context and textbook	161	26
9. Level of presentation relative to age, learning level, text and culture	71	4
10. Layout & linkage of entities in displays and proximity to relevant text	97	5
11. Use of arrows as label lines, with other arrow symbolism or label lines	50	8
12. Cumulative assessment of arrow symbolism (relative to student level)	185	30

The continuity effect (a continuous line of marks tends to be grouped), was poorly presented in 9% of diagrams and, the proximity effect (marks near to each other tend to be interpreted as a unit), was unclear in 4% of diagrams. Few diagrams repeated arrows for the similarity (similar marks tend to be associated), and frequency (the size of the group indicates meaning) effects, thereby reducing the overall percentage given for Criterion 3b. In 12% of diagrams, arrows within a group, or groups of arrows within a diagram, were not well positioned, thereby compromising the implicit or explicit boundaries (formation of discernable units) (Criterion 3a), sometimes resulting in unintended emergent properties (unexpected patterns).

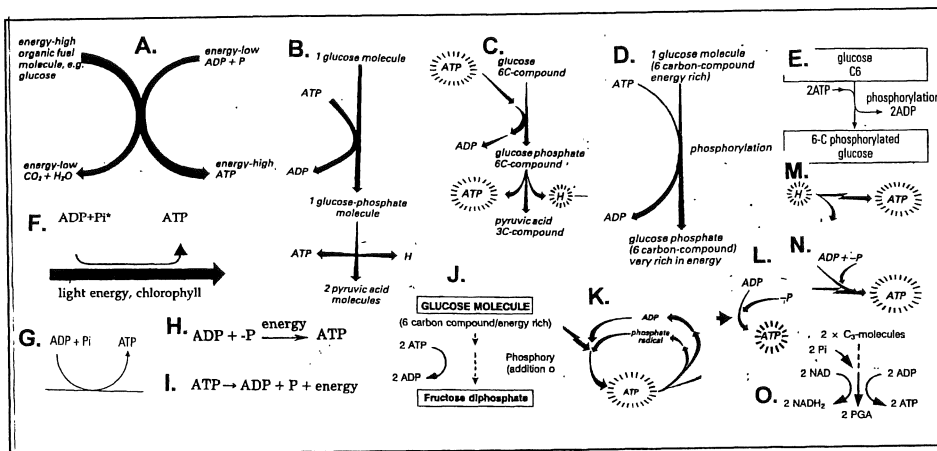


Figure 3. A selection of diagrams (or portions of diagrams) illustrating ADP/ATP conversions in respiration and photosynthesis. Diagrams A, B, C, D, F, G, H, I, K and L (Ayerst, *et al.*, 2000b); E and J (Ashwell, *et al.*, 1999b); M, N and O (Degenaar, *et al.*, 2000).

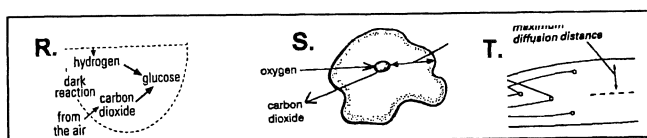


Figure 4. Diagrams showing misleading use of arrow symbolism. Diagram R (Ashwell, *et al.*, 1999b); S and T (Degenaar, *et al.*, 1999). Diagram R presents part of the process of photosynthesis. Diagrams S and T indicate the diffusion distance during gaseous exchange.

Arrows were not readily discernable from the background detail (or labels) of the diagram in 15% of diagrams (Criterion 3diii). Cohesion was lost (Criterion 3dii) where arrows were widely spaced (e.g. as in case of curved and straight arrows in Fig. 3, diagram J and O), or with arrows not linked specifically to discernable elements. An inappropriate number of arrows (Criterion 4a) was found in 12% of diagrams. The connective role of the arrows was compromised in the case of too few arrow links, or when obscured by unnecessary arrows (e.g. in Fig. 3 diagrams C and K, multiple arrows connect ATP and ADP). Four percent of diagrams, mainly abstract diagrams of life cycles and biochemical pathways, included too many arrows for information processing at Grade 11 and 12 levels (Criterion 9).

During processing, significance (for meaning) should be assigned to the position of the arrow, arrow features and style. In 9% of diagrams (Criterion 3di), arrows were not placed between the relevant connections (e.g. in Fig. 4. diagram R, hydrogen and carbon dioxide should join prior to the formation of glucose, which again could mislead students regarding the correct chemistry). The position of the arrow did not allow meaningful interpretation (Criterion 3dii) in 17% of diagrams (e.g. in Fig. 4 diagram S, the arrows incorrectly imply the destination of gases as the nucleus). Where the origin of the arrow shaft and the position of the point of the arrow were not precise (Criterion 3e), correct interpretation of the symbolism depended on prior knowledge (e.g. in Fig. 4 diagram T, the arrow heads stop short of both the exchange surface and midline, thereby not indicating the external source and destination of gases). In 6% of diagrams (Criterion 3f), the intention, or the sequence, of the merge or split of arrows was not clear (as in Fig. 3 diagram B, where ATP appears to be connected to H).

The clarity of meaning of arrows within the diagram is important for sound diagrammatic reasoning, leading to conceptual understanding. Twelve styles of arrow presentation were identified (Criterion 5a). In 5% of diagrams, arrow style was inappropriately presented for meaning in context. For example, the conversion of ADP to ATP shown in Fig. 3 diagram A, indicates relative energy levels, but despite being in close proximity in the textbook, the taper of the arrows in diagrams B, C and D ignore or contradict this. This could impact on the interpretation of students, alerted to the significance of the taper, thereby affecting their conceptual understanding. Some degree of ambiguity (Criterion 6a) with one or more arrows occurred in 22% of diagrams. Expected conventions (such as the broken line depiction for inhibition, the zigzag of energy and the parallel process of the ADP/ATP reaction) were not adhered to in 11% of diagrams (Criterion 5d) in which they were used (as in diagrams J and O in Fig. 3). In addition, conformity of particular arrow styles within diagrams, contexts and textbooks (Criterion 8) was ignored in 26% of diagrams. In Ayerst, *et al.* (2000b) eleven different depictions of the ADP to ATP transformation occurred. A further five novel presentations occurred in the other two series of textbook. Some examples of the styles of presentation of this reaction, given in Fig. 3, illustrate non-conformity as a potential source of confusion, especially to novices in the field. Further confusion could result from lack of direction in presentations. Labelling (Criterion 6b) of arrows, keys (Criterion 6c) or other cues for interpretation, were absent in 16% of diagrams. Some diagram captions or annotations ignored the presence of arrow symbolism in the diagram, thereby denying a specified goal of search to the interpreter (Criterion 7).

This analysis shows that inappropriately presented arrows can result in, or influence, perceptual, reasoning and conceptual difficulties, thus prompting the following investigation.

4.2 Identification of student difficulties with arrow symbolism.

4.2.1 Analysis of the diagrams in Figs. 1 and 2, selected to investigate students' understanding and difficulties with the interpretation of arrow symbolism, showed possible sources of confusing or misleading symbolism that may result in difficulties. Both diagrams are composed of several perceptual units and are therefore, according to the results of our analysis, classed as complex for school level biology. This is supported by the following quote, relating to Fig. 2, from a student interview:

I think it's a good way of showing thermoregulation... but umm...I think its quite confusing because there are so many arrows and you really need to take a lot of time to look at it and try to understand it.

Fig. 1 has only one style of arrow representing several concepts (Criterion 5b), namely flow of blood (arrows 1, 3, 4, 5 and 6), the amount of pressure (or alternatively, degree of contraction or change in size), (arrows 2 and 7), and alternating processes (arrows 8 and 9). The frequency effect (Criterion 3b) shown by the number of arrows in groups 2 and 7 may, depending on the interpretation of the group size, influence syntactic emphasis. According to the analysis, there is no misleading use of arrow symbolism in Fig. 2.

4.2.2 Analysis of student responses to the various probes (see appendix) revealed several categories and subcategories of perceptual, reasoning and conceptual difficulties with various features of Figs. 1 and 2. These difficulties, all classified at level 3 on the 4-level framework, are summarised in Table 2. Since a detailed discussion of all these difficulties is beyond the scope of this paper, we will illustrate key difficulties with specific examples. In some cases

we will give specific incidences of difficulties rather than the average values given in the table.

Table 2. Descriptions of student difficulties with the interpretation of arrow symbolism in the diagrams in Figs.1 and 2, classified at level 3 on the 4-level framework (Grayson, *et al.* 2001). Incidence of difficulties is presented as the average % of students showing the difficulty over a series of related questions in the multiple choice probes. # = Incidence not given in the case of interview evidence only.

	DESCRIPTION OF DIFFICULTY	Fig	Av %
	PERCEPTUAL DIFFICULTIES from inadequate observation (search and detection), selection, sequential and organisational skills.		
1	The spatial organisation of the diagram is not established.		
A	The spatial organisation (layout) is partially identified.	2	50
B	The spatial organisation (layout) is incorrectly identified. Unexpected perceptual patterns, that use irrelevant or unintended features, emerge.	1	18
2	Inadequate perceptual strategies hinder the selection of relevant information and thus the formation of perceptual units.		
A	A universal answer is provided, such as explaining the overall layout of the diagram, instead of only the relevant elements being selected.	#	#
B	Absence of, or inadequate search patterns preclude grouping of appropriate information into elements within the diagram.	2	20
C	Inadequate perceptual strategies exclude relevant information from a perceptual unit. One or more arrows in a pair or group of arrows are ignored.	1 & 2	41
D	Inadequate sequential logic may preclude tracing of the correct pathway.	2	11
E	A local rather than a global focus limits the value of supporting cues.	1	90
3	The relevant feature or cue is not distinguished from other information.	1	48
4	The position of the arrow relative to supporting information is poorly identified.	1	26
5	The position of the arrowhead, origin and shaft relative to supporting information is not identified.	2	19
	REASONING DIFFICULTIES (from inadequate processing skills)		
6	The syntactic emphasis of cueing strategies is misunderstood or not considered.		
A	Differing intentions of arrows presented in similar style is misunderstood or not considered.	1	59
B	Syntactic emphasis presented by the size and number of arrows in a group is misunderstood or not considered.	2	20
C	Significance is not afforded the position of the arrow or its features, relative to surrounding information.	#	#
7	The intention of arrow style is misunderstood or not considered.	2	14
8	The role of arrow symbolism as the link in the cause – effect relationship is not given significance.	1	18
9	Meaning in context cannot be attributed to arrows.	2	13
	CONCEPTUAL DIFFICULTIES		
10	Integration of information is limited by poor prior knowledge of the relevant concept.	2	17
11	Integration of information is limited by the use of prior knowledge without accessing layout.	#	#

The results suggested that some difficulties could be attributable to the misleading or confusing use of graphic principles in the diagram presentation. For example, difficulties may be influenced by the complexity (Table 1; Criterion 9) of the diagrams, particularly of Fig. 2. The spatial organisation or layout (Criterion 1) of Fig. 2 was partially identified (Table 2; Difficulty 1A), with crucial elements of the diagram being overlooked, by 50% of students. For example, 11% of students explained only the effects of external temperature on blood temperature, while another 11% selected or explained only the effects of the internal feedback mechanism (Appendix; Question B3). Further probing during interviews, showed a preference for the vertical pattern (Criterion 1) initiating from environmental temperature. This preference is illustrated by the following quote:

Interviewer: The layout of the diagram, is it arranged in a suitable way?....

Student: Like everything else goes straight down except the blood temperature, but that's obviously, the most obvious because that's where it ends, where the whole diagram ends.

However, despite methodical probing, this difficulty persisted during interviews. This suggests that students' poor observational and organisational skills are also a consideration.

Complexity will compound inadequate perceptual strategies required during diagram processing, resulting in difficulties with the selection of the relevant information needed to form perceptual units (Difficulty 2). For example, in Fig. 2, 70% of students omitted to identify (Difficulty 2C) at least one of the four arrows pointing to the heat loss/gain centres (Question B4).

The singular style of arrow presentation (Criterion 9) in Fig. 1 may have influenced the interpretation of the diagram. For example, the layout of the diagram was incorrectly identified as a result of unintended emergent properties (Difficulty 1B) by an average of 18% of students. In determining the sequence of flow of blood, 14% of students found arrows 8 and 9 strongly suggestive of a circular pattern (Criterion 3b) and indicated the pathway of blood flow between diagrams A and B, from arrows 1 and 2 through 3, 9, 7, 6 and 8. The positioning of arrows 8 and 9 in close proximity (Criterion 3b) to other arrows of similar style in the diagram contributed to the tendency to create a continuity effect. In addition, the combined effects of poor perceptual discrimination and similarity of presentation caused 59% of students to have some difficulty interpreting the intentions of arrows 1, 2, 4 and 7 (Difficulty 6A). Arrow 1 is drawn as part of, and in similar style to, the group of arrows labelled 2. Consistently over five questions, 39% of students did not isolate arrow 1 from the group of arrows labelled 2 (Difficulty 3), despite specific probing for the function of arrow 1 in its singular form. Twelve percent of the students interpreted arrows 2 and 7 as indicative of the path of blood flow.

In addition to difficulties related to problems with diagram presentation, several other perceptual, reasoning and conceptual difficulties emerged. The position and features of arrows require careful observation and identification in order to determine the relationship between the communicant information (Criterion 3d). Failure to access this vital information (Difficulties 4 and 5) and, using reasoning ability, afford it significance (Difficulty 6), will compromise the meaning of the arrow as a connector. Despite the position (Difficulty 4) of arrow 5 in Fig. 1 being entirely within the ventricle, 24% of students interpreted it as indicating flow of blood leaving the heart (Question B1). Arrow 1 was interpreted by 39% of students as showing blood entering the atrium despite it being positioned entirely outside the atrium. This is substantiated by the quotes: "blood through into atrium" and "blood going into (atrium)". Fourteen percent of students interpreted arrow 4 as indicating the opening, and not blood flow, despite the arrow passing through the opening and into the atrium (Question B2). In Fig. 2, an average of 19% of students did not detect the position of the arrowhead and recognise its significance (Difficulty 5). One consequence was the reversal of cause and effect. This is illustrated by the following responses:

Question: Stimulation of the skin warm receptors has the following effect(s):

Response 1: Skin warm receptors increases the skin temperature.

Response 2: Skin temp. increases because environmental temp. has increased.

And:

Question: Stimulation of the heat loss centre has the following effect(s):

Response 1: B occurs (the cerebral cortex and skin warm receptors are inhibited) so that there is no more heat being produced/stimulated ∴ allowing the heat loss process to take place.

Response 2: The skin warm receptors and the cerebral cortex are stimulated to cause a decrease in blood temperature, keeping the body at a constant equilibrium.

Response 3: The blood temperature has to increase for the stimulation of heat loss centre.

Inadequate reasoning ability, resulted in some of the several different styles of arrow used in Fig. 2, proving confusing (Difficulty 7) to an average of 14% of students. Interpretations of the dashed shaft of the arrow (Question C5) representing negative feedback included:

Student 1: not permanent or they don't always happen.

Student 2: because its not going anywhere as such its just umm.....

Student 3: maybe because their function is prolonged ..umm.....ja.

Student 4: ummm... well the part here with the blood temperature and the negative feedback mechanism, the line was dotted so makes you think that its not umm very clear or important.

Arrow 4, evoked this response:

Student:and number 4 has a longer tail.

I: Okay. Any reason for the longer tail?

S: Um, I think maybe because blood is slowly coming into the... or maybe blood has ...has a lot of blood has come in and its sort of closing and its getting less.

Further, students without a sound prior knowledge base experienced difficulty interpreting aspects of the arrow symbolism (Difficulty 10). As a result of poor conceptual understanding of the terms 'cause' and 'effect', 41% of students chose the alternative "Pressure causes contraction" as the function of arrow 1 in Fig. 1, the reverse of the intended relationship. In questions specifically probing understanding of either cause or effect at various points of the diagram in Fig. 1, 35% could not identify the effects, and 29% had difficulty with the cause, of blood flow. Seventeen percent of students not conversant with the meaning of the term 'inhibition', were unable to link the left and right sides of the diagram effectively in order to interpret the role of the feedback mechanism in Fig. 2.

This investigation showed that students have various difficulties when interpreting diagrams, and that these difficulties may be aggravated by presentations contrary to graphic principles.

5. Conclusions

The content analysis of biology textbooks has shown that arrow symbolism is used extensively in diagrams and is, therefore, an important consideration in the interpretation of biology diagrams. Not only is there a wide range of pattern, style and purpose of arrow symbolism, but there is also little conformity of presentations between, and sometimes even within, diagrams. These factors can all contribute to difficulties with the interpretation of arrow symbolism. In addition, the graphic principles used in the creation of diagrams using arrow symbolism may not be adhered to. Presentation of arrow symbolism that is not in

accordance with graphic principles may be inappropriate to the purpose of the diagram and may therefore impact negatively on its interpretation.

Several student difficulties were found to be influenced by poorly presented graphic principles. The complex nature of both diagrams and the similarity in style of the arrows in the cardiac cycle diagram (Fig. 1) may have negatively influenced the interpretation of the diagrams. In addition, several perceptual, reasoning and conceptual difficulties emerged. Perceptual difficulties were evidenced by inadequate organisation skills, poor detection, selection and sequential skills and difficulty distinguishing relevant features and related elements within a diagram. Inadequate processing skills inhibit significance being assigned to the position of the arrow, to arrow features relative to other information in the diagram and to arrow style. As a result of these difficulties, the process of reasoning is hampered and meaningful new knowledge is then not extracted from the diagram. In addition, limited prior knowledge and conceptual understanding may preclude interpretation.

6. Implications

In order to minimise difficulties with the interpretation of diagrams, and the possible formation of alternative conceptions, we suggest that authors and editors should be obligated to ensure that arrow presentation in textbook diagrams is in accordance with sound graphic principles. Furthermore, educators need to be aware of the implications of graphical devices when selecting textbooks and diagrams that include arrow symbolism to use as teaching tools. They should also not presume an understanding of arrow symbolism in novel diagrams, or diagrams being used as teaching tools. Educators should therefore ensure that students are aware of the potential role of arrow symbolism in different types of diagrams, that they have knowledge of graphic principles and are competent in the skills necessary for interpreting diagrams. Strategies need to be designed for teaching students how to read, interpret and learn from diagrams effectively. As there appears to be no standardised style for the presentation of arrow symbolism, conventions should be introduced.

Future research will focus on the elaboration of student difficulties with the interpretation of arrow symbolism, the development of a guide for the teaching and learning with diagrams using arrow symbolism, and the design of strategies for the remediation of the difficulties through improved teaching approaches and diagram design.

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APPENDIX

A. Free-response questions referring to Fig. 1.

Instructions were to: Note features shown in the diagram to account for your reasoning.

1. Refer to diagram A - Explain what is happening in this diagram.
2. Refer to diagram B - Explain what is happening in this diagram.
3. Explain the flow of blood as shown in these diagrams.
4. Why are arrows drawn between the diagrams A and B?

B. Examples of multiple-choice questions. Every multiple-choice question carried the instructions to: Circle the correct answer(s) and give a reason for each choice of answer. Examples of multiple-choice questions referring to Fig. 1. (* = Propositional statement)

1. In diagram A, the arrow labelled number 1:
 - A. Shows blood surrounding the atrium
 - B. Represents contraction of the muscles around the atrium
 - C. Shows that pressure is exerted onto the atrium so that it contracts
 - D. Shows the direction of flow of blood leading to the atrium *
 - E. Shows blood entering the atrium
 - F. None of the above

2. In diagram B, arrow 4 indicates:
 - A. The opening (entrance) to the atrium
 - B. An open valve into the atrium
 - C. Inward pressure
 - D. The direction of flow of blood *
 - E. The relaxation of the atrium
 - F. None of the above

Examples of multiple-choice questions referring to Fig.2. (* = Propositional statement)

3. The blood temperature will be increased:
 - A. If the environmental temperature decreases ONLY
 - B. If the blood temperature decreases ONLY
 - C. If EITHER the environmental temperature OR the blood temperature decrease *
 - D. If BOTH the environmental temperature AND the blood temperature decrease at the same time
 - E. None of the above

4. Which of the following options DIRECTLY (with no intermediate steps) affect the functioning of the heat loss centre:
 - A. An increase in environmental temperature
 - B. A decrease in environmental temperature
 - C. Stimulation of the heat gain centre *
 - D. An increase in blood temperature *
 - E. A decrease in blood temperature
 - F. Sweating
 - G. Stimulation of skin warm receptors *
 - H. Cerebral cortex *
 - I. Stimulation of skin cold receptors
 - J. Dilated skin arterioles
 - K. Shivering
 - L. None of the above

C. Examples of interview questions, referring to Fig. 2.

1. What is the topic of this diagram?
2. What does the diagram tell you? Explain it to me.
3. What does this portion of the diagram tell you? (depending on response to question 2).
4. What does this arrow, in this particular position, tell you? What does it mean?
5. Why is this arrow (as indicated), drawn in this style?

RESEARCH-BASED TEACHING ABOUT BIOLOGICAL EVOLUTION

Mats Hagman, Clas Olander and Anita Wallin
Göteborg University (Göteborg – Sweden)
mats.hagman@ped.gu.se

Abstract

This paper reports an attempt to design a teaching-learning sequence in which the students are stimulated to construct a scientific model of evolution, and to use this model in various contexts. Theoretical reflection, instructional design and classroom research have been linked in a cyclic process of development. Basic principles in the sequence were to make the students aware of different ideas about evolution, both scientific and “alternative” ones, to encourage them to reflect on their own thinking, and to use group discussions as a tool for effective learning. A group of 18 students, all at the age of 17, were followed during a 16-hour unit on evolution. The sequence was evaluated both in terms of the students’ learning and in terms of their experience of the teaching. The results from a delayed post-test, about one year after instruction, show that most students had abandoned pre-instructional “alternative” conceptions, in favour for more scientific ones. As judged from logbook entries, a vast majority of the students also appreciated the teaching approach during the unit, and some students spontaneously expressed their satisfaction with being able to use the theory of evolution as a scientific tool.

1. Introduction

Evolutionary theory is nowadays generally considered to be a cornerstone in the science of biology and it provides a unifying framework for most biological knowledge. This makes the theory of evolution necessary for a sound understanding of biology and implies that it should be an important part of biology education. Although the basic principles of the theory of evolution have been described as logical and obvious (Mayr, 1997), many students have problems in grasping them. A major reason for these problems might be that its principles may seem counter-intuitive, both in relation to the students' own experiences of biological phenomena and to the everyday language used to explain these phenomena.

Research on teaching and learning science has for some decades been dominated by investigations on students' conceptions, first on the content level and later also on meta-levels, e.g. conceptions of learning and of the nature of science. Thousands of studies on students' pre- and/or post-instructional conceptions from various scientific domains, including evolutionary biology, have been published (see Pfundt & Duit, 2000). The studies on "alternative" conceptions have to a large extent been embedded in constructivist theories of learning, often inspired by Jean Piaget and with a focus on the individual learner. The major teaching approaches derived from this individual constructivist perspective are based on conceptual change (Posner, Strike, Hewson & Gertzog, 1982; Strike & Posner, 1992), and seem to have been more successful than traditional teaching. However, the classical conceptual change approaches have been criticised, both for being too rational and thereby paying to little attention to e.g. affective and motivational aspects of learning, and for leaning too one-sidedly on an individual constructivist epistemology. As a response to this criticism there has been a movement for merging individual and sociocultural perspectives on science learning and teaching (Hewson, Beeth & Thorley, 1998; Duit & Treagust, 1998).

This paper reports an attempt to design a teaching-learning sequence on biological evolution, which enables the students to construct a scientific understanding of biological evolution and use the theory of evolution in various contexts. The design draws, in a pragmatic way, both on knowledge about students' "alternative" conceptions and learning problems in this subject content area, and general teaching recommendations derived from different theories of learning. Previous research, and teachers' professional knowledge, on the teaching of evolution was also used to inform the design. Theoretical reflection, instructional design and classroom research was linked in a cyclic process of developmental research (Lijnse, 1995).

1.1- Conceptual analysis

The basic idea of the theory of evolution arises from three premises: 1) Organisms tend to produce more offspring than can survive. 2) There is inherited variation between offspring. 3) Some variations are beneficial to its carrier. As a result, the proportion of individuals with advantage-giving characteristics will increase in a population. This chain of thoughts is rather close to Darwin's own argumentation before he coined the term: "I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection" (Darwin, 1859). During the twentieth century genetics was incorporated into the theory of evolution in what is called "the modern synthesis" (Futuyma, 1998), and biological evolution is since then usually seen as a change in the proportions of genes in the gene pool of a population.

For educational purposes the points above have been rewritten into five principles (Ferrari & Chi, 1998). These principles were focused in the teaching-learning sequence, and also served as a template for assessing student responses:

1. Individual variation (variation)
2. Differential survival rate (survival)
3. Genetically determined heritability (heredity)
4. Differential reproduction rate (reproduction)
5. Accumulation of changes (accumulation)

In addition to these principles two other concepts are of basic importance and will be emphasised in the sequence; mutations as the ultimate origin of new variation and the concept of common descent, with the evolution of life depicted as a branching tree.

1.2- Students' pre-instructional conceptions of evolution

A number of studies have shown that students from different countries share a number of common conceptions of evolution, which are not consistent with biological knowledge (see Wallin, Hagman & Olander, 2001, for overview). These studies show that students often have an intuitive and undeveloped view of evolution, which makes them unaware of some of the more important principles of the way evolution works. For example, the process of evolution is often conceptualised as one single process in which characteristics of the species change gradually (Bishop & Anderson, 1990). The scientific view recognises (at least) two separate processes. The origin of new traits is a random process that generates genetic variation, and the survival of these traits is a non-random process, which decreases genetic variation within populations, basically by natural selection.

Many students also have a typological view on populations, i.e. they consider the individuals in a population to be virtually identical, and do not pay attention to the variation among individuals in a population. With this view natural selection does not work, and students tend to think that populations (or species) change because they need to change (Greene, 1990). Although many students probably consider evolution to be a need-driven process, the frequent use of the word *need* in the context of evolution doesn't necessarily mean that they have misunderstood the evolutionary processes. It is possible to express oneself in the words of need and still have a sound understanding of evolution (Wallin et al., 2001; Southerland, Abrams, Cummins & Anzelmo, 2001). Furthermore, evolution is often seen as just a gradual change in the traits themselves, instead of mainly as a change in proportions among individuals with different traits (Brumby, 1984; Bishop & Anderson, 1990). All of this is closely related to the conception that evolution is caused by individuals adapting to their environment.

In many cases evolutionary theory uses a terminology that is confusing for students. The evolutionary meaning of the word *adaptation* has, for example, proven difficult for students to capture. One reason for this is probably that the everyday uses of this word contradict its evolutionary significance. By applying the everyday meaning of adaptation in evolutionary contexts the notion of individual adaptation is enforced. *Fitness* is another word with multiple meanings, which is troublesome for students. In evolutionary theory it is defined as an individual's reproductive success, but many students have problems connecting natural selection with reproduction success. They often tend to discuss fitness and natural selection only in terms of physical fitness and survival.

Thus, the main "alternative" conceptions a teacher has to face are a) evolution as one single, gradual process, b) a typological view of populations, c) need driven evolution, d) individual adaptation. Furthermore, everyday interpretations of terminology have to be considered.

1.3- Evaluations of teaching on evolution

A few specially designed teaching strategies, mostly based on constructivist views on learning, have been reported to give slightly better results than “traditional teaching”. Bishop and Anderson (1990) noted that the use of specially designed materials during one week of instruction in a college course was moderately successful in improving students’ understanding. However, a later replication of this study could not show any difference between conceptual change and traditional teaching (Demastes, Settlege & Good, 1995). They suggested that time is a limiting factor and that the teachers epistemological beliefs are important. Jimenez-Aleixandre (1992) describes a conceptual change strategy, to Spanish 14 year old pupils, that gave better results than traditional teaching. The main features of the strategy were that it focused on the pupils’ own ideas and that the students were given plenty of opportunities to discuss and work with them and compare them with scientific ideas. Jensen and Finley (1996) used a somewhat similar approach, and showed that the use of a historically rich curriculum, which explicitly addressed different ideas of evolution, combined with paired problem solving was slightly, but significantly, more effective than traditional (didactic) teaching in improving the students’ use of Darwinian explanations. However, the time period during which evolution was taught was rather short (about 6 lessons during one week), and the authors conclude that further studies are needed in which the students are given more time for learning evolution.

The conclusion from this is that previous evaluations indicate that the teaching of evolution needs a considerable time to give acceptable learning outcome, that it is important to engage the students in active work with different ideas, and that the teacher must be familiar with the basic ideas of the teaching approach.

1.4- Aims of the study

The main purpose of this study was to gain insight in how research can improve teaching and how students respond to a research based teaching-learning sequence. To achieve this the outcome of the sequence was evaluated, in terms of both the students’ content knowledge and their experience of the sequence, and discussed in relation to the teaching.

2. Methods and samples

The teaching-learning sequence described in this paper was designed for a compulsory course in biology (Biology A) in the Natural Science Programme at upper secondary school in Sweden. This course comprised 50 hours of teaching and covered mainly ecology, ethology and evolution (Skolverket, 1994). Evolution was strongly emphasised in the curriculum of the course, and we used 16 out of the 50 hours exclusively for teaching evolution. These 16 hours were divided into 9 lessons and a 3-hours written exam. After the return of the exam the students were given the opportunity to evaluate and comment on the whole unit. The specific content and activities within the unit were based on two pilot studies, literature studies and the national curriculum for the course. Both the general outline of the sequence and the detailed plans for each lesson were discussed thoroughly by the research team. All lessons were taught by one of the authors (CO) and were observed and videotaped by another (AW), who also took field notes. The outcome from each lesson was analysed and assessed in a formative way, in tape-recorded meetings, so that the plans for the next lessons could be adequately modified. The general design of the study is shown in figure 1.

Sept. 2000	Nov. - Dec. 2000		Dec. 2001
Pre-test	Teaching sequence	Exam	Delayed post-test

Figure 1. The design of this study.

2.1- Students

A group of 18 students (13 males and 5 females), all at the age of 17, were followed during the unit on evolution. They attended a school in central Göteborg, but most of them came from areas around the city. Most of them are ethnical Swedes and, due to the reputation of the Natural Science Programme to be highly demanding, can be described as well motivated and talented. All of them gave written agreements to participate in the study

2.2- Tests

Students' prior ideas were investigated by a pre-test (Göteborg University, 2000a), which to some extent became part of the instruction, e.g. in structured small group discussion and as starting points for discussions in class. The pre-test consisted of nine problems, some open-ended but mostly multiple-choice, and were given about two months prior to instruction. Since we were particularly interested in long-term retention, the students were also given a post-test, approximately one year after the teaching-learning sequence. This post-test was essentially identical to the pre-test, except for one problem, which had been added (Göteborg University, 2000b). It is a risk that the use of similar pre- and post-tests might lead to an overestimation of the learning outcome, but it was believed that the long time between the tests reduced this effect significantly.

Problem 2	
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 30 km/h?	
Problem 3	
A number of mosquito populations are today 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.
Problem 4	
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.	3. Living organisms strive to develop.
2. Random changes in the gene pool of the organisms.	4. Great variation is needed in order to get balance in nature.
Problem 6	
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	

Figure 2. Four problems from the pre- and post-tests.

Seal problem

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?

Figure 3. The “seal” problem from the written exam.

The results from four of the problems that occurred in both pre- and post-tests (figure 2), and one of the problems from the written exam (figure 3), will be discussed in this paper. Problem 4 was specially designed for this project, whereas the other problems were adapted from the literature (Bishop & Anderson, 1986; 1990; Settlage, 1994; Jensen & Finley, 1995). Both the pre- and post-tests were distributed over the Internet, so the students answered the tests on computers and their answers were submitted directly to our database. It was made clear to the students that the pre-test should not have any influence on the grading and that their biology teacher would only be allowed to see the results from the pre-test at the group level. The written exam was given directly after the teaching-learning sequence and was of great importance for the grading of the students. The students answered these questions very carefully and often with rather long answers.

2.3- Categorisation, ranking and statistics

The answers to the “cheetah” problem in the pre- and post-tests were categorised according to which major type of explanation the students offered. The main categories were identified as “general development”, “need”, “acquired” and “natural selection”. In order to assess the quality in more depth, and be able to compare to the “seal”-problem in the written exam, each answer was also given a rank, based on which of the scientific principles (variation, survival, heredity, reproduction and accumulation) they included according to table 1.

Table 1. Ranking of the cheetah and seal problems.

Rank	Principles
1	No response
2	Don't know/irrelevant
3	General development/need etc
4	General development/need etc + additional principle or scientific concept
5	Variation + Survival
6	Variation + Survival + additional 1 principle
7	Variation + Survival + additional 2 principles
8	Variation + Survival + Heredity + Reproduction + Accumulation

A total rank was determined for the pre- and post-tests for each student. This total rank was based on eight of the nine problems that were identical on both tests. One problem was omitted because it concerned the students' religious beliefs, rather than their knowledge on evolution. The multiple-choice problems were given ranks between 1 and 4, the Likert-type problems (including motivations) between 1 and 8, and the open-ended problems also between 1 and 8 (table 1). The possible rank of a whole test was thus between 8 and 52.

The students' pre- and post-test results were compared by a paired t-test. To test for the post-test results dependence on the pre-test result a regression analysis was done, and the coefficient of determination (R^2) was calculated. (Snedecor & Cochran, 1967)

2.4- Logbooks

The students regularly made logbook entries, in which they were asked to reflect on the different activities, on what they learned and on their way of thinking. The students were allowed to express themselves fairly freely. The response from the teacher was given orally and usually at group level, at suitable occasions during the following lesson(s). At the end of the unit they were asked for a concluding remark as a kind of evaluation. The logbook entries were used to assess the students' experiences of different parts of the teaching learning sequence.

3. The sequence

3.1- Content specific aims

Although the Biology A course was supposed to be a fairly high-level biology course, and the students could be considered to be both motivated and talented, we chose to put emphasis on basic concepts of the theory of evolution. The main objective of the unit was to "allow the students to construct a sound understanding of the theory of evolution". With this we mean that they should be able to understand the theory of evolution in a way that is in accord with the scientific view, to differentiate between scientific and "alternative" conceptions, and to use the theory of evolution as an explanation in new situations according to the principles outlined in the conceptual analysis. In this context we also emphasised the theory of evolution as a model, which the students were encouraged to use in different situations (Passmore & Stewart, 2002).

3.2- Teaching approach

The main purpose of this project was to design a teaching-learning sequence that "works" in practice, so it is to a large extent based on teachers professional knowledge and general recommendations derived from a variety of sources. However, the design also draws more explicitly on a combination of individual and sociocultural views on learning. We agree with Tobin and Tippins (1993), that the knowledge of students is "personally constructed but socially mediated", and emphasise the importance of social interactions for learning. The most distinguishing feature of the sequence was the many structured small group and whole class discussions. They were inspired by two different views on learning, and served two purposes, which was combined into a single strategy. One purpose, inspired by a sociocultural perspective on learning, (Vygotsky, 1986) was to allow the students to integrate the scientific language and their own everyday language, and to sharpen their ability to move between different discourses. We believe that this is of fundamental importance for the long-term retention of knowledge. Another purpose, inspired by the conceptual change model (Hewson, Beeth & Thorley, 1998), was to make the students aware of their own and their peers' existing ideas and compare those with the scientific ones. By articulating ideas and examine them critically, some ideas will lose in status, and others (hopefully the more scientific ones) will increase in status. In addition to the group discussions, some tasks were also specially designed to elicit metacognition, e.g. a computer based activity in which the students step by step had to reconsider their previous thoughts (Göteborg University, 2000c).

3.3- Teacher's role

The teacher has a central and important role in this teaching-learning sequence. He not only has to create a classroom atmosphere that is open and friendly and invites the students to express and discuss various ideas, but also to introduce and support scientific ideas in the classroom. Special effort was made to show the students that all contributions were taken

seriously. Much of the authority to decide what ideas that count as valid was handed over to the students, who were allowed to decide this for themselves on the basis of the explanation power of the ideas. All discussions, both in whole class and groups, had specific content aims and structured frames regarding time, number of students and material.

3.4- Lessons

Although the teaching-learning sequence was supposed to work as one integrated unit, with different parts intertwined, each of the 9 lessons had its own specific aim(s) (table 2). Lectures were kept short (usually not more than 20 minutes), and often with breaks for short small group discussions. The purpose of this was to initiate the process of internalisation of new concepts immediately (Olander, Hagman & Wallin, 2001).

Table 2. Main content in the nine lessons.

Lesson	Short description	Duration (minutes)
1	Historical perspective on thoughts of evolution (lecture) Basic genetics; DNA, inheritance and mutations (lecture) Origin of variation (group discussion)	120
2	Time; analogies (lecture) Timeline in the school's corridor (student activity)	80
3	Common descent, speciation, extinction (lecture) Origin of life (group discussion and computer activity) The giraffe's long neck (group discussion)	90
4	Role play with historical texts (student activity) Peppered moth (lecture) Natural selection game (student activity)	80
5	Nature of science: especially belief and science (lecture) Main strands of the theory of evolution (lecture) Chance: Yatzu (student activity) and "the eye" (lecture) Co-evolution (lecture and group discussion)	80
6	Organisation levels, example: sickle cell anaemia (lecture) Antibiotics resistance (group discussion), Reindeers legs (computer activity)	90
7	Evidence for evolution (lecture) Fossil reconstruction (student activity)	80
8	Speciation: allopathric and sympatric (lecture) Speciation of salamanders, Ensatina (student activity)	90
9	Significance of animal behaviour for survival and reproductive success: Fitness, animal behaviour and sexual selection (lecture) On which level of organisation do evolution work? (group discussion)	80

4. Results

4.1- Pre-instructional conceptions

The results on the pre-test were close to what might have been expected on basis of previous results, including our own results from previous rounds of the teaching-learning sequence (Wallin et al., 2001; Hagman, Olander & Wallin, 2001). Despite the limited reliability of a short pre-test, it is clear that our students entered the unit with a generally poor understanding of evolutionary theory and with frequent "alternative" conceptions.

For example, on the “cheetah” problem (see figure 2), only 28% of the students gave explanations based on natural selection, while explanations that were categorised as general development (some of which included the idea of individual adaptation) or need-driven evolution were common (Table 3).

Table 3. Student responses to the “cheetah” problem (problem 2), by category (n=18).

Category	Pre-test	Post-test
No response/irrelevant	1	0
General development	4	0
Need	7	2
Acquired	1	0
Natural selection	5	16

Also from the students’ responses to the other problems it was evident that the pre-instructional understanding of evolution was rather poor (figure 4, 5 and 6). Responses based on “individual adaptation”, “need” and “strive” were common.

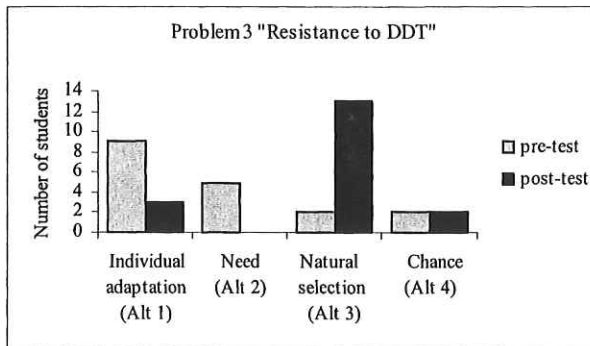


Figure 4. Number of students (n=18) choosing different alternatives on problem 3.

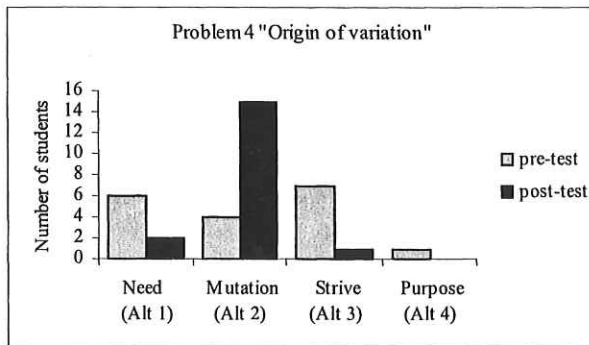


Figure 5. Number of students (n=18) choosing different alternatives on problem 4.

4.2- Learning outcome

A comparison of student responses between the pre-test and the delayed post-test reveals that most students had abandoned their pre-instructional conceptions of “individual adaptation”, “need”, and “strive”, in favour of “natural selection” in problem 3 and in favour of “mutation” in problem 4 and 6.

On problem 6 (the “trait of webbed feet”) the students were asked to choose between two alternatives, based on “need” and “mutation”, respectively, on a Likert-scale, and also to motivate their choice. These motivations, which were categorized according to the acceptance of the “need”- and “mutation”- statements, corresponded well to the students’ choice on the Likert-scale. Some students accepted both statements, but in the post-test they used “need” in a way that was in accord with the scientific view. The number of students who gave motivations in accord with the theory of evolution increased from 2 in the pre-test to 14 students in the post-test.

In the open-ended “cheetah” problem (problem 2), an overwhelming majority of the students, (16 students) used natural selection in a correct sense in the post-test, compared to 5 students in the pre-test (table 3).

In the written exam, immediately after teaching; most students used scientific explanations in their answers. One of the tasks in the written exam (the “seal” problem) was comparable with the “cheetah” problem in the pre- and post-tests, and the rank of this problem was determined in the same manner (table 1). When the mean ranks on the “seal” and “cheetah” problems are compared (figure 7), you can see an increase from 3.8 ± 1.6 in the pre-test to 7.1 ± 1.5 in the written exam, followed by a decrease to 6.6 ± 1.5 (mean \pm s.dev.) in the post-test.

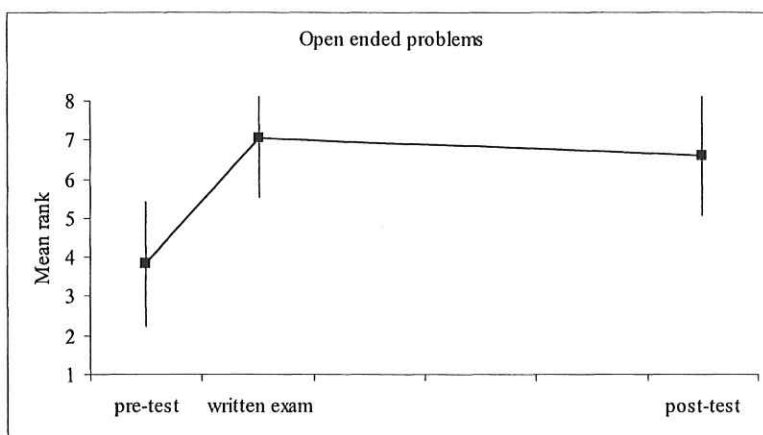


Figure 7. The mean rank of the “cheetah”-problem in pre- and post-test, and the “seal”-problem in the written exam. All the students in this study were included ($n=18$).

The students’ total ranks were higher in the post-test compared to the pre-test (figure 8). In fact all students in this study increased their total rank. The mean sum of rank increased from 26.2 ± 6.0 to 40.6 ± 7.9 (mean \pm s.dev.). This increase was highly significant (paired t-test 9.5; $df=17$; $p < 0.001$).

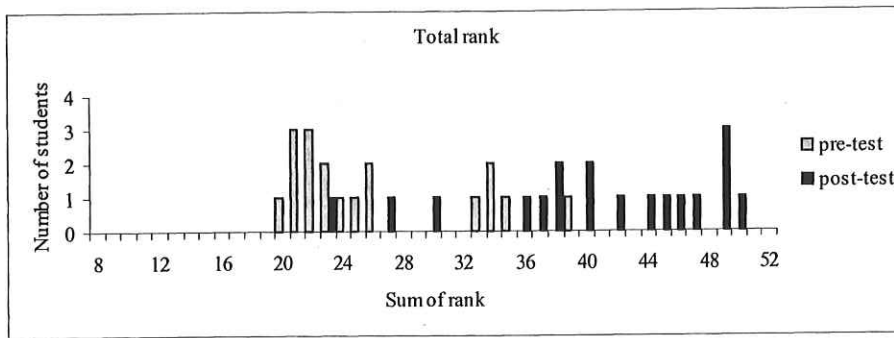


Figure 8. The students' pre- and post-test results (n=18).

To explore the effect of the students' pre-test results on the outcome of their post-test, a regression analysis was performed (figure 9). A linear model was applied with a significant result ($F=9,1$; $p=0.008$). This analysis indicates that about one third of the variation in the post-test results could be explained by results on the pre-test ($R^2=0,36$).

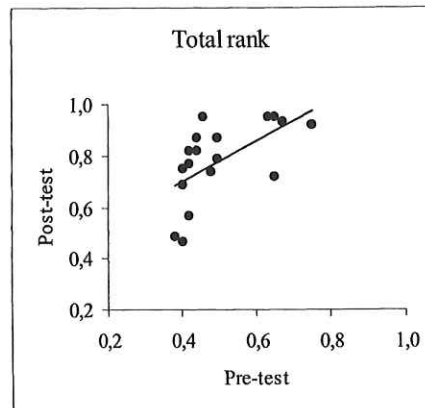


Figure 9. The students' post-test results as a function of their pre-test results (given as proportions).

4.3- Student attitudes and experiences

Analyses of the logbook entries show that most students' really appreciated the teaching approach during the unit. Fifteen of the 18 students were clearly positive to the teaching as a whole, and the other three did not express any opinion. The reasons for their appreciation can be divided into two main categories. 1) They enjoyed the teaching per se. 2) They appreciated the outcome of the teaching, i.e. they felt that they really learnt something in depth. One student expressed both these points very clearly in a concluding remark in the logbook: *"My honest opinion is that the evolution lessons have been interesting and fun. I have also learnt heaps of new things. And I really mean learnt, because I think this is something I'm gonna remember until I'm 80 years old!!!"*

The logbook entries indicate that the students found the classroom climate open and friendly so that they felt free to express their own thoughts. One student wrote for example: *"It's good*

that we can say and think whatever we like, and you don't get laughed at if you're wrong." This result is supported by the impressions of the observing researcher. The students also seemed to appreciate the discussions of different ideas (13 students expressed clearly positive evaluations), and found the many small group discussions stimulating and thought promoting, e.g. *"It was interesting to hear a lot of views which you could either reject, accept or develop"*, *"Our 'lets-take-a-few-minutes-and-think-of-this' discussions are really good! You have to think for yourself, it's necessary"*, and *"I think our group discussions are good. You hear other people's ideas and exercise your brain"*. One student was sceptical to the discussions because he/she thought they were dominated by just a few persons.

Many students do appreciate the learning outcome of the unit, and they stress the difference between this teaching approach and their traditional teaching. They describe the teaching approach as "free", interesting or thought promoting: e.g. *"It's good with tasks in which you have to think for yourself, instead of just reading how it is"*, *"I don't think I would have understood so much by just listening and taking notes. I think the good learning is due to all activities"* and *"All of this, that it is not just didactical teaching, is great!! Because that is soooooo boring!!!"* One student expressed a slightly different view: *"It would probably have been just as good with didactical teaching to me, but for a majority it was probably good"*

Some students even expressed the satisfaction with being able to use the theory of evolution as a scientific tool. Two examples: *"It was good with that internet thing about reindeers- You learn to think yourself, to use the theory of evolution."* and *"... you can use Darwin's theory on everything, that's nice ..."*.

5. Discussion

5.1- Learning outcome

The students' understanding of evolution did not only develop towards a more scientific level between the pre-test and the exam, but most of this knowledge also seemed to persist at the post-test one year after instruction. Furthermore, all students in this study improved their results from the pre-test to the delayed post-test. The decline in results between the written exam and the post-test is not very large. Considering that the motivation to give good answers probably was greater in the written exam, since the results of this was used for grading the students, while the post-test was not, the long term retention is remarkably good. We regard the learning outcome as satisfactory in relation to the content specific aims of the unit. Also in relation to the learning outcome reported in other studies, the results in this study appear to be relatively good. We can conclude that most of our students, after teaching, had a sound and long lasting understanding of biological evolution.

5.2- Student attitudes and experiences

The overall response of the students to the unit was very positive, especially on an affective and motivational level, i.e. they enjoyed the lessons and felt motivated to learn about the biological evolution. All students were not altogether positive. Some of them thought that there were too many group discussions and "games", that the same basic principles were addressed all the time etc. But the overall response to the unit was never the less very positive. This positive attitude might be due to our effort to create an open and friendly atmosphere in the classroom, which, according to logbook entries and field observations, succeeded to a considerable extent. Other factors may also be involved, e.g. that the students felt they really learned something (also supported by logbook entries), that the biological

evolution is a popular subject, or just the contrast between the teaching during this unit and their traditional, more didactical, teaching. We can conclude that the teaching during the unit was seen as meaningful and interesting to a vast majority of the students.

5.3- Learning as a result from teaching

All students in this study improved their results between the pre- and the post-test, albeit to different degrees. Although there was some correlation between the individual students' results on the pre-test and on the post-test, this correlation was mainly due to the students with the lowest rank on the pre-test. For students with average and above average results on the pre-test the results on the post-test seems to be independent on their pre-instructional knowledge.

If it is relatively clear that the students gained knowledge to a satisfactory degree, it is much harder to see what specific factors were crucial in the learning process. We can identify three main categories of possible learning promoting factors:

5.3.1- *The teacher* during this unit can be described as well informed about the subject content and the aims of the course, committed to the teaching approach and popular with the students. This had almost certainly a positive effect on motivation and learning, but we don't see it as a drawback in our study. The research question that remains to be answered in this respect is to what extent the "teacher factor" affects the learning outcome. It would be very interesting to try this teaching-learning sequence with other teachers in order to study to what extent "transfer" of teaching sequences is possible.

5.3.2- *The general teaching approach*, i.e. to build on ideas contributed by both the teacher and the students, and to express them and examine them critically, is appreciated by the students. Teaching ideas similar to ours have been tested elsewhere and often found successful (see Hewson *et al.*, 1998), and, in the light of the learning gains reported here, this seems to be a fruitful approach also when teaching biological evolution. From the logbook entries it was obvious that at least some of the students shared this view, e.g.:

"Generally speaking, I think that the teaching has been good. Mostly because you have to do your own thinking and come to your own conclusions from what you've learnt"

There might, however, also be other factors contributing to the positive response, e.g. the very fact that there was research being done in the classroom. Although we tried to keep the "research factor" as low as possible (for instance that we did not perform any interviews, and that the observer had a very low profile in classroom), it is still possible that being the target of research stimulated the students.

5.3.3- *The sequence*: During the observations in the classroom some key points in this learning process were noticed. Already in a group discussion during first lesson, after instruction on basic genetics, it became obvious that the students readily abandoned "strive" and "purpose" as valid explanations to the origin of variation. Instead they chose between "need" and "mutation". Later, at the end of lesson 3, after further discussions of the origin of life and of different explanations to evolution, the "mutation" alternative had raised in status even more. Probably the importance of mutations in evolution is exaggerated in the students' minds at this time, but at least they seem to really have abandoned several "alternative" explanations to the origin of variation. Finally, during lesson 5, after the students had actively worked with natural selection, the observer noted that the students understood the random part

of evolution. Now it was clear to them that evolution consists of two processes and that only one of them includes chance, and during the remainder of the unit they had lots of opportunities to work with and strengthen this idea. Maybe this is the key to a sound understanding of evolution, as is suggested elsewhere (Bishop & Anderson, 1990), and our good long-term retention is dependent on successfully finding a way to solve the problem with the conception of evolution as one single process.

6. Conclusion

This study shows that you can design teaching that helps students to construct a scientific model of biological evolution. The design of this teaching-learning sequence was based on a combination of individual and sociocultural perspectives on teaching and learning, an approach that we found promising, especially regarding the long-term retention. We have been convinced that practice really can be improved by research.

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**TEACHING SOCIALLY CONTROVERSIAL SCIENTIFIC ISSUES :
RESISTANCE AND MOTIVATION, REAL OR PERCEIVED ?**

Laurence Simonneaux and Virginie Albe
Ecole Nationale de Formation Agronomique
virginie.albe@educagri.fr
laurence.simonneaux@educagri.fr

Abstract

Several countries have developed curricula which include issues relating Science, Technology and Society. In France, when considering the development of new curricula teachers are asked to question socio-scientific issues (for example genetically modified organisms and the greenhouse effect among others). Recommended pedagogical methods assume that the introduction of socio-scientific issues helps students understand the economic, political, environmental, cultural and ethical aspects of science. However, not all teachers are used to leading debates. The purpose of this study was to identify the reasons why the introduction of socio-scientific issues in classrooms is either promoted or restricted and then to establish indicators for them. We used Ajzen's Theory of Planned Behavior (Ajzen 1991). This model assumes that people's intentions depend on their attitudes, perceptions of social pressure (subjective norms) and perceptions of their ability to perform the behavior. A questionnaire was submitted to 183 teachers (pre-service and in-service) of different subjects (biology-ecology, history-geography, agricultural machinery, mathematics and physical sciences, animal and vegetal production). The results revealed different factors of motivation and resistance concerning the introduction of socio-scientific issues, depending on the subject being taught and the teacher's experience.

1. Introduction

As a component in the implementation of new science programmes in agricultural training curricula, science teaching has to help students to reflect on social issues that involve science. To help us to get a clear idea of attitudes among teachers in different disciplines, we have drawn on the theory of planned behaviour (Ajzen 1991). This theory is often used in social psychology, but is rarely applied in the field of didactics (Erten et al. 2000, Leclerc 2000). It postulates that individuals' intentions have a direct impact on their behaviour, in this case on the practice of teachers. Their intention depends on their (positive or negative) attitude towards the practice they are teaching, on their perception of the norms imposed by their environment (socio-professional requirements) and on their perception of their own control over the educational practice in question.

Pressed as they are to adopt new teaching practices with which they are unfamiliar and which address socially controversial scientific issues that involve economic, political, environmental, cultural and ethical questions, how will teachers adapt to the new context?

In order to identify the patterns that prevail in the teaching of socially controversial scientific questions, we conducted a study among novice and experienced teachers in different disciplines.

2. The theoretical framework

In seeking to grasp the orientation of teaching behaviour among teachers in different disciplines addressing socially controversial issues, we drew partly on the theory of planned behavior (Ajzen, 1991). In Ajzen's model, behaviour is assumed to be a function of individuals' intentions and their perceptions of the way they control their behaviour (see Fig.1).

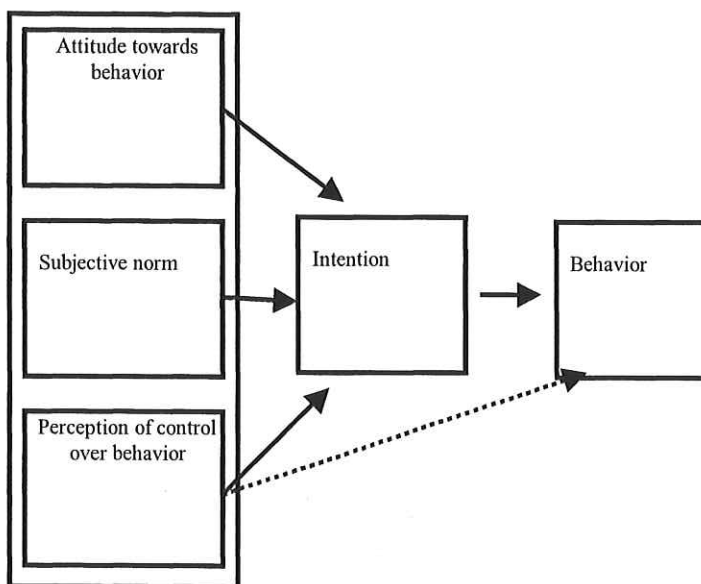


Figure 1. Model of the planned behaviour (Ajzen, 1991)

According to Ajzen, an individual has many different attitudes for any given behaviour and only a few of these attitudes are considered to be essential, depending on the expected result. The subjective norm consists of the perceived demands and assumed expectations of reference individuals, which depend on the population and behaviour being studied (for instance, family, colleagues, medical personnel, management, etc.) and also on personal motivation to satisfy these external pressures.

How individuals perceive they way they control their behaviour depends on how much they trust their own capability to achieve and control such behaviour. This perception also depends on other factors which are assumed to facilitate or obstruct the behaviour in question.

From a theoretical perspective, the effect of intention on behaviour is modified by the impact of perceptions on behaviour control (dotted arrow in figure 1), in such a way that intention is only followed by suitable behaviour if individuals' perceptions of the way they control behaviour are highly favourable. In this context, Ajzen considers intention to be the immediate antecedent for behaviour (solid arrow in figure 1).

In our study we have focussed on the behaviour involved in implementing curricula dealing with socially controversial, scientific issues in agricultural high-school classrooms. Intentions depend on the attitudes of teachers to the practice being taught, on their perceptions of the norms imposed by their socio-professional environment and on their perceptions of the way they control the didactical and pedagogical situation.

The ToPB has often been used in social psychology in order to orient individuals' behaviour by identifying indicators of their intentions. Much research has been done in the Health field (Conner et al., 1996) to promote physical activity (Godin, 1993, Hausenblas, 1997), the use of condoms (Terry et al. 1993, Albarracin et al., 2001), to encourage blood donors (Armitage et al. 2001) and organ donors (Borgida et al. 1992), to modify food and nutrition habits (Sparks, 1994, Brug et al. 1995), to reduce exposure to the sun's rays (Hillhouse et al. 1997), and to discourage drug consumption (Babrow et al. 1990, Conner et al. 1994). In the field of work research, studies have been made of job searches (Kolvereid 1996, Van Ryn et al. 1992), career choices (Giles et al. 2000), and the investment decisions of company managers (East 1993). In the environmental field, work has been done on the choice of the type of transport (Bamberg et al. 2001), the way water is used (Lam 1999), waste recycling (Taylor 1995, Cheung 1999), and reforestation (Pouta 2001).

Not much work has been done in the educational field and most of it has focussed on teachers' behaviour in relation to having to adapt to reforms (Haney, 1996), on the implementation of a problem solving approach (Shapiro et al. 2000), on health education (training for food and nutrition, Astrom et al. 2000, on AIDS prevention, Burak, 1994), on education for the environment (Erten et al. 2000, Leclerc et al. 2000). Studies have also been made of students' intentions to study physical science disciplines (Crawley, 1992).

One of our goals for this study consisted in testing the usefulness of the planned behaviour model for identifying the intentions and motivation of teachers to implement curricula based on socially controversial scientific issues. We focussed on trainee teachers since we consider that our task also involves training teachers how to deal with controversial issues being debated by scientists and society in general. However our aim is not to act on the indicators underlying intentions but to train future teachers how to reflect on their work in an objective way. This will help them to distinguish between their personal positions and the way they intend to behave when teaching controversial scientific issues.

3. Methodology

The study was carried out among 183 teachers from different subject matter in agricultural *lycées* (secondary school). This sample was made up of trainee teachers : 47 in Physics and Chemistry (PC), 49 in Biology and Ecology (BIO), 32 in Mathematics and Physical Sciences (MPS), 23 in Agricultural Machinery and mechanized farming (AM), 12 in History and Geography (HG), 8 in Livestock Production (LP) and 12 in Crop Production (CP). We subsequently made up groups of teachers by subject matters : physical sciences (PC + MSP), life sciences (BIO + LP + CP), agricultural machinery (AM) and history and geography (HG). To begin with, an open-ended questionnaire was given to 40 trainee economics teachers. Three open-ended questions were asked on attitude, perceived norms and perceived ability to remain in control of the teaching of socially controversial scientific issues.

Is it a good thing to address socially controversial scientific issues in class ? Why ? Who or what is encouraging teachers to do so ?

Do you feel capable of carrying out teaching activities that deal with socially controversial scientific issues ? Why ?

The replies provided us with various items that we used during the next stage to build up a closed questionnaire. The 183 teachers we surveyed had to reply using a scale of 1 to 3 (from *very important* to *not very important*).

4. Results

4.1 Teachers attitudes

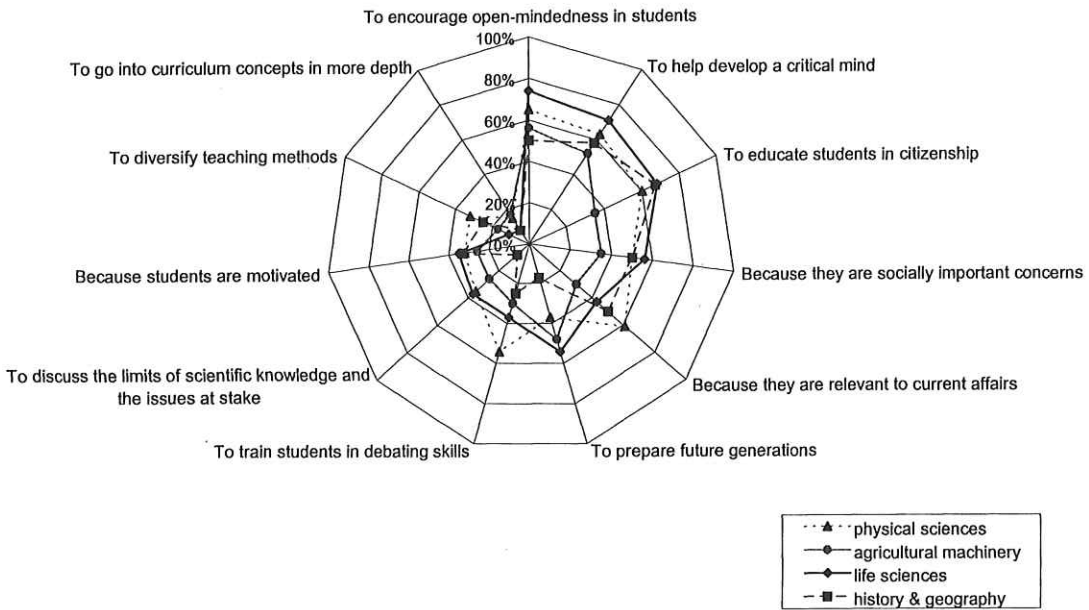
Concerning attitudes to the teaching of socially controversial scientific issues, the group of life sciences teachers (biology-ecology and livestock and crop production) appeared the most numerous to consider the importance of 7 items out of the 11 proposed items (see Figure 2).

They were 74% to select as 'very important' *to encourage open-mindedness in students*, 71% *to help student develop a critical mind*, 68% *to educate students in citizenship*, 56% *because they are socially important concerns*, 54% *to prepare future generations*, 37% *to discuss the limits of scientific knowledge and the issues at stake* and 35% *because students are motivated*.

Fewer teachers of physical sciences also considered the previous items to be very important, but made different choices in the importance attributed to 3 other items, for which they were more numerous : 61% *because they are relevant to current affairs*, 54% *to train students in debating skills* and 32% *to diversify teaching methods*.

Substantially fewer teachers of agricultural machinery (AM) saw the items selected as 'very important'. For example, only 35 % of the AM group saw *to educate students in citizenship* as very important, compared to 60 % of physical sciences, 67% of history and geography teachers and 68% of life sciences teachers. Similarly, 30 % and 35 % of the AM group selected *because they are relevant to current affairs* and *because they are socially important concerns*, as compared to respectively 43%, 50% and 61% of the life sciences, history and geography and physical sciences teachers, and to 50 % of physical sciences and history and geography teachers and 56% of life sciences teachers.

it is very important to teach socially scientific issues ..



it is not very important to teach socially scientific issues ..

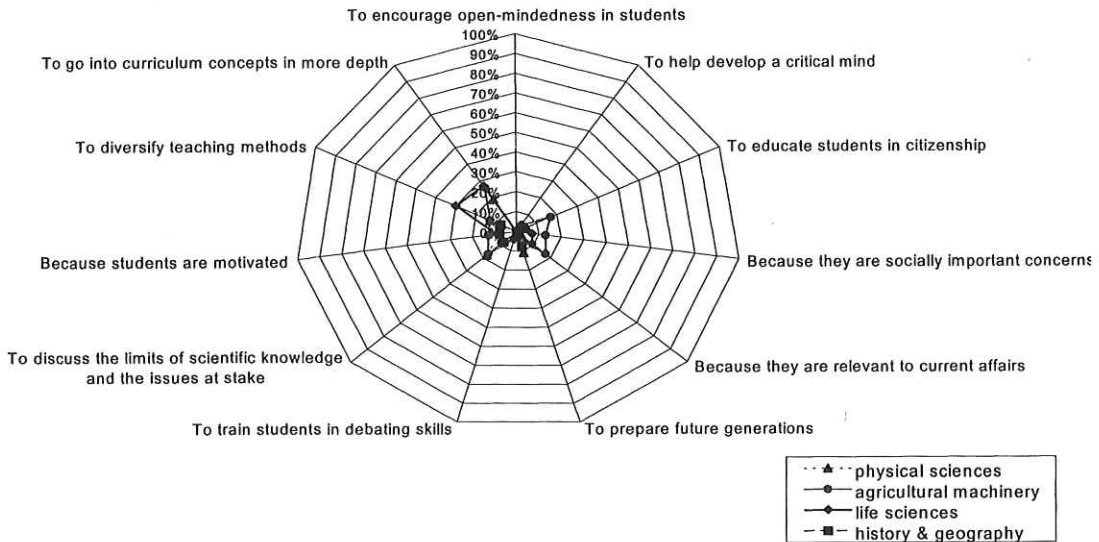


Figure 2. Teacher attitudes towards socially controversial scientific issues

A similar trend appeared for 2 other items, for which agricultural machinery teachers were the less numerous seeing them as “very important” : *to help student develop a critical mind* and *because students are motivated*.

Only the item *to go into curriculum concepts in more depth* was selected as 'very important' by 17% of agricultural machinery teachers first. With the second rank, 48% of agricultural machinery teachers selected *to prepare future generations*, after 54% of life sciences teachers.

History and geography teachers were the less numerous to consider 5 items as 'very important'. It was the case for : *to encourage open-mindedness in students* (50%), *to train students in debating skills* (25%), *to prepare future generations* (17%), *to discuss the limits of scientific knowledge and the issues at stake* and *to go into curriculum concepts in more depth* (8%). Only the items *to educate students in citizenship, because they are socially important concerns* and *because they are relevant to current affairs* were selected as 'very important' by respectively 67%, 50% and 50% of history and geography teachers, after life sciences or physical sciences teachers.

In the same time, 30% of life sciences teachers considered that *diversifying teaching methods* was 'not very important' (see Figure 2). 27% of the latter, like 26% of the agricultural machinery teachers, also felt that dealing with socially controversial scientific issues was 'not very important' as a way of *going into curriculum concepts in more depth*.

4.2 Norms as perceived by the teachers

On the subject of perceived norms relating to the teaching of socially controversial scientific issues, the physical sciences teachers, life sciences teachers and agricultural machinery teachers selected 2 items as 'very important' with close proportions (see Figure 3). It was the case for *my teaching conception*, for which they were the most numerous, respectively 56%, 55% and 52% of the life sciences, physical sciences and agricultural machinery teachers, and for *current affairs*, selected as 'very important' by 36%, 34% and 31% of physical sciences, agricultural machinery and life sciences teachers.

Then came 2 items these teachers also considered as 'very important' but with larger gaps, as fewer agricultural machinery teachers selected these items. *My own interest* was selected respectively by 51% and 50% of life sciences and physical sciences teachers, while by 39% of agricultural machinery teachers. In the same way, *students* were considered as 'very important' by 41% and 40% of life sciences and physical sciences teachers, while by 30% of agricultural machinery teachers.

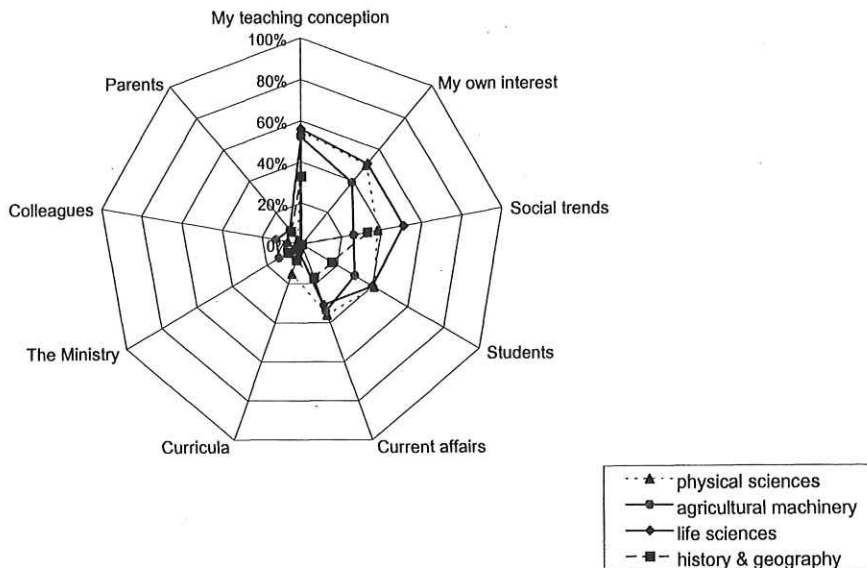
Only 26% of the latter chose as 'very important' *social trends* to encourage them to the teach socially controversial scientific issues.

On the opposite, a third of the history and geography teachers selected *social trends* and *my teaching conception* as 'very important'. These items were the only these teachers were significantly enough numerous to consider as 'very important'. We can also notice that any of them chose *my own interest*.

In the same time, they were the most numerous (55%) to declare that *colleagues* are 'not very important' towards the teaching of socially controversial scientific issues (see Figure 3).

More life sciences (63%) and physical sciences (73%) teachers considered the *parents* as 'not very important'. Finally, life sciences teachers were the most numerous (52%) to choose *the Ministry* and, like 44% of the agricultural machinery teachers, *curricula* as 'not very important'.

it is very important to teach socially scientific issues ..



it is not very important to teach socially scientific issues ..

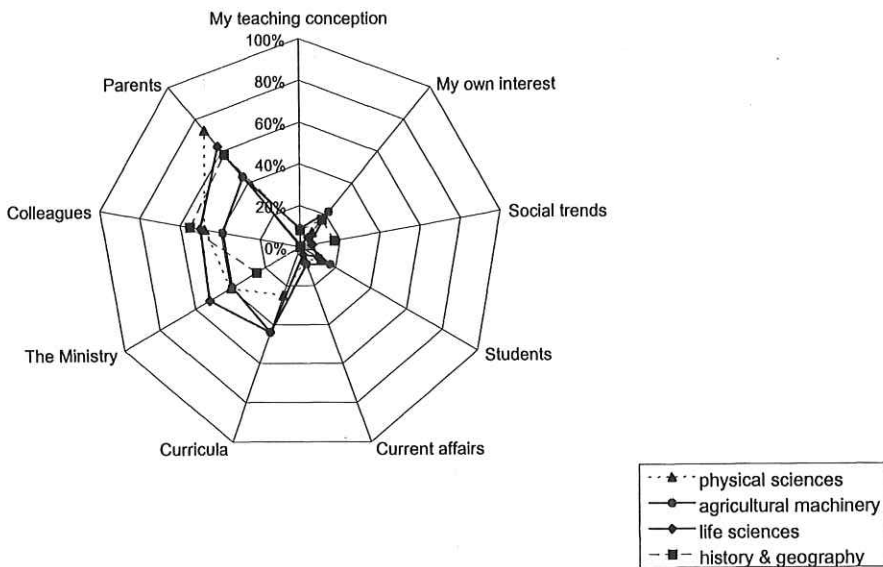


Figure 3. Norms as perceived by the teachers towards socially controversial scientific issues

4.3 Control factors as perceived by the teachers

Concerning perceptions of their ability to remain in control of the teaching of socially controversial scientific issues, we found that 4 items out of 7 were considered as 'very important' by half and more of the agricultural machinery, physical and life sciences teachers. These items were the following : *having time for these activities in class*, *working in multidisciplinary situations*, *having time to prepare activities of this kind* and *knowing how to conduct a debate*. For this latter item, the teachers of these 3 subject matters agreed within the same proportions. The agricultural machinery teachers were the most numerous to select the two items related to time. The physical sciences were the most numerous (58%) to consider as 'very important' to work in multidisciplinary situations. The lowest percentage (33 %) was for history and geography teachers. Over half of the agricultural machinery teachers (56%) and life sciences (51%) saw *working in multidisciplinary situations* as 'very important'.

Half of the history and geography teachers also selected *having time to prepare activities of this kind* as 'very important'. 42% of them considered as 'very important' *knowing how to conduct a debate* and *having taken a course in conducting activities of this kind*, while few of the other teachers selected this latter item. Moreover, 25% of the life sciences teachers, followed by 17% and 11% of the agricultural machinery and physical sciences teachers, considered this item as 'not very important'.

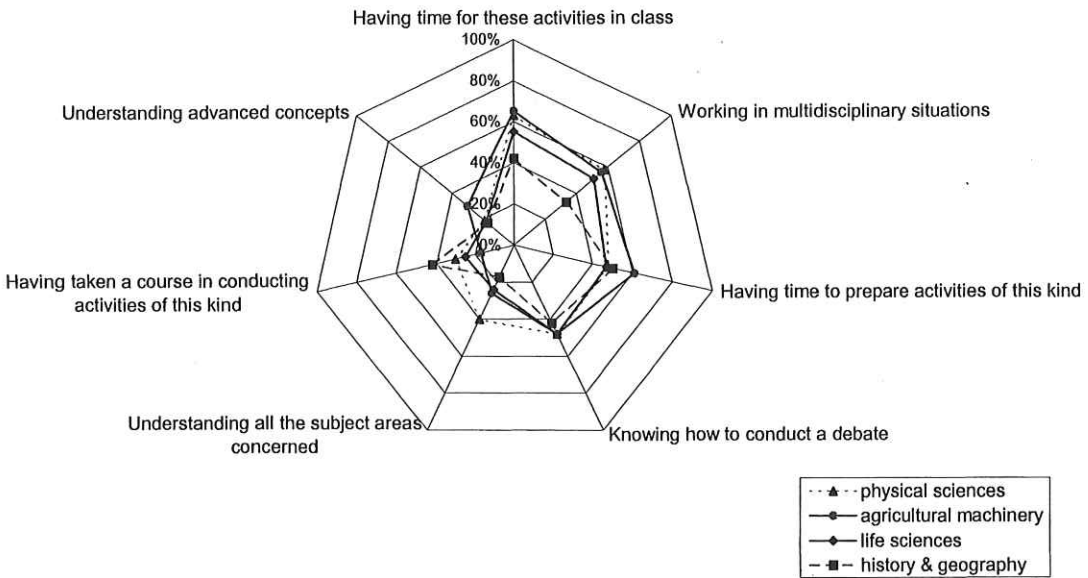
40% of the physical sciences teachers also considered as 'very important' the item *understanding all the subject areas concerned*, while 30% of the agricultural machinery teachers selected as 'very important' *understanding advanced concepts*. In the same time, this item was considered as 'not very important' by 42% of the history and geography and physical sciences teachers, and by 40% of the life sciences teachers.

The item *understanding all the subject areas concerned* was also selected as 'not very important' by respectively 29%, 25%, 24% and 22% of the life sciences, history and geography, physical sciences, and agricultural machinery teachers.

Concerning perceptions of their ability to remain in control of the teaching of socially controversial scientific issues, we found that teachers were divided according to discipline as regards the importance of *working in multidisciplinary situations*. The physical sciences were the most numerous (58%) to consider this item as 'very important' while 40% of them also considered as 'very important' the item *understanding all the subject areas concerned*. This raises the question of the meaning that physical sciences teachers attach to *working in multidisciplinary situations*. Are they expecting to develop all-rounder skills that would enable them to understand all the subject areas concerned ?

As for *knowing how to conduct a debate*, an item that all the teachers selected as very important, only the history and geography teachers did also select *having taken a course in conducting activities of this kind*. Do the others feel that training in this area is superfluous (because they already have the knowledge) or impossible (such things cannot be learned) ? Do these teachers think that the ability to conduct a debate is a gift, an innate or natural skill ? Or are they not interested because they are not going to teach on these questions ?

It is very important to teach socially scientific issues ..



It is not very important to teach socially scientific issues ..

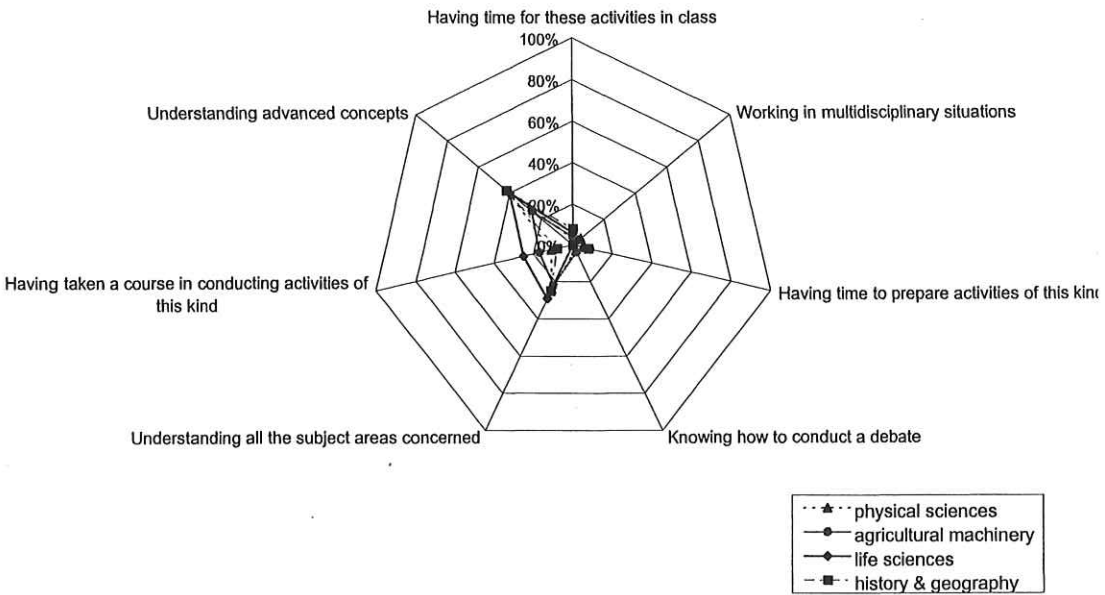


Figure 4. Factors affecting the potential to teach about controversial scientific issues

5. Discussion

This study shows that overall, teachers are in favour of teaching that deals with socially controversial scientific issues. The reasons which appear to underlie teachers' intentions appear to differ according to the subject taught.

The teachers who appear to be most in favour of teaching socially controversial scientific issues are those who teach life sciences and then physical sciences. The objective for them would be to train students to be socially responsible citizens by initiating them to the epistemology and sociology of scientific disciplines as well as by raising socially controversial issues. They are also the ones who identify the most social norms for teaching these issues, with teachers of life sciences taking more account of social pressure. While the teachers of life sciences have emphasised how important it is to have enough time to prepare for and to lead a debate in the classroom in the framework of a multi-disciplinary approach, the physical sciences teachers do not have a coherent view of the problem in that, while apparently accepting the idea of a multi-disciplinary approach, they stress that it is important for them to master all of the disciplines involved at the same time which contradicts the idea of different teachers being involved in the same training module.

History and geography teachers also appear to have a stronger consensus in favour of an approach based on introducing controversial issues. They seem to want to focus on students as responsible citizens by involving them in current issues. They only identified two social norms. These are their conceptions of teaching and of society, since they clearly do not consider their personal interest to be of any importance. This raises the question of whether their conception of their mission is not in itself a norm of greater worth?

As far as the way they perceive their control, they were the least numerous when it came to identify the importance of various control items for teaching socially controversial issues and the most numerous in considering that it is very important to have undergone specific training in leading this kind of classroom activity, which appears to show that they consider training to be the only condition for implementing such curricula.

On the contrary, the teachers of agricultural machinery are more numerous when it comes to identifying control items as very important when implementing teaching based on the debate of socially controversial scientific issues in the classroom, but they do not appear to want special training in this kind of activity. These items may be perceived as simplifying constraints which may prevent them, for material and objective reasons, from broaching these issues in the classroom or which might become a pretext for not implementing such curricula. These teachers see the introduction of socially controversial scientific issues as an opportunity for encouraging their students to keep an open and critical mind and for preparing future generations, without going into the social context.

For these teachers who have remained faithful to the productivist model in agriculture, the concept of sustainable development runs counter to a disciplinary culture in which the essential aim of the teaching delivered is to reduce operating costs through the use of complex technical equipment. Manpower is replaced by automated systems, mechanical and plant protection treatments are over-developed in order to intensify production, with no particular questions being asked about the environmental impacts of such practices (water and soil pollution, landscape change) or their economic consequences (such as smaller numbers of farm labourers). For these teachers, does "preparing future generations" then simply mean providing enough food for future generations? Or preparing them to use the most efficient technology? rather than preparing them to reflect on socially controversial scientific issues?

This study demonstrates the influence of the socio-professional and disciplinary culture of individual teachers and argues in favour of a multidisciplinary approach to the teaching of socially controversial scientific issues.

6. Conclusion

This study shows that overall, teachers are in favour of teaching that deals with socially controversial scientific issues. However, on the one hand, teachers' intentions vary according to the subject they teach and on the other hand, teaching of this sort is rare in educational establishments.

Even though science teachers claim to seek objectives that are humanist and –to a lesser degree – socio-epistemological, we have observed during their training the resistances we have already mentioned: teaching science means teaching facts and certainties, and addressing these issues means venturing into registers which these teachers feel are not legitimately theirs, while conducting debates means wasting precious time and placing themselves at risk. Research at European level has shown that science and technology teachers feel responsible for teaching facts, but do not feel they have the required competence in social and ethical questions or in managing debates. The main result from a large-scale survey made in England and Wales was summed up as follows by its authors: “*half of all science teachers interviewed feel that teaching science should be ‘value free’*” (Levinson & Turner, 2001).

These findings led us to discuss the theoretical model of planned behaviour and, in parallel, to look at new ways of designing multidisciplinary courses.

First, the theory of planned behaviour postulates that the intentions of individuals have a direct impact on their behaviour, in this case of the practices they use. This direct link between intentions and actions is debatable in the case of teaching practices, but as we all know, the intention of going on a diet or giving up smoking, for example, is not always put into practice either. The teachers' statements enabled us to identify factors that determine attitudes and perceptions of socio-professional norms and the ability to remain in control of an activity. However, their declared stance, which is favourable overall, does not allow us to infer that they will actually behave accordingly. To do so, their effective practices would have to be studied.

As regards teacher training, we found that we had to reconsider the idea of cooperation between humanities and science teachers and look at the possibility of making humanities teachers responsible for the teaching of socially controversial scientific issues. Science teachers would then be called upon to deal with facts and uncertainties in relation to the knowledge in question and its repercussions. This requires an emphasis on socio-epistemological training for science teachers.

In particular, introducing ethics into science teaching is not unanimously agreed on. Reiss (1999) has given several of the arguments used. Opponents believe that the two areas are fundamentally different and rest on different concepts (space, time and energy / right, good and duty). Science does not rest upon values, it is objective and cannot be judged by ethical standards. Furthermore, science teachers are not trained to teach ethics. The arguments in favour of ethics teaching are socio-epistemological in nature: scientific knowledge is built up in specific social contexts, conditioned by the interests, motivations and aspirations of scientists and funding organisations and has aims, which may be considered good or bad. Ethical judgements may be made on the way scientific knowledge is built up. The importance

of the personal and social implications of techno-science justifies training in ethics for students.

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INTERACTIONS AMONG CHILDREN IN SCHOOL SCIENCE CONTEXTS AND KNOWLEDGE ACQUISITION IN BIOLOGY

Patricia Schneeberger

IUFM Aquitaine - University of Bordeaux 2, DAEST, France

patricia.schneeberger@aquitaine.iufm.fr

Abstract

This contribution presents the first results of an investigation in a school science context aimed at determining the conditions that favour the acquisition of knowledge in biology within interactions in groups of 4 pupils. The chosen biology concept is that of the seed.

Interactions' analysis showed that the co-development-type interactive dynamics (according to Gilly) contribute to constructing the conceptual field studied owing to the questions the pupils ask one another. The present study appears to confirm the need for a common formulation of the problem the pupils try to solve in order to progress cognitively. Conflicting comparison-type dynamics are beneficial providing that each pupil does not put forward only arguments that contribute to confirming his own opinions. Moreover, it seems that the quality of the interactions depends on the tasks the pupils are requested to accomplish.

1. Introduction

Having children work in groups is an old and frequent practice at school, but research in psychology and didactics has just started to assess in detail cross knowledge domains the substantial benefits associated with this mode of functioning. In other words, teachers are convinced of the importance of having children compare their ideas to help them progress but are unaware of actually how these interactions benefit the acquisition of conceptual knowledge (in what precise conditions and domains).

Studies to date on the role of co-resolution interactions in the development of cognitive capacities is currently very numerous both in the areas of psychology and in didactic disciplines (Amigues, 1991 ; Blaye, 1987 ; Carugati, Paolis & Mugny, 1980 ; Gilly, Fraise & Roux, 1988 ; Gilly & Roux, 1994 ; Hardy & Platone, 1992 ; Howe, Tolmie & Rodgers, 1992 ; Pine & Messer, 1998 ; Schubauer-Leoni, 1997). The authors have been influenced initially by studies of socio-cognitive conflict (Doise & Mugny, 1981 ; Perret-Clermont, 1979). Based on the hypothesis that children can benefit more from a co-resolution than from an individual solution during the completion of a task, these authors have discussed diverse conditions that may make such a co-resolution beneficial.

There are several investigations that have attempted to study the interactive processes of peer groups, in categorizing the different dynamic forms. Gilly (1988) describes four types of dynamics or co-working groups:

- Acquiescent co-development group: one of the children (A) develops a solution alone and proposes it to the other child (B) who listens and provides agreement: B is not passive; he or she works to construct a parallel solution to the response of A.
- Co-development group: the child (A) starts an action or a phrase, reformulated by B, who adds input to the work, which is then reformulated again by A, etc...(which expands the universe of possible solutions).
- Comparison with disagreement: A proposes and B does not accept but without discussion or other propositions.
- Contradictory comparison: A proposes and B does not accept. B reacts with a structured argument or another proposition. This confrontation results in either no-resolution, an agreement, or an experimental verification.

Roux (1996) distinguished two categories of children who may play an important role in a group interaction : (a) the cognitive leader, who proposes a resolution procedure and defends the proposition while making the ideas of the other group members progress, and (b) the social leader who organizes the social relations within the group and listens to what the others say.

The interactive process has been studied in psychology through classroom behavior, i.e. the interactions between the pupils and the teacher. Brossard (2000) explains the need to develop a framework for common activities between diverse interacting individuals, where there is a social space providing interpretation and meaning for the interventions of each of the group members.

For researchers interested in didactics of science, the diversity of student conceptions within the same class is a source of multiple confrontations between students that may trigger off the first reconsideration of his or her point of view. Such discussions may be more or less structured on real life (for example if you give a seed to the pupils, it could be opened or it could be water-soaked and it is'nt in its real form) and they constitute new occasions to

encourage exchanges between learners. At such moments one may observe the expression of disagreements concerning the meaning given to diverse observations. These moments of social interaction are often useful to induce social-cognitive conflict as identified through the numerous contributions of the works of Bednarz and Garnier (1989). However, some authors (e.g. Joshua & Dupin, 1993) underline the importance of considering the characteristics of the social situation of a given class including mediation by the teacher and the specific nature of the knowledge addressed.

For Dumas-Carré, Weil-Barais, and colleagues (1998) the concept of inter-subjectivity (borrowed from linguists) takes its meaning in the verbal interactions in science classes that involve the common quest for scientific meaning.

2. Present investigation

2.1- Our objectives and hypothesis

The work of our research team addressed the role of negotiations of meaning in scientific learning. The situations used were aimed at optimally exploiting the cognitive heterogeneity within pupil groups while also promoting dialogic exchange.

Without assuming that our results may be extrapolated to other settings, the present study attempts to complement previous research concerning the interactions between learners in school situations by focusing on the conditions that are likely to promote knowledge evolution. We had two main objectives: 1) to work on the interactive process rather than to focus only on the results of such interaction; 2) to promote acquisition of specific scientific skills (objectivity, problem-domain-development, etc), and the establishment of a conceptual domain and its components.

The first hypothesis indicates the need of a common formulation of the problem domain among peer groups in order to progress cognitively. As shown by the work of french researchers (Fabre M. & Orange C., 1997), scientifically-inspired debates among children may promote a "problems domain" development .

A second hypothesis concerns the role of interaction dynamics in the construction of new knowledge. It may be posited that a principal form of interaction such as that of "co-development" (as described by Gilly, 1988) should allow for cognitive progress in terms of the development of a questioning domain.

The third hypothesis addresses the necessity of a 'cognitive leader' within each student group with the objective to promote a "co-development" dynamic. The cognitive leader, through his or her multiple propositions and organisation of reason can encourage the construction of conceptual knowledge.

2.2- Method

Subjects

The 8 year-old pupils and their teacher from a third grade class in a city school participated in this study. We analyzed two work groups each composed of 2 girls and 2 boys (Group A: Zoé, Elise, Louis, Jules ; Group B : Lucie, Alexandra, Thomas, Benjamin). Within each group, considerable variance could be observed concerning basic knowledge of the biological concept studied (the seed).

Procedure

There were three work sessions in small groups and some sessions as a whole class. The pupils' conceptions were assessed at the beginning and at the end of learning. Conceptions were also assessed at the beginning of the first and the second group sessions. The pupils were asked to compare their ideas and draw one or several pictures with a caption or sentences to explain if necessary. The instructions for the three work sessions were as follows:

1. first session: the pupils responded to the two questions: (a) what is inside the seed ? and (b) what changes occur inside the seed when it begins to grow ?
2. second session: the pupils had to observe the insides of different seeds and make a drawing after reaching agreement (on the structure of a seed).
3. third session: in the beginning of the session, the teacher described the content of a seed and then gave sprouting seeds to the pupils. The pupils then responded to several questions: (a) what part of the seed becomes the plant ? (b) what happens to the sprout ? (c) what happens to the chaffe ? and (d) what happens to the skin ?

All classes were filmed and studied, and all student works (drafts and posters) were collected. Based on a large sample (30 to 40 minutes of recordings of each work group session) we analyzed the results of learning for each student by identifying the evolution based on different tests of the conceptions about seeds. The evolution profiles of pupils could then be compared and hypothesis could be formulated concerning the role of different intervening parameters: the initial student conceptions, the proposed situations, the interactions, the teacher's interventions.

To analyze the circulation of ideas we took extracts of the different categories of ideas articulated chronologically (see Figure 1). In this way, we could identify the first student who formulated an idea, those who took up the idea and at what moment they did so. Based on this graph, we conducted a micro-analysis of specific interactions.

To analyze the communicative nature and forms of interactions, we attempted to identify the elements allowing the appreciation of the social or cognitive status of the pupils in the group (e.g. the recentering on the required task, the reformulations of ideas and the questions asked to other members of the group). As well we examined the periods of common knowledge building where each student provided a building block or periods of exchange concerning the ideas formulated.

3. Results

3.1- Circulation of ideas within groups

Example from Group A- 1st Session of Interaction

Analysis of an extract of the session: just before the session each student drew the interior of the seed again as they had done the day before when working individually. The words pit, seed, and shell were pronounced. Nothing before was mentioned regarding the term 'sprout.'

Lo (23): " In my opinion, there are sprouts in the seeds."

El (24) : " Yeah but before it grows."

Lo (25): " Before the sprout grows ? "

El (26): " Uh, there's nothing. "

Ju (27): " There's the seed. "

- Lo (28): "No because if there was only the seed then how could that be?"
 Ju (29): "Maybe the seed is like all colored with a little white hole in the middle."
 Lo (30): "Maybe its just a tiny little dot in the beginning and then it starts to develop, etc.."
 Ju (31): "Then it becomes a line. That takes time. Its probably solid, and its probably very colorful because the seed takes time to come out."
 Lo (32): "In the beginning, what is it that makes the plant grow?"
 Ju (33): "Yeah, but that's not what they asked us."
 Lo (34): "They asked what there was before the seed grew."
 Zo (35): "In the beginning in the seed there's just like a little bit of dust and then after..."
 Lo (36): "Beans grow, that makes flowers and gives fruit."
 El (37): "In the seed before it grows there is surely something."
 Lo (38): "Who fed it?"
 Zo (39): "It is fed by what's inside."
 Lo (40): "Oh Ok, so what is inside?"
 El (41): "We're drawing."
 Lo (42): "For example, here you see this is the seed and here it's the ground. And you give it water for example."
 Zo (43): "Yes, but it won't be fed by water because there is a shell all around it."
 Lo (44): "Yeah, well..."
 El (45): "There's got to be some food on the inside."
 Lo (46): "And then it breaks the shell and it becomes a sprout."
 El (47): "A little shoot."
 Lo (48): "So it's the food that makes it grow."

Figure 2 presents a graph of the exchanges (the arrows permit a visualization of the establishment of different ideas).

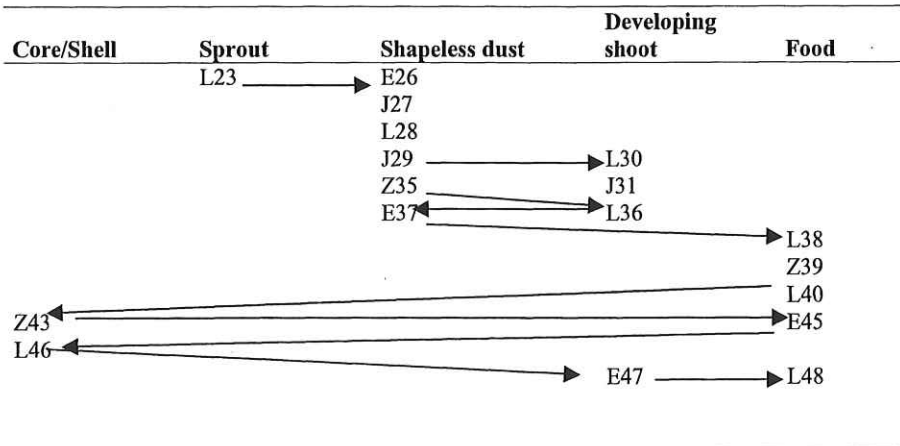


Figure 1. Circulation of ideas within group A (extract turn-taking 23-49, session 1).

Louis (23) presents a new idea (presence of a sprout inside the seed) that will be a source of confusion. Louis (23, 28) wonders about the origin of the plant that is inside the seed, which represents progress relative to his "spontanéiste" conception (the term "spontanéiste" is taken

from Giordan A. & De Vecchi G., 1987). In this conception, the plant arises from a sort of spontaneous generation.

Louis (30) introduces the idea of development. Finally, Jules (31) adds the idea of time duration and leaving (breaking the shell). Elise (37) restarts the debate. Louis (38) again introduces a new idea (food) therefore associating development and the need for food. He raises the notion of what is required ; the presence of something that develops inside the seed is only possible if there is food inside the seed (relation between the structure and the function of the elements). Note that even if Louis expresses first the idea of a sprout, he appears to hesitate in accepting the notion that a sprout exists before sprouting. There is some ambiguity concerning the term "sprout", which designates both a future plant that is sealed in the seed as well as a young root that appears at the moment of sprouting. It appears that Louis raises ideas in the hope that others will take them up, reject them, or develop them. Zoé (43) comes back to the idea of a shell (see 1st part) and Louis appears to admit that this shell could break to allow something to come out.

3.2- The scientific problems raised

Fabre and Orange (1997) propose the concept of a problem space development for the study and didactic regulation of scientific debates in class. This approach from cognitive psychology allows formalization of the phases of debate by triggering responses to problems on which they are based.

In order to finish the requested task over three sessions, the pupils raised different problems of a scientific nature (table 1), without formulating them explicitly, and attempted from time to time to resolve them. Given this, they entered the domain of research itself by studying the seed and its germination and with the help of the teacher defined a problem space. This construction was achieved by determining various empirical problems /constraints and by considering solutions that might be possible.

Table 1. Problems raised by pupils during three sessions.

	Group A	Group B
Session n° 1	<ol style="list-style-type: none"> 1. How is the germ formed during germination? <ul style="list-style-type: none"> -Where does it come from ? -Where is it formed (inside or outside) ? -What makes it grow ? Where does the food come out ? -How can the germ come out ? 2. How are the roots formed ? <ul style="list-style-type: none"> -Does the little plant contained in the seed have roots ? -When do the roots grow ? 3. What are the cracks in the shell for ? 4. What does the seed become after giving the plant ? 	<ol style="list-style-type: none"> 1. Do the roots come out first ? 2. Is there something between the germ and the shell ?
Session n°2	<ol style="list-style-type: none"> 1. Is there a germ inside the seed (an idea which Louis seems to question) ? 	<ol style="list-style-type: none"> 1. How and where does the shoot come out ? 2. Do the seeds have the same structure (hardly discussed)
Session n°3	<ol style="list-style-type: none"> 1. Are the germ and the little plant in the seed the same thing ? 2. Do the roots form part of the plant ? 3. What allows the germ to develop ? 4. Does the shell help to make the plant grow ? 	<ol style="list-style-type: none"> 1. Are the germ and the plant the same thing ? 2. How do the roots appear ? 3. What is the substance inside for ? (hardly discussed)

In total, group B worked much less on the problems than group A. The question is doesn't this fact represent an essential difference that has repercussions for learning? The results obtained in the post-tests appear to confirm the importance of creating a problem domain development in order to facilitate scientific learning.

3.3- Evolution of knowledge about seeds between pre-test and post-test

The pupils in group B had made less progress than those in group A between the pre- and post-test. In fact, certain aspects of germination were not understood (notably the structural and functional relationships between the roots, stem, and sprout) by group B while group A achieved a satisfactory level of knowledge for this class level (Elise and Zoé had a better stabilization of knowledge).

Table 2. Comparison of cognitive progress of pupils in group A and B

Group	Pupils	First ideas (pre-test)	Progresses in knowledge between pre and post-test	Comments : post-test errors
A	Elise	In the seed there is a little germ which turns into a stem	<ul style="list-style-type: none"> - the seed has a skin - inside the seed there is a germ with the beginning of a root, stem and leaf - the young plant first uses the food from the seed (contained in the cotyledons) 	This pupil has understood well the structure of the seed and what the different parts turn into.
	Jules	This pupil had few ideas at the beginning regarding the structure and transformations of the seed	<ul style="list-style-type: none"> - the seed has a skin - inside the seed there is a germ which turns into the plant - the young plant first uses the food from the seed (the flesh) 	This pupil has made good progress, however, he is not sure whether the germ is present in the seed at the beginning (before germination)
	Louis	<ul style="list-style-type: none"> - the seed is surrounded by a shell - in the seed there is a center - the germ can be seen on the surface of the seed 	<ul style="list-style-type: none"> - the seed has cracked skin which lets water in - inside the seed there is a germ (miniature plant) which grows and comes out and turns into a plant - inside the seed there is also food (flesh) which is used by the plant 	This pupil has changed his first ideas but still finds it difficult to admit that : <ul style="list-style-type: none"> - the germ is present in the seed even before germination, - the roots also are part of the germ.
	Zoé	In the seed there is: <ul style="list-style-type: none"> - flesh - a little shoot (germ) which turns into a stem. 	<ul style="list-style-type: none"> - the germ is a miniature plant with a root, stem and leaves - the young plant first uses the food from the seed 	This pupil has understood well the structure of the seed and what the different parts turn into.
B	Alexandra	Inside the seed there are pipes linked to the center (heart) which provide water The flesh protects the seed. The roots come out first and allow the plant to feed	<ul style="list-style-type: none"> - the seed has an integument which breaks when the germ comes out - inside the seed there is a germ which gives a plant - the young plant first uses the food contained in the seed 	This pupil has considerably progressed but thinks that the germ is not present in the seed at the beginning (before germination)

Benja- -min	<ul style="list-style-type: none"> - the seed contains another little seed - the seed breaks and a tiny piece of plant appears 	Inside the seed there is: <ul style="list-style-type: none"> - flesh - a germ which comes out of the seed (during germination) 	This pupil has not understood certain aspects : <ul style="list-style-type: none"> - he considers that the beginning of the stem and the beginning of the root are separate in the seed - he thinks that the plant takes its food from the soil from the very beginning
Lucie	<ul style="list-style-type: none"> - Inside the seed there is a stem which comes out of the seed - the germ grows 	Inside the seed there is a germ which comes out during germination . The flesh is used to feed the young plant.	This pupil has made little progress regarding the relationship between the germ and the roots.
Thomas	There is a miniature plant inside the seed.	<ul style="list-style-type: none"> - the seed has a skin which protects it - the roots and the stem are formed from the germ which is in the seed - the young plant first uses the food contained in the seed 	This pupil has clarified his first ideas but considers that the germ is not present in the seed at the beginning (before germination).

3.4- Nature of interactions

An analysis of dialogues demonstrates the 4 types of co-development proposed by Gilly (1988). The interaction still did not involve the entire group (only 2 or 3 pupils), and the dialogues contained moments when the children did not express their opinions about the object of the conversation but rather joked or discussed the materials (e.g. pens) used.

Figures 2 and 3 present the respective weight of the different co-developments for the two groups and over the three learning sessions.

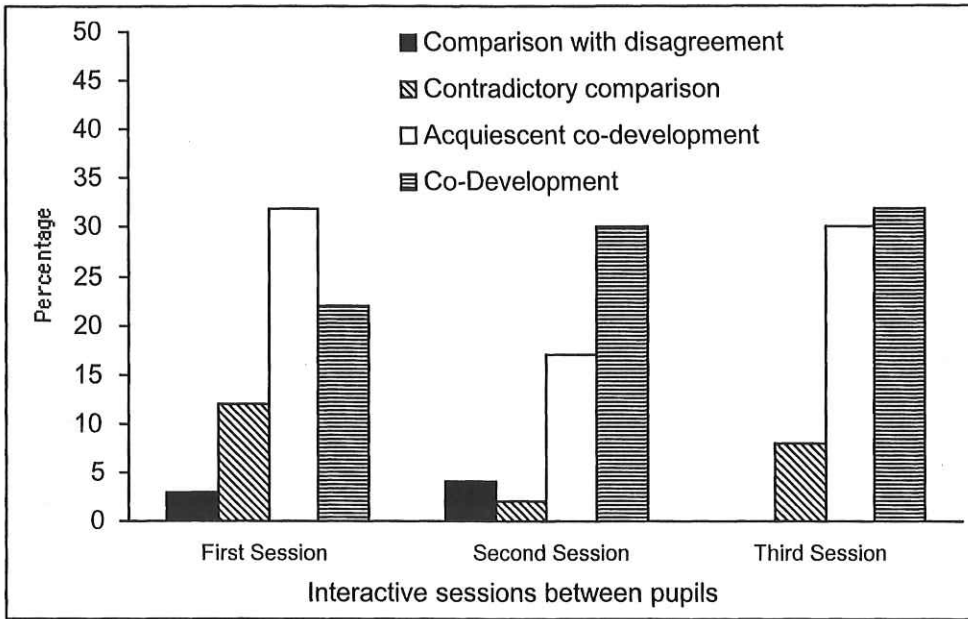


Figure 2. Evolution of types of co-development in group A.

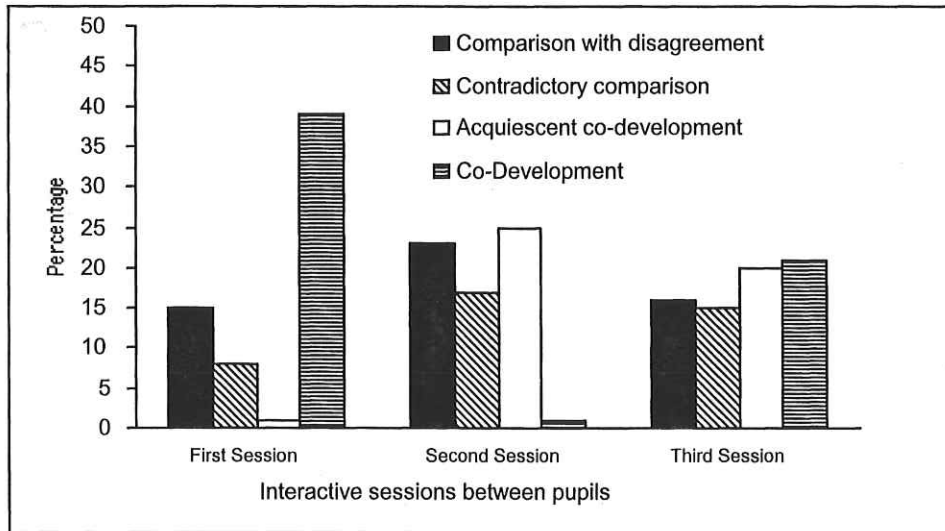


Figure 3. Evolution of types of co-development in group B

The pupils in group A behaved very similarly regardless of the specific session with a very high level of "co-development" phases and "acquiescent co-development". However, very few "comparisons with disagreement" were observed.

Analysis on the body of the sessions demonstrated that the phases of "co-development" appeared as early as the beginning of each session; those of "acquiescent co-development" appeared often when the discussion needed to be synthesized or when the teacher was present. For group B, the distribution of the different types of co-development varied with each session. During the first session, it was above all "co-development" that was dominant, while by the third session the four exchange modalities had equal importance. In any case, the level of "co-development" across the three sessions was much lower than in the other group.

For group B, analysis performed on the corpus showed that at the first session, the pupils functioned especially in a "co-development" mode and only from the 47th turn to speak. This resulted from the insistence of the teacher who encouraged them to think and discuss together. Again at the end of the first session the teacher seemed to be the factor triggering an interactive "co-development" type dynamic.

At the second session, a form of "acquiescent co-development" became apparent in group B because the children were simply taking turns to express what they saw or thought they saw inside the seeds.

4. Conclusion

This comparative analysis of two groups of pupils demonstrates certain conditions favouring the appropriation of cognitive skills (objectivity, problematisation) and scientific learning as well.

The interactive dynamics of the "co-development" type allow the conceptual field to be developed by the large number of questions that the pupils ask themselves (knowledge's problem domain development).

Clear progress was made on the post-test by the group of pupils who learned how to formulate questions and problems. This is an indication that they succeeded to create a "problem-domain" about the concept being studied. Such cognitive progress and the construction of the "questioning domain" seem to be possible, provided that the participants set up from the very beginning a space of shared meanings serving as a common framework (or common representations) in which any verbal locution may be interpreted.

The presence of a cognitive leader within the group would seem to be the prerequisite for creating a dynamic which is largely "co-development" in nature. However, for this process to be efficient it must evolve during the interaction. In a given group, several pupils may play the role of cognitive leader according to the different modalities and at different moments. Co-development was possible in group B whenever the teacher took on the role of cognitive leader. Indeed, the role that the teacher assumed was to help the pupils to better listen and to understand each other in order to participate in the process of comparison and accept each other's points of view (see Ponce C. & Schneeberger P., 2002).

The various situations proposed to the pupils during the whole phase of learning influenced the functioning of the groups helping them to stabilize certain meanings. The task of making a group drawing required common agreement and adopting a solution to the problem encountered. Discussion often ensued at the moment of making the decisions. The pupils could then better understand the different components of the problem that they were working on through discussion .

The phase of observation is also a propitious moment for the pupils to compare their notions with reality. Pupils did not interpret reality (e.g. two seeds cut into two parts) in the same way according to their level of knowledge. Observation was therefore a means of investigation and not a support for a demonstration as is often the case in the teaching of biology.

This study shows how teachers can take advantage of talks between pairs to build learning in science. Indeed, analysing the circulation of ideas among the groups gives a fairly good idea of how some pupils re-interpret other pupils' ideas to make them theirs. Such is the case in the passages related to co-construction that reported here; each production participates of a specific area of exchange according to a dialogical build-up. Thus, the different points of view may contribute or stimulate the others' thinking processes or raise arguments or explanations and the whole eases the way to understanding an object, a transformation, a biological or geological phenomenon.

One of the developments of this research would aim at exploiting our works in a teachers' training perspective. Our team proposes to use this research to build tools for school teachers and trainers to help them elaborate projects around interactive classroom situations liable to set up an efficient debate inside the class. The type of activity we favour implies some use of argumentative debate to develop children's ability to see another point of view, different from theirs, thus reaching a broader representation. The building of scientific knowledge is, for us, indissociable from this education to objectivity which is one of the issues of scientific learning.

The analyses we operated gave us an insight into how knowledge is reorganised through communicative situations. We will pursue our work by considering the pedagogical implications ; to do so, we will need to develop studies on what happens during the learning process, paying particular attention to a number of conditions ,which we have started to point out, which should be respected in the way teaching is organised.

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**WHAT BIOLOGY TEACHERS SAY
ABOUT LABWORK AS PART OF BIOLOGY EDUCATION**

Maryline Coquidé
Institut Universitaire de Formation des Maîtres de Bretagne
(Rennes – France)
maryline.coquide@bretagne.iufm.fr

Abstract

What are French biology teachers' conceptions as regards practical work in schools? A survey has been carried out amongst 7 secondary school teachers in the form of semi-guided interviews. Whilst strongly in favour of experimental practices, the teachers' comments underline several difficulties. On analysing the content of these interviews, various ambiguities are highlighted concerning the situations in which experimental activities take place in biology education. The teachers interviewed consider that labwork activities develop multiple competence, and also allow intellectual constructions in each and every case. The interviews also brought to light the difficulties involved in achieving a certain level of coherence between didactic choices and educational activities.

The application of different "didactic modes" (Astolfi & al. 1985; Martinand, 1986), adapted to experimental activities, can help to define the purposes of practical work in biology education (Coquidé, 2000). In this sense, it is possible to characterise a mode of "practical familiarisation" with regard to living beings, a mode of "empirical investigation", and a mode of "intellectual elaboration" for concepts and biological models. These can be used as a framework for discussing the use of living beings in biology practical work. An important question concerns the relationship between these various modes and how they inter-relate in terms of progression and coherence: at the level of successive educational choices by the teacher to organise pupils' learning activities, and in terms of organisation of the curriculum.

1. Introduction

It may seem "obvious" that Biology education, with its references to scientific practices, should automatically involve laboratory work. Laboratory activities can fulfil multiple purposes (Lazarowitz & Tamir, 1994; Galiana, 1999). However, the European research project (*Labwork in Science Education*, Séré M.G., 1998) underlines the difficulties involved in the application of practical work in science education and the impact of these activities remains under discussion (for example, Millar, 1996; White 1996; Hodson, 1998; forum *Beyond 2000*). Moreover, with regard to biology, practical work in the laboratory is faced with several ethical restrictions and must take into account multiple scientific and practical constraints. Thus laboratory activities in biology education appear as a "false obviousness": an obviousness which is not in fact self-evident but which has to be constructed.

A collaborative research project involving the INRP and the IUFM at Rouen (Coquidé & al., 1998) investigated the empirical approach in relation to the theoretical approach in science education. The educational problem, which motivated the team's research was to avoid possible educational drift, such as experimental approaches in biology being limited to analyses or data collection and processing exercises. The team was also interested in the place of experimental activities in biology education.

2. What can be the purposes of labwork?

A European survey (Séré, 1998) has been carried out which highlights science teachers' diverging opinions with regard to labwork purposes. In their synthesis of science education studies (from 1954 to 1990), Lazarowitz and Tamir (1994) commented: "*Perhaps no other area in science education has attracted so many research reviews as learning, teaching, and assessment in the laboratory*". They identify 4 groups of purposes for labwork:

1. *Science laboratories should provide concrete experiments and ways to help students confront their misconceptions.*
2. *Science laboratories should provide opportunities for data manipulation through the use of microcomputers*
3. *Science laboratories should provide opportunities for developing skills in logical thinking and organisation, especially with respect to science, technology, and society (STS) issues.*
4. *Science laboratories should provide opportunities for building values, especially as they relate to the nature of science."*

For their part, Nott and Wellington (1996) consider ten purposes for labwork. We can group them into 4 categories:

1. Motivation and pupil interest,
2. Learning of skills,
3. Learning of scientific concepts and theories
4. Epistemological perspectives and nature of science

These categories are to be compared with Hodson's propositions (1988):

1. To stimulate interest and enjoyment
2. To teach laboratory skills and techniques
3. To teach the process of science
4. To assist the learning of scientific knowledge.

But these categories are wide and don't take account of specific questions about learning and teaching biological concepts, theories and models. They can be considered more "psycho-

pedagogic” than “didactic”. Hence, Millar (1996, 1999) analysis of laboratory activities was based on comprehension and scientific knowledge rather than technical abilities.

In Martinand’s epistemological, psychological and pedagogical point of view (1986), relations between material aspects, concepts and theory are very intricate. In order to construct a progressive approach to the world in science education, he argues that students’ familiarisation with nature, with matter and with living beings, will be achieved and articulated with their intellectual elaboration (Figure 1: diagram of scientific modelling and conceptualisation, 1996).

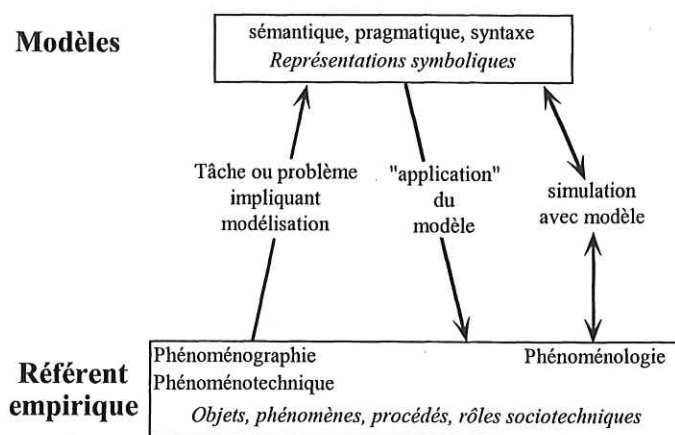


Figure 1. Diagram of scientific modelling and conceptualisation (Martinand, 1996)

In biology teaching, experimentation contributes to the creation of an empirical reference for developing concepts or scientific models and for learning skills. How, from an epistemological point of view, is school labwork (“*Travaux Pratiques*” or TP in French curriculum) valid? How could it contribute towards teaching how “to do science” and not just to learning how to achieve experimental results?

In our research, experimental activities for pupils are considered as being:

- a reference for building knowledge,
- and a means to be confronted with the reality of doing science, within an educational setting.

3. Methodology of the study

In one stand of our research, investigations were centred on trying to obtain more precise information about the actual practice in schools. What image do teachers have nowadays concerning experiments on living beings? What empirical situations are currently organised in schools? What are the characteristics and possible obstacles currently encountered in experimental practices carried out on living beings in classrooms? The classroom of « Première » (sixteen and seventeen old students) was chosen because the opportunity of the « experimental sciences » option which allowed long time of practical activities.

Semi-structured interviews (Figure 2), about the “experimental sciences” option in the classroom of “Première”, were carried out with seven contrasted teachers from secondary schools (age, sex, school’s characteristics, Figure 3). Interviews lasted about one and a half

hours and were designed to enable us to ascertain teachers' conceptions of experimental practices at school, as reflected in their own practice.

Could you tell me about the "experimental science" option? What is your personal experience in the domain? What are your students' achievements? How would you define your role as a teacher? What scientific problems are to be resolved? How have they been built? What interests and what limits do you find in experimental activities? According to you what practical work seems to be interesting at secondary school level? What are the pupils' interests?

Figure 2. Questions about the "experimental sciences" option

Teacher	A	B	C	D	E	F	G
Sex	M	M	M	M	F	F	M
Grade	agrégé	certifié	agrégé	certifié	agrégé	agrégé	agrégé
Ancients	5 years	5 years	25 years	15 years	6 years	5 years	10 years
School	Public school	Public school	Public school	Private school	Public school	Public school	Public school
Town	12 000 residents	13 000 residents	17 000 residents	110 000 residents	200 000 residents	17 000 residents	110 000 residents

Figure 3. Profile of the teachers

Interviews were analysed through a thematic analysis (Figure 4).

A. Appreciation of the "sciences experimentales" option

- A. 1 : positives and negatives aspects for the teacher
- A. 2 : positives and negatives aspects for students

A. Choice of option's themes

- B.1 : biological themes which were worked in the year
- B.2 : living beings' level of organisation
- B. 3 : biological concepts

B. Experimental practices' characteristics

- C.1 : functions of experimental practices
- C.2 : pertinence and feasibility
- C.3 : relations with literature
- C.4 : characteristics of biological labwork

C. Characteristics of scientific approaches described

- D.1 : exploration
- D.2 : validation

E. Pedagogical organisation

- E.1 : material and time aspects
- E.2 : teacher's intervention
- E.3 : nature and functions of didactic aids used
- E.4 : nature of regulation and evaluation

F. Others commentaries

Figure 4. Thematic analysis of the interviews

Then an analysis grid of didactic modes for experimental activities was used to analyse interviews. First the context and purposes of experimental practices, as well as the explicit management activities (set up devices, teacher's guidance...) were selected in the teachers' comments. Then, it was necessary to recombine some elements of the teacher's speech to reconstruct the underlying logic of their approach.

4. Main results of the thematic analysis

Results of this thematic analysis can be compared with those produced by other researchers (Brunet, 1996; Vialle, 1998; Lika, 1999). These thematic analysis identified interests and difficulties in experimental practices, implemented methods, and teachers' conceptions of practical activities. Biology teachers underlined labwork's interest but also showed its difficulties.

4.1- Teachers views on the role of labwork in the teaching and learning of biology

The biology teachers mainly stress psychological and pedagogical arguments. They commented on "*students' motivation*" and noted that labwork "*makes them active*". Practical activities are essentially considered as necessary for active learning and as the alternative to transmitted "frontal" teaching.

Experimental activities are also considered as concrete and pupils' hands-on an essential key for comprehension. The essential interest of labwork seems to be the student's manipulation.

"I have chosen these themes because of the opportunity for manipulation" (teacher B, reply R 1). *"It's necessary to encourage the most students' manipulation"* (E, R 1).

"Nutrition, it's a theme with not a lot of manipulation" (E, R 7).

"If students don't manipulate, it's not a practical activity" (F, R 18).

But the importance of the concrete manipulation aspect can induce confusion between investigation and experiment.

"It's concrete because it's the student who does the physical exercise, and it's concrete because variation of respiration is in real time on the microcomputer" (D, R 11).

"It would be better to propose themes which have the possibility of real experiment in school laboratory, not themes which rely on paper exercises, it's not concrete enough" (F, R 32).

Development of reasoning skills is also frequently mentioned and some teachers make a link between students' manipulations and the development of skills.

"It's interesting at a methodological level, for inductive and deductive reasoning" (A, R 20).

"During these option they are real practices. Students work to develop the technical skills and that helps them to learn the biology" (B, R 15).

Investigative practical activities provide an opportunity for students to develop an understanding of the practices and processes of science (Nott & Wellington, 1996). Teachers find the uncertainty inherent in this learning process difficult to cope. They want students to develop an understanding of how to undertake scientific investigations but they also want the experiments to be done in the "right" way and to achieve the expected results. So, they frequently intervene in the students' working process during labwork.

"Every time I leave students to their own, they have difficulties with many practical details, for instance how too keep constant humidity during germination ?" (B, R 9).

"It will be go in several and different directions if I don't lead them" (G, R 18).

4.2- Teachers' comments on the implementation of labwork in biology

When teachers considered students' difficulties in problem setting and resolving, two of them comments on methods and scientific approach with moments of investigation and moments of validation. But, referring to Claude Bernard's experimental approach, three others only talked about a step by step experimental method.

"Students have a lot of difficulties with scientific problem building" (A, R1).

"If I ask them to set a problem, I fail..." (E, R 20).

"I think that scientific problem is very difficult for our students" (F, R 4).

"I consider that germination is a very good theme to study different stages of an experimental method" (...) *"I have a problem, I give an hypothesis, I made something to test and I obtain a result"* (G, R 18 and R 21).

When French Biology teachers compare labwork in Biology with abwork in Chemistry or in Physics, they consider the "ready-made" files used for teaching these subjects as more "imposed" on the pupil. However they don't comment on the complex nature of biological investigations or about the variability of living beings. Biology experiments are essentially described as physical investigations requiring rigorous separation of factors.

"At the beginning, students have difficulties to control only one factor" (F, R 8).

"The notion of evidence seems to be obtained, the necessity of working with only one factor also" (B, R 14).

"Students have to see that they can't say anything with only one experiment, without proof" (A, R 16).

While these teachers often talked about the need for pupils to produce a lab report they rarely discussed other forms of writing such as literature or web searches or the production of a bibliography. One teacher regreted the absence of documentation or information really adapted to the students' needs and level.

"If students consider their work ended, they have to give a report with biological theme and motivation in introduction, then scientific problem, different stages, and also which difficulties they had". (C, R 10).

"Students must go to library and search the literature, but documents are often too difficult for them" (E, R 11).

The pedagogical practices of most of these biology teachers were generally aimed at the validation and application of biological concepts and theory. The possibility of exploration by the students themselves seems uncommon. Clarke and Fujimura (1992) have pointed out that biological research is dependent on access to resources. Although these teachers don't mention "mini-projects", some of them showed students the equipment and materials available to them in the school laboratory.

"I show to students all the materials available to them in the laboratory" (C, R 3).

"Students don't know what activities and investigation they can carry out, even though I show them the materials and equipment" (G, R 1).

4.3- Difficulties of labwork in school biology

There are some obvious constraints on labwork in school biology, including security, ethical and economical reasons, school time and space, and opportunities to experiment on living things is restricted in the new curriculum.

The French Biology teachers spoke about difficulties, in relation to school time or space organisation. They also commented on the students' lack of autonomy and regretted that experimental competencies are not taken into account in the assessment of student's work.

The students' lack of experience of working on living beings and their lack of technical skills was often described.

"Students aren't accustomed to using equipment. For example, they don't know how to use a microscope" (A, R 31).

"Really, a lot of students have never touch a microscope before" (B, R 27).

Discourse-analysis identifies the difficulty of including coherent didactic choices and educational interventions, revealing multiple tensions:

- Tensions between collecting and analysing data only and the resolution of scientific problem. Orange (1997) argues about the possibility in science education to construct problems and not only to solve them.
- Tensions between science in development and science as recognised knowledge, between process and product in science, between the logic of research and the logic of communication.

5. "Didactic modes" of instructional activities and pedagogical devices

On the one hand, school practical activities have always been many-sided and Hodson (1993) showed that teachers' priorities have consequences for the guidance of labwork. Investigation and validation points of view have often been seen as being on two opposite sides. There is a divide between empirical and scientific points of view. Scientific research, however, admits to these two different objectives. On the other hand, students' practical familiarisation with nature and living beings will be discerned from and articulated with intellectual elaboration (Martinand, 1986, 1996). In order to integrate this demand into biology lessons, I have given an epistemological analysis (Coquidé, 2000, 2001).

In order to help explain teachers' choices or to help the construction of curriculum, Astolfi (1985) and Martinand (1986) distinguished between different logics and priorities to elaborate instructional activities and called them "didactic modes". By referring to three examples, extracted from the literature, I put forward a first analysis of contexts and possible objectives of experimental activities in various "didactic modes" (Coquidé, 1998). I made a distinction between three "didactic modes" of instructional activity: practical familiarisation, empirical investigation and theoretical elaboration. These modes, in connection with various epistemological registers, do not represent stages but possible learning objectives.

The teacher adapts the interventions to the objectives: so the educational control of situations, in connection with the three didactic modes, will be reflected in this adaptation. This table (Figure 5) summarises the didactic points of view on the context and purposes of experimental practices in each of these three modes, as well as the educational point of view of the nature of the device set up for pupils and teacher's guides.

The context of the *mode of practical familiarisation* is the introduction to a new subject of study, a first scientific initiation. Experiences and experiments to see, to try or to act contribute to elaborate the student's first elaboration of a mental representation of the world and of living beings.

In the context of the *mode of empirical and scientific investigation*, experimental activities, with the articulation of empirical and experimental points of view, exploration and validation opportunities, can help to introduce students to scientific methods. As Désautels and Larochelle (1993) proposed, this didactic mode can contribute to the development of metacognitive abilities and an understanding of the nature of science.

In a context of “systematic” learning of concepts, tested or evoked experiments may support the construction of scientific concept, theory and models. Instructional activities are then in-between empirical register and intellectual elaboration. Experiments represent references for intellectual elaboration and opportunities to test the validity of theoretical construction.

An important question is the relationship between these various modes. The dynamic, articulation and hierarchy between experiences and experimentation on living beings favouring learning progress and curriculum coherence:

- at the level of the different educational choices made by the teacher to organise his pupils' learning activities,
- at the level of curriculum organisation.

“Practical familiarisation” mode

Experiences and experiments to see, to try, to act

Context: First scientific initiation or access to a new subject study.

Aims: Familiarising the pupil with scientific objects and phenomena.

Nature of pupils' task and pedagogical device: Empirical exploration and action control

Priority of teacher's guidance: Propose varied and diversified activities. Introduce an articulation between reality and abstraction. Solicit comparisons, boost pupils' interrogation and introduce doubt.

“Empirical and scientific investigation” mode

Experiments to test, to dispute, to argue

Context: Practices of investigation, initiation to scientific research.

Aims: Introduction of scientific methods, and use investigation techniques.

Nature of pupils' task and learning device: Operate (in whole or in part) a real investigative approach, inquire, realise a “mini-project” including bibliographical research, scientific problem construction, protocol conception and realisation, communication, discussion...

Priority of teacher's guidance: Help the students construct a scientific problem, favour investigation, develop rigorous methods of validation, encourage debate, make pupils reflect on their research steps and their reasoning.

“Theoretical elaboration” mode

Experiments to demonstrate, to conceptualise, to model

Context: “Systematic” learning of concepts, theory and models, and conceptual elaboration

Aims: Contributing to the theoretical construction of sciences (elaboration and application of theory, concepts and models), opening up on a larger choice of references.

Nature of pupils' task and learning device: To go back and forth between the empirical register and intellectual concept elaboration.

Priority of teacher's guidance: Propose activities to elaborate concepts and models and to test the domain of validity of the theoretical construction.

Figure 5. Didactic modes of instructional activity for experiences and experiments at school.

6. Analysis of the Biology teachers' comments with the didactic modes grid

6.1- Are the contexts of lab work, the teacher's didactic intentions and aims, the pupils' tasks and the pedagogical guidance in coherence?

First, the didactic intentions and aims of every teacher in the labwork context, the nature of the task for the pupil and the pedagogical priorities, were analysed using a grid of the different didactic modes.

The intentions of teacher A and teacher C can then be compared. They considered labwork essentially to be a mechanism for introducing the pupils to scientific process and they developed pedagogical interventions in coherence with this aim. *"During every theme, we have liberty and time. These are ideals opportunities for learning experimental approach"* (C, R 1).

Teacher D's intention and aims are different. The instructional activities are very focussed on theoretical elaboration logic. *"This teaching has to include research and tasks for the students (...), it's a great difficulty because it's necessary to "jumble" and "trick" to lead students to good biological knowledge"* (D, R 1).

Commentaries by other teachers are more complex. They considered different logic and different didactic modes during the same instructional activity, but did not clearly identify these. They did not make alternative choices nor did they plan the pupils' tasks, the pedagogical devices or the pedagogical guidance in advance, which may raise difficulties. *"I suggest some experiments with vegetables hormones, as pupils don't know what they are and I tell them how to conduct the experiments because they aren't be able to find out"* (F, R 10). *"If we go slowly, students will be weary, so it's also necessary to show them many various things"* (G, R 12).

The comments analysis, using the didactic modes grid (Figure 5) shows that three teachers developed coherence between context, pedagogical aims, learning device and educational guidance. The didactic choices and educational interventions of the other four teachers seemed less coherent. Experimental activities purposes and didactic modes are often confused.

6.2- Reconstruction of the underlying logic of the teacher's approach

We have seen that, in one situation in laboratory, some teachers mobilise one didactic mode: empirical and scientific investigation for A and C, theoretical elaboration for D. What about the other teachers? How have they mixed, juxtaposed or rearranged didactic modes?

For a better understanding of the logic of their instructional activities, every teacher's practical activity discourse was reconstructed in order to analyse its underlying logic (Figure 6). For example, teacher E made the following successive comments about one piece of labwork:

- Teacher's guidance of scientific investigation or theoretical elaboration: *"I impose experiments because they aren't be able to find"* (E, R 1).

- Teacher's guidance of empirical investigation: *"If they propose strange experiments, if I predict answers about result, I let them alone, then we discuss"* (E, R 5).

- Context of theoretical elaboration: *"These practical activities could be trained during lesson, because biological themes of the option are always in relation with biological lessons"* (E, R 27).

- Purpose of practical familiarisation: *"I have given up microbiology, in fact it's allow students' learning of sterile manipulation"* (E, R 39).

This teacher's discourse analysis pointed out a mixture and juxtaposition of different didactic modes.

	MPF	MEI	MTE
Interview A			
Context		x	
Purposes/aims		x	
Pupil's task		x	
Guidance by teacher		x	
Interview B			
Context	x		
Purposes/aims		x	
Pupil's task		x	x
Guidance by teacher		x	x
Interview C			
Context		x	
Purposes/aims		x	
Pupil's task		x	
Guidance by teacher		x	
Interview D			
Context			x
Purposes/aims			x
Pupil's task			x
Guidance by teacher			x
Interview E			
Context	x	x	x
Purposes/aims	x	x	
Pupil's task	x	x	x
Guidance by teacher		x	x
Interview F			
Context		x	
Purposes/aims		x	
Pupil's task		x	x
Guidance by teacher		x	x
Interview G			
Context		x	
Purposes/aims	x	x	
Pupil's task	x	x	
Guidance by teacher		x	x

Figure 6. Underlying logic for experimental activities called by the teachers

MPF: practical familiarisation mode

MEI: empirical and scientific investigation mode

MTE: theoretical elaboration mode.

7. Conclusion and perspectives

Some French biology teachers' comment that the purpose of labwork, each and every time, is to develop multiple competence and to allow for intellectual constructions, which leads them to giving up the idea of having to make a choice altogether. White (1996) noted that in Great Britain also, multiple purposes for labwork could lead to teachers' difficulties. Yet it was what ministerial and official French recommendations have praised during one century:

- "Scientific teaching gives in the same time knowledge, discipline and wake up" (French official recommendations in 1891).
- "The student builds up actively his knowledge, learns scientific methods and techniques, by following an investigation approach to explain biological phenomena" (French official recommendations in 1992).

In summary, it seems important on the one hand to study the dynamic links of various didactic modes in education, to give coherence to the forms and functions of experiences and experiments in biology classes, and to initiate the construction of an "experimental relationship to living beings" in biology education. For example, young pupils and children through their own experiences to living beings, such as caring animal and plants, as visiting farms and zoos, and discovery of the nature. They may discern complexity and variability of living beings and of biological phenomena, ask new questions about life and living beings. Through experimental practices and fieldwork, older pupils and students may construct biological concepts, keep closer to reality and understand better concrete aspect of science. On the other hand, both these various modes and the renewal of the instrumentation lead to question the various resources and potentialities which support the use of ICT in these activities. As Brigitte Vialle (2001) pointed out, activities with computers (for instance ExAO Experimentation Assistée par Ordinateur) are often limited to data collection and analyses and don't carry actually all educational possibilities,

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REASONING

DISCURSIVE INTERACTION AND SCIENCE EDUCATION IN PRE-PRIMARY SCHOOL

Milena Bandiera

Biology Department – “Roma Tre” University (Roma – Italy)

bandiera@bio.uniroma3.it

Abstract

Based on current constructivistic views of learning and on the increasing relevance of rhetoric, argument and discourse in science education, discursive interaction in pre-primary school can be regarded as crucial training towards the establishment of a scientific attitude. Fifteen pre-primary school teachers were involved in a research activity aimed at the exploration of habitual ways of dealing with bio-naturalistic questions and problems, during “circle-time” sessions, and at the collaborative conception of innovative targeted methodological strategies. Identified and described were the teacher’s role, discursive interactions, and outcome in terms of the construction of scientific discourse and knowledge. The main proven and undesirable peculiarities that emerged were the evident dispensability of children’s ideas in the elaboration of the answer/explanation, along with the representation of: knowledge as a collection of unequivocal, unquestionable and uncontested truths, the teacher as the holder of clear and right answers, and the student’s personal world view as useless and alien with respect to scientific conceptions. Some pragmatic methodological indications conceived and tested by the teachers concerned the reversal of such peculiarities, placing special attention on fully understanding the children’s utterances and recognising the bases of their opinions, and on fixing consolidated opinions in a way that makes them accessible for future correction and completion.

1. Introduction

A repertory of *explanatory procedures* upon which to draw has been indicated (Toulmin, 1972) as a basic requisite for the transmission of scientific knowledge and construction of *understanding attitudes* as one of seven pieces of knowledge which will be necessary for education in the future (Morin, 1999). Accordingly, interest in comprehending the nature of discursive interactions between students and teachers and the process through which meaning is made in school science (Martins et al., 2001) is lively and fruitful. It is widely agreed that rhetoric and argument are central features of the practice of science (Fuller, 1997, Taylor, 1996), and that beliefs, epistemologies and conceptions are properties of discourse, something which is created precisely through discursive interactions themselves (Roth & Lucas, 1997). In light of this, it is surprising that science teaching displays such scarce interest in an activity which lies at the very heart of science, and even more surprising that attention is not paid to the nature of discursive interaction in the pre-primary school where the learning profile of *students* is established. A disregard for the practice of argument at this first school level can produce more serious consequences than at higher levels where Norris and Phillips (1997) pointed out its failure to empower students with the ability to critically examine the claims generated by the plethora of socio-scientific issues that they are confronted with in their lives. Furthermore, the appropriateness of dedicating research to this topic is reinforced by the qualified indications of the Italian national curriculum (Orientamenti dell'attività educativa nella scuola materna statale, DMPI 3 June 1991) which, proposing as specific goals *the initial formation of attitudes and skills of a scientific type*, indicates among the skills to be developed those regarding *the placement in relation, order and correspondence, ... formulation and verification of predictions, expectations and hypotheses, use of a specific lexicon as an instrument for describing and reflecting, and logical reasoning for discussing and explaining events*. The same curriculum requires the teacher to be *open to the conceptions that they (the children) express and their ways of formulating those conceptions*, to *leave room for their questions*, and to *avoid giving premature answers*, to *be able to trigger individual and collective research and classification processes by means of observation, experimentation and group discussion*, to *enhance personal views and using one's head*, and *not to penalise mistakes which, as expressions of one's own viewpoint and opportunity for self-correction, stimulate critical thinking*.

The present study follows up a previous investigation on scientific education at pre-primary school (Bandiera, 2001) which – taking into account the poor level of scientific education provided to Italian prospective pre-primary school teachers – singled out some attitudes and habits they adopt when approaching issues concerning knowledge of natural phenomenology. The lack of scientific competence and “sensitivity” was confirmed, emerging in giving explanations and answers prematurely provided in order to *protect pupils against anxiety*, the use of a very limited repertory of so-called *scientific* educational activities, and a systematic privileging – to the detriment of scientific education – of objectives pertaining to socialisation, communication, aesthetic/artistic expression, and simultaneous, active involvement of all the children, emerged.

The main objectives of the present study are the characterisation of teachers' role in discursive interaction aimed at scientific education which usually takes place in the pre-primary school involving 3-5 year old children, and the definition of alternative procedures by means of the engagement of teachers themselves.

2. Preliminary indications on teachers' educational orientations

With the purpose of giving an idea of pre-primary school teachers' educational orientations, a useful premise to the presentation of specific findings could be a glance at some findings concerning the assessment grids compiled on pupils in the course of "circle-time" sessions that dealt with bio-naturalistic questions proposed as concept cartoons (Keogh & Naylor, 1997).

In 2000, 35 teachers from pre-primary municipal schools were enrolled in an in-service training course at the Biology Department (this location is to be considered a relevant feature when reviewing their performance). In the context of a task focused on the assessment of pupils in the above mentioned activity and being fully aware on the specific aim of the monitored activity, the teachers prepared 109 grids which can be categorised as follows based on the considered "educational" aspect: 40 grids were dedicated to *general behaviour* (some included items such as: "disrupts group work", "pays attention", "wanders"), 29 grids were dedicated to *linguistic/lexical skills* (collections of terms children used to indicate "scientific" objects or events), 21 grids dealt with *types of intervention* (some included items such as: "pertinent question", "pat statement", "concrete example"), and 4 grids to *debating behaviour* (some included items such as: "non-response to question", "linking back to earlier intervention", "interruption of an intervention in progress"). The remaining 15 grids include non-homogeneous items and therefore cannot be categorised.

Although the importance of lexical skills in early scientific education was not underestimated, true debating skills seem to have been given little importance, while conceptual correctness and consequent reasoning none at all.

3. Research design and Method

Fifteen pre-primary school teachers – with at least six years seniority – attended an advanced in-service training course held at the University from September 2000 to May 2001. All of them had their initial training at the "*Scuola magistrale*", the only three-year (as opposed to five-year) secondary school stream. Within the context of this course they were involved in a two-phase research activity.

In the first phase they were asked to tape-record "circle-time" sessions devoted to a bio-naturalistic topic. (In the course of such a session the teacher proposes a theme – problem or question – and the children, seated in a circle, are asked to express their own opinions in an orderly way and in turns.) The tape transcripts of a first round of sessions were read and discussed openly by the group in a free form manner, with three main objectives: to optimise registration and transcription procedures, to identify teachers behaviour that appeared in contrast with a constructivist teaching/learning conception and a scientifically-rooted investigative and explanatory attitude, and to draft self-correction strategies.

The tape transcripts of subsequent sessions were analysed by the group in the same way as defined above, and later in a formal way – based on point-by-point examination – in order to discern indications that meaningfully characterised the general features a) of the role of the teacher in guiding the debate aimed at the formulation of an answer to the initial question, b) of the discursive interaction, and c) of the outcome in terms of the construction of scientific rhetoric and knowledge.

The second phase alternated group-work, aimed at the collaborative conception of methodological strategies, and classroom-work in order to test the practicability of the strategies proposed.

Though pre-primary school science education (and the present study as well) takes into consideration attitudes and habits rather than topics, the activities planned within this context concerned, in principle, bio-naturalistic objects and events. Sometimes bio-naturalistic questions arose from extemporaneous and fanciful curiosities (“How can witches fly at night without making noise?”). In general the themes belong to a collection of real questions formulated by children at school. Occasionally teachers also made use of concept-cartoons (Keogh & Naylor, 1997).

4. Findings and implications

4.1- Basic intentions for change.

Group analysis of the very first session transcripts led teachers to compare their moderating behaviour with their own constructivistic conceptions of teaching/learning and with the general features of a scientific approach to knowledge of objects and events. Consequently they agreed that it would be opportune

- to at least stimulate children to bring out their concrete experiences,
- to carry out – as learning supports – observations and experiments, and
- to facilitate collaborative building of knowledge, thereby demonstrating their interest in honouring the recommendations of the national curriculum (avoiding giving premature answers, being open to children’s conceptions, enhancing personal views and using one’s head, ...).

4.2- Discursive interaction during circle-time sessions.

The analysis, limited to the correctly documented subsequent sessions, is concerned with 22 sessions carried out by 12 teachers, for a total of 178 interventions by teachers in the course of the sessions.

Four main types of intervention were identified: questions (98), non-interfering supports (27), summing-up/synthesis (19), carrying out/pointing out of experiences (23). One direct answer to the initial question, two direct evaluations of children’s explanations and 8 statements without justifications were also identified.

33 “lost” interventions were noted.

4.2.1- Questions.

The types of questions appear particularly significant:

- a) questions asked in order to elicit something teacher does not know (n°37). These are open, real questions which have mainly to do with the teacher’s need to create a situation in which knowledge can be built collaboratively by peers, first of all clarifying the children’s thoughts and enhancing their contributions.

(initial question: “Why do mosquitoes bite?”)

Margherita: They suck blood because their mouths as tiny as a speck and so nothing else could get in.

Martina: They have to eat what we have in our stomachs.

(initial question: “Why are pumpkin seeds salty?)

Davide: Yum! Salty!

Cristiano: That’s right. But why?

T: Martina, can you explain that to us better.

Martina: What we eat is in our stomach and that's what they eat.

T: But when they bite your arm, how can they eat what you have in your stomach?

Davide: Because they put salt on them!

T: How do they do that?

- b) question asked in order to induce a line of thinking that follows what the teacher has in mind (n° 14). The teacher, without referring to children's previous interventions, introduces "new" elements that she considers suitable for shifting the children's attention onto a terrain considered more fertile.

(initial question: "Is an onion peel dead?")

T: But the onion is not a rabbit, a hare...

Gianfranco: But the onion looks like a ladybird ... all we have to do is put some paste on it and shape a couple of legs.

Matteo: This could be the neck. But it's us that change it into a ladybird.

T: When we look at an onion what do we think about? A living being? Or a non living being? And this big onion we're looking at today, was it always like this?

(initial question: "Why does it rain?")

Daniele: The clouds crash into each other and then dump water onto the Earth.

T: Good! Now let's all try to figure out how the water got into the clouds. What does the sea remind you of?

Martina: I went to Ostia this summer!

- c) questions that confuse or divert from the issue (n° 20). The teacher apparently loses sight of the initial question and seizes onto what she considers a stimulus for discussion for herself and the children.

(initial question: "What does an antibiotic do when you are sick?")

Matteo: The antibiotic makes you better.

T: And how do you know that?

Matteo: My Mom told me so.

T: Can only the antibiotic make you better?

(initial question: "How come the sea changes colour?")

Asia: Maybe because there's seaweed, the sea is green.

Brian: But where I was it was blue; maybe because there were mountains.

T: In your opinion what is the sea made of?

- d) questions that clarify or lead back to the issue (n° 15). The teacher intends to bring the focus back to the idea proposed by the initial question.

(initial question: "Why does Shamine have dark skin?")

Gugu: I say that (*black people*) don't live in another world because they live also in Rome, all over the place.

Andri: They also live in Morocco where there are lots of them. Lots of black people.

T: Tell me something: if these people live, as Gugu has said, all over the place, how is it that they stay black?

(initial question: "What do plants need to grow?")

Federico (*looking at the roots*): What do they need?

Elisa: That's the plant's mouth.

Francesca: Because they suck.

Simone: They suck the wet ground.

Matteo: There are little worms in the ground.

Martina: No! Plants don't have mouths like birds do!

T: So how do plants grow then?

4.2.2- Non-interfering support.

Considering the fact that children speak in bursts, tend to wander off the subject, and are more apt to listen to their teacher than to their classmates, the teacher's moderation of the discussion implies that she focuses, summarises and specifies, while at the same time encouraging continuation of the debate, respecting the course it takes and enhancing its contents.

(initial question: "What does the antibiotic do when you are sick?")

Alessandra: I take medicine!

T: Which one?

Alessandra: Those little ones that melt in your mouth.

Pietro: Or else suppositories!

T: So, suppositories, little medicine and antibiotics make you get better, but how?

(initial question: "Is an onion's peel dead?")

Gianfranco: To be dead it has to be born a man, a ladybird, a caterpillar, a rabbit, a hare.

T: But the onion isn't either a rabbit or a hare!

4.2.3- Lost interventions.

The children express their thoughts in an imprecise and incomplete manner. The clues they provide so doing are thought-provoking and can lead to a potentially profitable line of reasoning. The teacher's failure to pick up on them results in a two-fold loss: the opportunity to follow that line of reasoning as well as to explicitly appreciate the children's contributions.

(initial question: "What does the caterpillar do in the cabbage?")

1° child: It waits a long time, then there's a shell and the butterfly comes out.

T: Do you all agree that then the butterfly comes out?

2° child: Yes, it's hidden in the plant.

(initial question: "What do we mean by the word energy?")

Giulio: It means strong, fast. Do more things.

Luigi: With energy you run and get warm. Energy gives you the maximum speed.

Giulio: With energy you get looser.

(initial question: "Is an onion's peel dead?")

T: Do we have a peel?

All children: No!

Gianfranco: We have a peel when we get tan in the sun.

(initial question: "Why does an elastic stretched around a box make music?")

Elisa (pulling the elastic): Because it becomes two.

4.3- Summary and synthesis.

As the children's interventions accumulate and overlap it is necessary that the teacher summarise, taking into account if possible all the opinions and information expressed. The teachers do tend – in the course of the sessions – to carry out this function which should be a summary, but which consistently proves an opportunity to substitute the terms of the earlier discussion with what they consider to be correct and complete information.

(initial question: "Why does it rain?")

T: Here, children (*on the lid of a pot of boiling water*) we see very little (*water vapour*), **but so much water vapour rises from the sea that clouds are formed; and when those clouds bump into each other, because of cold air currents, that makes the water that we call rain fall.**

(initial question: "What do plants need to grow?")

Francesca: The water melts the dust of the dirt that makes things grow.

Matteo: No, there are vitamins.

Federica: My Mom told me that there's iron too.

Simone: Like in spinach.

Giovanni: In spinach and in other things we eat.

T: The plants grow on substances that we call iron, nitrogen, phosphorus and potassium.

As for final summary/synthesis (the outcome of a circle-time session), it is not surprising that children of 3 to 5 years are unable to follow a discussion/study to its natural conclusion (question/explanation formulation). This takes place in two of the sessions examined. Out of 14 cases only one session ends with the formulation of a summary or synthesis of the information/explanations that emerged in the course of the discussion. In another 7 cases the teacher assertively formulates a conclusion, entirely leaving out the considerations expressed in the course of the discussion.

4.4- Experiences.

Finding themselves theoretically in agreement on the appropriateness of anchoring the knowledge of bio-naturalistic objects/events to the children's concrete experiences, the teachers invited the children to bring something into class something for discussion, and conducted observations and simple experiments (seed germination under various conditions in order to *establish what plants need to grow*; various treatments of pumpkin seeds in order to understand *why they are salty*; manipulation of the hour-glass as a means of dealing with the concept of measuring with reference to the question "*what is time?*").

It should be pointed out that a good 9 experiences out of 23 are to be considered completely irrelevant or non-significant.

(initial question: "Why does Shamine have dark skin?")

Andrei: Because we are different from them: because we are born from pink moms, where their moms are brown.

Guglielmo: I think Andrei is right. Shamine is brown like her mom and dad.

T: Of course, we planted the seed of the apple.

Andrei: Even little animals look like their moms and dads.

(initial question: "How does the witch fly at night without making noise?")

T: If the witch has no wings how can she fly?

Nicole: She has a magic broom!

T: What does magic mean?

Daniele: That it can change things into what it wants.

T: Does the broom think?

(silence)

T: Let's take the broom and see if it's thinking!

4.5- Implications

Teachers' orientation towards assessment, demonstrated in their grid formulations, supplies an essential indication. They had at their disposal a new tool to be used in their professional life and they had the opportunity to use it in every-day activity: even though they were taking part in science teacher training and they were asked to assess children in the course of

sessions devoted to scientific education, they applied the grids to aspects that did not pertain specifically to this educational field (which they have little knowledge of practise poorly). But they did apply them to fields that they appreciated due to what had mainly been emphasised in their formation (social behaviour, oral production and understanding).

This said, we come to the circle-time session which represents a very popular and well-appreciated methodological strategy in pre-primary school. It seems usually to be carried out in a nearly identical way and is characterised by the following main features:

- a) **the teacher initiates the dialogue, normally with a question; she is almost exclusively concerned with the orderly conduction of the session, and expresses positive or negative assessment on the correctness of children's opinions and hypotheses (sometimes – essentially apart from these opinions and hypotheses – providing a thorough answer or a detailed explanation). Evidence of an actual flow of the discourse (Mortimer, 1998) is not recognisable.**
- b) the children's utterances are for the most part doubtful, incomplete and incomprehensible, but specifications, and clarifications and completions are not requested by the teacher. The children's contributions turn out to be substantially unheeded and useless in teacher' devising of answers or explanations. Moreover the children's personal experiences and creative reasoning are not solicited, nor are they questioned or negotiated.
- c) the construction of knowledge simply does not occur; on the contrary, misconceptions are easily formed about scientific discourse – the relevance, purpose and advantage of communication in helping shape a shared view of bio-naturalistic objects and events.

The teachers involved in the study here presented experienced a change in tendency. In fact they appeared somewhat inhibited in giving direct answers to questions, in assessing children's expressions and in providing categorical and unquestionable statements. The prevailing intervention categories in the course of circle-time sessions were non-manipulative, true questions (4.2.1a) and non-interfering supports to the discussion (4.2.2), which represented real facilitating actions. Questions that clarified or led back to the issue (4.2.1d) are also rather frequent. Moreover teachers tried – with the difficulty deriving from their limited scientific preparation and complete lack of familiarity with scientific practices – to carry out or point out concrete, real-life experiences, which, furthermore, were not always pertinent and meaningful.

Evident and consistent, nevertheless, were signs of the teachers' reluctance to hand "centrality" over to the child, thus relinquishing their traditional qualifying (and gratifying) role as reassuring experts – a role which allows them to avoid the embarrassment of having to admit not knowing, not being able to follow a line of reasoning based on assumptions that they have not mastered, and not being able to develop that creativity considered one of the distinctive and precious qualities of their profession.

Thus all too seldom they fail to make the effort to fully understand the information and comments expressed by the children ("lost" interventions); they guide their reasoning process by proposing lines of thought that lead to concepts/information that they – the teachers themselves – know well and privilege (4.2.1b); they abandon the terrain of the initial question and undertake one less problematic or already tested (4.2.1c). All this has a negative impact on the possibility for children of actively making meaning by anchoring new knowledge to personal experiences and of "adjusting" their own thinking instruments rather than acquiring the instruments of others. (Not to mention that all this damages self-esteem, aspiration of autonomy, and faith in the efficacy of co-operative learning.)

As far the image of science and the possibility of attributing to argument and discourse a crucial function in the building of knowledge, another aspect of fundamental importance can be added to those misleading ones indicated above: the fact that most sessions end with the failure to summarise results and in the lack of a) reliability of the positions expressed, b) discrimination between the data/conceptions that it would be opportune to keep in mind and those that could be abandoned (unfounded, not pertinent, not shared), and c) reinforcements of one or more shared answers/explanations. These latter would represent the fruit of the reflection/research activity and, at the same time, a strong (legitimate) indication of the temporary nature of the answers/explanations – an epistemologically emblematic and qualifying conception.

5. Methodological indications

Departing from the proven and undesirable peculiarities of the usual management of group discussion on scientific issues, and taking into account the changes found in the experimental sessions, two main aspects of inadequacy seem to be confirmed and underlined, as well as some strategies for remedying them devised by the same teachers:

- 1) The evident dispensability of children's ideas: This problem has been dealt with by suggesting that the teacher
 - fully understand children's utterances and recognise the basis of their opinions, hypotheses or assertions, by means of explicit request;
 - engage in connecting the object/event, which is the subject of the discourse, with children's concrete experiences, in order to stimulate the recovery of acquired and matured knowledge and to promote self-confidence in their capacity to autonomously construct meaningful answers/explanations;
 - recapitulate the expressed opinions and underline one or several derived answers/explanations which are not necessarily scientifically correct but which, in any case, represent open and approximated views of the objects/phenomena, and are substantiated by the children's present ideas and concrete references.
- 2) The representation of knowledge as a collection of unequivocal, unquestionable and uncontested truths, of the teacher as the holder of clear and right answers, and of the students' personal world view as useless and alien with respect to scientific conceptions: The following recommendations, which partly coincide with those mentioned above, suggest that the teacher
 - declare her need and intention to construct the answer/explanation based on the children's collaboration ("Let's try to understand!", "Let's try to do something similar!", "Let's all think about this together!", "That's a good question! Can somebody help me find an answer?").
 - ask questions when children's opinions appear not fully clear, and try – if possible – to recognise the *personal experience* they are referring to;
 - at the end of the session, fix more or less shared opinions in a way that makes them available for future corrections and completions;
 - supply verbal and instrumental stimuli so that children can conceive and carry out pertinent and illuminating *experiments*.

It is imperative to point out that the above-mentioned indications, considered practicable by the teachers as described, could prove completely demagogical and academic – a university degree being for some time now a requirement in Italy also for pre-primary school teachers

and in light of current university curricula reform – if they did not qualify and enhance the teachers' scientific literacy.

Pre-primary school teachers' attitudes would benefit from an active, strong reversal of the idea, supported what's more by pre-university school teaching, that science is simply an archives of information and, in this form, obviously not suitable for children of 3-5 years of age.

N.B. The translation of the excerpts of the transcripts do not pretend to faithfully reproduce the linguistic-grammatical errors and ingeniousness that characterised the expressions of both children and their teachers.

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STUDENTS' REASONING WHILE COLLABORATING ON A TASK IN THE CONTEXT OF GENETIC ENGINEERING

Marida Ergazaki, Vassiliki Zogza
University of Patras, Greece
ergazaki@upatras.gr

Abstract

This paper aims at highlighting the shared reasoning processes of 2nd-year biology students collaborating in a small group on a task of genetic engineering. The task which is focused on the selection of a plasmid vector among two options, is part of a didactic sequence of genetic engineering designed considering aspects of the situated-learning theory, in order to function as a context of students' cognitive apprenticeship in scientific reasoning and discourse. Since the shared reasoning of students is embedded in their discursive activity, cognitive and social aspects of the latter become our focus. Thus, this paper is concerned with the argumentative and epistemic operations activated in the discourse, as it attempts to explore the construction of peers' arguments, persuasion devices and biology-bound reasoning patterns towards the solution of the task. Furthermore, the paper is concerned with the social dimension of the group's collaborative work, as peers' participation pattern and mode of interaction shape it.

1. Introduction

Recent research in science education focuses on the study of students' discursive activity in various contexts (Mason, 1996; Jimenez et al, 2000; Diaz de Bustamante et al, 2000; Simonneaux 2000; Osborne et al, 2001). Some of the aspects of research interest concern the study of the structural elements of the argument, warranting strategies, cognitive procedures through argumentation schemes, social distribution of the argument in the group and peers' discursive devices (Pontecorvo et al, 1993; Resnick et al., 1993; Kelly et al, 1998; Roth, 1995; Kumpulainen & Mutanen, 1999, Desautels & Larochelle, 1999).

This growing body of science education research on students' discursive practices is grounded on a social constructivist perspective assuming that knowledge is socially constructed and subsequently internalized by the individual (Vygotsky, 1978). Furthermore, it emphasizes the significance of promoting the argumentative activity in science classrooms recognizing controversy, social dispute and argument not only as effective means of constructing meaning, but also as integral elements of the scientific enterprise itself (Kuhn, 1993; Driver et al, 2000).

Our study is a part of a research project on the development, implementation and evaluation of a student-centered teaching approach of genetic engineering, aiming at the enhancement of scientific thinking and discourse. This paper focuses on a peer group discussion of one selection-task of the developed teaching sequence. Students' discursive activity is analyzed on both cognitive and interactional levels, attempting to shed light to how peers construct their arguments, persuasion devices and reasoning patterns, while producing a collectively valid answer to the task.

2. Theoretical framework and objectives of the study

2.1- Theoretical framework

This study theoretically draws on the Vygotskian model of *social constructivism*, assuming that the construction of knowledge is primarily accomplished on the inter-psychological level and subsequently appropriated on the intra-psychological level (Vygotsky, 1978). Considering learning as both an inter-personal and intra-personal process, Vygotsky actually stresses its social and situated nature: knowledge is constructed in social settings through cultural tool-mediated interactions. Thus, engagement of individuals in collective activity is considered to be essential for their cognitive development (Roth, 1995).

Originating in the work of Vygotsky, *situated-learning theory* proposed by Lave assumes learning as a function of the activity, context and culture in which it occurs (Brown et al, 1989). Social interaction is a key element of the theory, since learners take part in a 'practice community' and become more actively engaged with its culture, moving gradually from the 'periphery' of the community to its 'center'. The notion of 'cognitive apprenticeship' emphasized in this theoretical context (Brown et al, 1989) suggests engagement of the learners in 'authentic' domain activity, 'meaningful and purposeful' to both the culture of the practice and the learners, and in fact absent from traditional school settings. Given the view of scientific thinking as argument proposed by D. Kuhn (Kuhn, 1993), apprenticeship in scientific thinking implies apprenticeship in scientific discourse, that is in the construction and justification of scientific claims aimed to be collectively valid.

The *activity-theory* perspective of Vygotsky and Leont'ev offers a significant theoretical tool for the analysis of teaching-learning activities (Engstrom et al, 1999). More specifically, a peer

group discussion as the *action* of collaborative construction of knowledge embedded in a teaching-learning *activity*, can be analyzed on the micro-level of the *operations* through which it is carried out (Pontecorvo et al, 1993). Furthermore, students' interactional processes occurring on the *action* level are of key importance. Analyses of such interactions can be performed with the contribution of notions such as peers' participation pattern, maintenance of inter-subjectivity and mode of interactional process (Roth, 1995).

2.2- Objectives of the study

The work presented here is part of a research project on the development of a student-centered teaching approach aiming at the promotion and study of students' scientific reasoning and discourse in the context of genetic engineering. It is specifically concerned with one task of the developed didactic sequence and attempts to explore biology students' shared reasoning processes, assumed as embedded in their discourse while dealing with this task. The question addressed is 'how do collaborating students construct knowledge in the context of a genetic engineering task which requires a choice among experimental options?'. In other words, 'do students construct arguments and how, do they employ any kind of rhetoric devices to persuade their peers, what sort of biology-bound reasoning patterns do they develop towards the task solution and how do they socially interact with their peers in the overall process of creating a joint answer?'. Thus, the objectives of this paper are to highlight:

- 1.the construction of peers' arguments on the level of the *argumentative operations* employed and the domain-bound *epistemic operations* carried out through them
- 2.the activation of discursive devices for supporting or undermining given premises
- 3.the development of biology-bound reasoning patterns for the solution of the task, and
- 4.some features of the group's social interaction, such as peers' participation pattern and mode of the interactional process

3. Methodology

3.1-The task & the setting

The specific task is part of a didactic sequence on the basics of genetic engineering for biology students attending the subject of Molecular Biology in the University of Patras. The overall sequence was developed considering aspects of the situated-learning theory to provide students with a context of apprenticeship in scientific reasoning and discourse.

Thus, students are supposed to participate in a hypothetical research project of designing drugs against cancer disease, with the mission of cloning a plant gene responsible for the synthesis of a protein potentially useful for this cause. The overall cloning procedure to be completed by the students is segmented to a series of partial tasks. These are concerned with making experimental choices about restriction enzymes and cloning vectors, predicting the outcomes of the bacterial transformation process, proposing gene-locating treatments and stating - testing hypotheses regarding the failure of the cloned plant gene in synthesizing its coded protein in bacterial cells.

The task in question concerns the selection of a plasmid vector for the cloning procedure on the basis of the number of plasmid's target sequences for the already chosen restriction enzyme. Being embedded in the hypothetical activity of cloning a medically useful gene, the study of the particular characteristic of plasmid vectors becomes potentially *meaningful* and *purposeful* to the students, since it functions as a prerequisite for the ultimate accomplishment of the activity. Providing students with two optional plasmids, the task aims at engaging them in a decision-

making process based on a comparative evaluation of the given alternatives regarding to the goal of the cloning procedure. The evaluative process challenged by the task favors the construction of 'for-against' arguments (Diaz de Bustamente et al, 2000). Supported further by peers' social interaction in a small group, the task can be considered as a context of practicing the argumentative reasoning. Hence, in the context of a student-centered classroom setting peer-group work is adopted. Students collaborate in small groups to create a joint answer without having been assigned pre-defined roles, while the teacher's contribution is restricted to introducing the study-subject, giving hints to facilitate peers if necessary and conducting the whole class discussion that follows those of peer- groups.

3.2- The data

The data presented in this paper concern the discussion of one peer-group on the above-mentioned task. The discussion was tape-recorded, transcribed and subsequently segmented to message units, each expressing a single statement-idea and corresponding to one or possibly more linguistic clauses (Kelly et al, 1998; Mason, 1996). Sequences of message units were then identified on the basis of the different levels on which they were carried out. Hence, the specific discussion proceeds through:

- on-task sequences on the level of constructing a joint answer to the task
- repair sequences on the level of re-establishing inter-subjectivity, as a necessary condition for an effective shift to the previous level (Roth, 1995)

The segmented discussion was finally coded for argumentative and epistemic operations (Pontecorvo et al, 1993).

3.3- The analytic tools

Concerning the analysis of the *argumentative operations*, we used the framework proposed by Pontecorvo & Girardet (Pontecorvo et al, 1993), slightly elaborated with an addition ('*challenge*') from the framework proposed by Resnick (Resnick et al, 1993). Thus, the categories we used are the following:

- *Claim*: any clause stating a position, without necessarily constituting an answer to the task
- *Justification*: any clause providing adequate grounds to a claim (or to a concession / opposition)
- *Concession*: any clause admitting a point claimed by another peer, that is confirming a claim or a justification
- *Opposition*: any clause denying a point claimed by another peer, that is rejecting a claim or a justification
- *Challenge*: any clause requesting either justification or inquiry of specific issues

Concerning the analysis of the *epistemic operations*, we considered the frameworks proposed by Pontecorvo et al (1993) on historical topics, by Mason (1996) on ecological and environmental topics and by Jimenez et al (2000) on high-school genetics. However, the fact that these cognitive procedures are domain-bound (Pontecorvo et al, 1993) led us in the construction of our own framework, which is consisted of the following categories:

1. *Appeal to*: 'the action of supporting a claim by appealing to something that the speaker considers relevant to the topic' (Pontecorvo et al, 1993). Several sorts of appeals may be identified on the basis of their content:

- *appeal to consequences*: i.e. supporting the adequacy of the experimental *option A* on the basis of its expected consequences

- *appeal to experimental goals*: i.e. supporting the adequacy of the experimental *option A* on the basis of either the proximate or the ultimate goals of the experimental procedure of which it will be part
 - *appeal to experimental handlings*: i.e. supporting the possibility of overcoming a procedural problem on the basis of utilizing a specific experimental handling
 - *appeal to uncertainty-questionability*: i.e. supporting the inadequacy of the experimental *option A* on the basis of the uncertainty concerning specific critical features of it
 - *appeal to probability*: i.e. supporting the inadequacy of the experimental *option A* on the basis of the idea of *probability* as an inherent characteristic of a process, like for example the recombination of a plasmid
 - *appeal to instances*: i.e. supporting the inadequacy of the experimental *option A* on the basis of an illustrative example
 - *appeal to authority*: i.e. supporting the adequacy of the experimental *option A* on the basis of teacher's claims
 - *appeal to task data*: i.e. supporting the adequacy of the experimental *option A* on the basis of task data
 - *appeal to previous knowledge*: i.e. supporting a prediction for the outcome of a process on the basis of previous knowledge
 - *appeal to analogies*: i.e. supporting a prediction for the outcome of a process on the basis of an analogical relationship between the process in question and another one
2. *'Refer to'*: It is obvious that the *'appeal to'* operation concerns exclusively *justification* statements. On the other hand, when one tries rather to formulate than to support a claim, opposition or concession, then the *'refer to'* operation is actually carried out (Mason, 1996). The content of a *'refer to'* operation may be similar to that of the *'appeal to'* (i.e. *refer to experimental handlings*: proposing experimental handlings either independently or as steps of an overall treatment).
 3. *Reframing of task*: shifting the question from the level defined by the task to an equivalent level where the solving process might be facilitated
 4. *Definition of conditions*: stating presuppositions for supporting a claim, that is performing conditional reasoning
 5. *Abduction*: stating a hypothesis (mainly on the basis of previous knowledge)
 6. *Deductive prediction*: predicting the outcomes of a hypothesis-testing experimental process based on the assumption that the hypothesis in question is valid
 7. *Interpretation of outcomes*: explaining the outcomes of an experimental procedure to make judgments regarding the issue in question or the adequacy of the proposed procedure
 8. *Identification of assumptions*: recognizing and stating explicitly tacit suppositions taken for granted
 9. *Definition of concepts*: stating the meaning of a concept
 10. *Evaluation*: asserting a premise with an evaluative intention; reflecting upon peers' contributions -either partial ones or as a whole shaping an overall reasoning about an issue- or upon task's own character

Finally, concerning the *social aspect of peers' discourse*, we drew on the analytical framework of student-student interactions proposed by Roth (Roth, 1995). This framework includes macro descriptions of peers' participation in the discourse, as well as meso- micro descriptions of the mediational work done by them to achieve agreements. Particularly, it is concerned with peers' *participation patterns* and *mode of interactional process*. The former is characterized as *symmetric* (contributions equally distributed among peers and over time), *asymmetric*

(contributions unequally distributed among peers and/or over time) and *shifting asymmetric* (contributions equally distributed among peers, but unequally distributed over time). With regard to the latter, assuming that peers in our study work with the *collaborative goal* of constructing shared understanding and producing a joint answer to the task, we focus exclusively on the *processes* through which they interact for the accomplishment of their common goal. The *mode of peers' interactional processes* can be characterized as *collaborative* ('peers achieve their common goal without taking adversarial positions which would have to be resolved in a compromise') or *adversarial* ('peers achieve their common goal taking adversarial positions and using productively their differences for novel constructions') (Roth, 1995).

4. Results

The following results concern a peer-group discussion on the task of selecting a cloning vector between two options: a plasmid with one target sequence for the chosen restriction enzyme (*option A*) and a plasmid with three such sequences (*option B*). The peer group is consisted of three 2nd-year biology female students (*Elsa, Vasso, Fani*) who volunteered to collaborate with each other. The analysis of the particular conversation of the group is cited next.

4.1-Description of the peer-group discussion analysis

Elsa initiates the discussion on the level of constructing an answer by proposing *option A* (*claim E: 4.1*). First, she attempts to support her proposal directly by appealing to positive consequences of *option A*, such as the 'opening' of the plasmid in the exact site where the plant DNA is to be inserted (*justification E: 4.2*). In addition, she employs an indirect way of supporting her claim, by appealing to negative consequences of *option B*, such as the difficulty of re-joining all its restriction fragments (*claim E: 6.2 & justification E: 6.1: a subsequent justification*). On the contrary, *Vasso* denies unequivocally the underlined negative consequences of *option B* (*opposition V: 7*), indicating implicitly the group's need to explore further this option's adequacy. *Fani* makes her first contribution to the dialogue by reframing the task. In other words, shifting the focus from the number of plasmid's target sequences to the number of the deriving restriction fragments (*claim F: 10.2*), by appealing to the knowledge that in circular DNA molecules both numbers in question are equal (*justification F: 10.1*). Afterwards, *Elsa* changes her mind and proposes *option B* (*claim E: 11.1*) on the basis of the analogy '1target sequence - single insertion of plant DNA / 3 target sequences - triple insertion of plant DNA' (*justification E: 11.2*). *Vasso* accepts the position favoring *option B* (*concession V: 12.1*), by appealing to the experimental goal of producing a large quantity of plant DNA copies (*justification V: 12.2*). *Fani*, on the other hand, rejects the same position (*opposition F: 13.1*) considering the consequence of the re-joining difficulties (*justification F: 13.2*) and also the probability of disturbance of fragments' arrangement in the recombinant molecule (*justification F: 13.3*). *Vasso* changes her mind and accepts *Fani's* stance (*concession V: 14.2*), evaluating that the possibility of ending up with a dysfunctional recombinant plasmid compromises the advantage of multiple DNA-insertion possibly offered by *option B* (*justification V: 14.3*).

Elsa, on the other hand, appears to insist on her adversarial position in favor of *option B* claiming that there is no problem with the triple-insertion (*claim E: 15.1*), based on the knowledge of 'sticky ends' (*justification E: 15.2*). The overall argument 'E: 15.1 & E: 15.2' supports *subsequently* *Elsa's* claim for option B. *Vasso* expresses her disagreement to the previous claim (*opposition V: 16.1*), appealing once more to the consequence of fragments' re-joining difficulty

(*justification V: 16.2*). Fani, admits Vasso's point (*concession F: 17*) as expected, but Elsa appears doubtful. So, she challenges the idea of fragments' re-joining difficulty by a direct justification request (*challenge E: 18*).

Peers do not provide an answer to the specific challenge. On the contrary, Fani, who has been reasoning so far on the basis of the just challenged idea, attempts to underline its significance by appealing to the potentially powerful instance of *ori*'s probable 'loss' in the case of selecting *option B* (*claim F: 23.2 & justification F: 23.1*). The overall argument '*F: 23.1 & F: 23.2*' subsequently undermines *option B*, proposed by Elsa through *claim E: 11.1*.

Vasso doesn't seem to follow this last argument, as she explicitly requests clarification (*V: 24: What happened?*), thus shifting the discussion to the repair level. Within the repair sequence '*V: 24 – V: 34*', Fani repeats the '*ori*-loss' idea, Vasso requests clarification about *ori*'s following 'luck' and Fani suggests that it may stick to another plasmid, making 'useless' the plant DNA that has joined this one.

The dialogue is shifted to the level of constructing an answer by Fani (*'claim F: 35.2 & justification F: 35.1'*) who implicitly evaluates the '*ori*-loss' possibility as inconvenient, by stressing the fact of the small quantity of DNA available to work with (*appeal to task data*). Finally, Fani attempts to undermine *option B* using a different path. She discredits the possibility of the triple-insertion to plasmid B (*claim F: 35.5*) subsequently, by suggesting the 'loss' of two per three fragments (*claim F: 35.7*) on the basis of the arbitrary statement that the ratio valid for the insertion is 'one restriction fragment per plasmid' (*justification F: 35.6*).

Elsa challenges the 'two-fragment loss' argument by requesting its further justification (*challenge E: 36*), but Fani reacts to the challenge rather superficially, appealing to the knowledge 'no *ori* – no replication' (*justification F: 37*). Elsa is not satisfied with the answer (*opposition E: 38*), while Vasso seems also not to have followed Fani's alternative path against *option B*, since she prefers to draw on the '*ori*-loss' (*justification V: 39.2*) to support her counter-opposition to *E: 37* (*opposition V: 39.1*).

The following exchanges *F: 40 – V: 47* constitute a repair sequence initiated by Fani and aiming at establishing a common definition of *option B*'s consequences, which obviously still lacks among peers. Thus, with Elsa insisting on the position of the triple-insertion being possible with *option B* (*claim E: 41*), Fani sets the challenge of the 'probability-concept', which is inherent in the phenomenon of re-joining the DNA restriction fragments (*challenge F: 42*). This challenge results in Elsa finally admitting that *option B* is problematic (*claim E: 43.1*), since she can now recognize the probability of '*ori*-loss' (*justification E: 43.2*).

Fani proceeds with another challenge concerning the replication of the plasmid suffering '*ori*-loss' (*challenge F: 44.3*) and Elsa answers referring to the consequence of replication weakness (*claim E: 45*). Thus, the common definition of the situation following *option B* seems to be accomplished. The sequence terminates with a clarification request by Elsa about lost *ori*'s luck (*E: 46*), answered by Vasso (*V: 47*).

The dialogue shifts to the level of constructing an answer by Fani, who practically undermines once more *option B* (*claim F: 48. 4*). She is based on the 're-joining difficulty'-idea, this time reformulated as *plasmid's B* weakness of re-producing itself (*claim F: 48. 1 and 'claim F: 48. 2 & justification F: 48.3*' constitutes a 'complex' justification structure supporting *claim F: 48.4*).

Elsa suggests that the reproduction of the initial plasmid after recombination is impossible even in case of *option A* (*claim E: 49.2*), because there are various DNA fragments to be inserted (*justification E: 49.3 / appeal to task data*). Subsequently, Fani clarifies (*F: 52*) her own definition of 'reproduction of identical plasmids after recombination' on the repair level, since she has been aware that Elsa doesn't share it. Afterwards, Vasso explicitly requests clarification

about Elsa's statement '*E: 49.3*' that implies that the desired gene has not been isolated from the plant genome. Thus, the exchanges '*V: 53 - V: 70*' constitute a new repair sequence where peers clarify the issue by looking at the project data, although finally they judge it as irrelevant to their specific task.

Finally, the dialogue is shifted to the level of constructing an answer for a synopsis of the collectively valid answer. Thus, Vasso rejects *option B* (*claim B: 71.1*) appealing to the probability of fragment-loss / ori-loss (*justification B: 71.2*) and Fani expresses her *concession F: 74*. The dialogue terminates with Vasso (*V: 75*) suggesting that they should write down their answer and deliver their worksheet.

4.2-The findings of the peer-group discussion analysis

In the peer group discussion, which includes totally 74 exchanges among peers, we have coded the following *argumentative operations*: *claims* (18), *justifications* (19), *challenges* (4), *oppositions* (6) and *concessions* (3). The 19 *justifications* coded support directly 13 *claims* (one justified twice), 3 *oppositions* (one justified twice) and 2 *concessions*, while 5 *claims*, 3 *oppositions* and 1 *concession* appear as non-directly justified. Thus, among the 27 potentially justifiable *argumentative operations* coded overall (*claims, oppositions, concessions*), we identified 17 directly justified versus 10 non-directly justified. Concerning the latter, it is worth-mentioning that:

- Two out of five *claims* appearing as non-directly justified (*F: 35.5, F: 48.4*), are in fact grounded on higher-order justification structures, *subsequent* and *complex* (see below). In regard with the remaining 3, it is noted that the first one (*E: 41*) constitutes a reoccurrence of a previously justified *claim*. The second one (*F: 48.1*) is part of a *complex* justification structure and may be considered as implicitly justified into peers' shared knowledge resources about gene cloning goals. Finally, a similar view applies to the last *claim* (*E: 45*), which provides an answer to a scaffolding-aiming *challenge* and implicitly draws on peers' shared knowledge about *ori*'s essential relationship to DNA's replication. Thus, it is clearly indicated that although the 5 *claims* in question appear typically as non-directly justified *operations*, they are practically grounded on either explicit higher-order justification structures, or peers' implicit shared knowledge resources.
- One out of three non-directly justified *oppositions* is in fact supported *subsequently* (*F: 17*), while the remaining 2 (*B: 7, E: 38*) are rather arbitrary predicative statements than valid objections, since they probably arise from peers' lack of understanding for their 'target'-issues.
- The unique non-directly justified *concession* (*F: 74*) is a discussion-ending confirmation to the group's joint answer. Since its contributor had previously introduced the main idea upon which the specific answer is built, it is obvious that such a premise is rather expected and does not actually need to be justified.

Furthermore, the analysis of peers' discussion revealed higher-order justification structures, either *subsequent* (Kelly et al, 1998) or *complex*. A *subsequent justification* of a *claim* includes an overall new argument supporting that claim (Kelly et al, 1998), while a *complex justification* may be consisted of more structural elements (i.e. a direct and a subsequent justification, or more arguments combined with claims and/or direct justifications). Specifically, the structures identified include:

- A *complex individual justification* (*E: 4.2 - E: 6.2*), which is spontaneously constructed towards to a judgment about the required selection. Aiming at supporting *option A*, it draws on a direct *justification* for it, followed by a *subsequent justification* against its alternative. The former is consisted of an *appeal to A's positive consequence* of a convenient 'opening' and plant DNA insertion, while the latter is consisted of an *appeal to B's negative consequence* of difficulties in

multiple restriction fragments' re-joining. This *complex* structure could be schematically presented as: $[J + (C + J)] \rightarrow \text{Claim}_{\text{option A}}$
(J stands for direct justification and C for claim).

- A *subsequent* individual justification (E: 15.1 - E: 15.2), constructed to reinforce an already justified *claim* for *option B* that is however strongly doubted by the rest of the peers. Thus, the idea of the triple insertion of plant DNA in *plasmid B* is supported by *invoking the knowledge* of sticky ends being a key condition for joining DNA fragments. The overall argument is *subsequently* used to validate *option B*: $(C + J) \rightarrow \text{Claim}_{\text{option B}}$

- A *subsequent* individual justification (F: 23.1 - F: 23.2), constructed to support a peer's *opposition* against *option B* in which another peer persists up to this point. Invoking the abstract *possibility* of any fragment's loss, but through the specific example of the well-known *ori*, the argument emphasizes the possibility of a dysfunctional recombinant *plasmid B* and *subsequently* supports an *opposition* against its use:

$(C + J) \rightarrow \text{Opposition}_{\text{option B}}$

- A *subsequent* individual justification (F: 35.6 - F: 35.7), constructed to undermine the main criterion leading to *option B*. In fact, it represents a device aiming at shifting one peer from her persistent *option B* to *option A*. Thus, the *claim* for *option B* rather than rejected directly, it is undermined through the indirect path of doubting the main *justification* that grounds it. This persuasion strategy can be rather powerful since doubting effectively the reliability or sufficiency of a warrant supporting a claim, can make the claim itself no further plausible and consequently viable. Nevertheless the application of the strategy at this point is not successful, probably due to peers' inability to internalize the reasoning carried out. The specific argument is consisted of a *claim* pinpointing the inability to really take advantage of the triple insertion possibility, *justified* by the arbitrary ratio 'one fragment to be inserted per *ori*'. The overall argument *subsequently* justifies a *claim-denial* of the triple insertion: $(C + J) \rightarrow \text{Claim}$

- A *complex* individual justification (F: 48.1 - F: 48.3), aiming at a decisive rejection of *option B*. It is consisted of a *claim* and a *justified claim*. The former defines the recombination *goal* as the production of plasmid copies, recombinant but still similar to the original, while the latter transforms a previous idea of re-joining difficulties to the idea of non-achieving the recombination goal, *appealing to the possibility* of multiple alternative re-arrangements in *plasmid B*. Schematically, the *complex* structure in question may be presented as: $[C + (C + J)] \rightarrow \text{Claim}_{\text{no option B}}$

Concerning the four *challenges* set by peers, it is noted that two of them function as *justification requests* prompted by doubt and caution, while the remaining two are part of a scaffolding device developed in a repair sequence. Finally, only one out of two *justification requests* is directly answered.

Summarizing the above, it is worthwhile to underline:

- the much higher frequency (20) of the variously justified *operations* (*directly, subsequently or by complex structures*) compared to the ones (6) which are not justified in any explicit way (the latter is almost 1/3 of the former)
- the particular self-evident nature of the completely unjustified *operations*, which are either drawn on peers' shared knowledge resources or they constitute predicative 'non-following'-originated objections and natural confirmations to joint constructions
- the development of a range of higher-order justification structures.

Thus, it can be clearly claimed that peers' discourse has a strongly argumentative character, shaped by peers' adequate employment of warranting tactics.

The *epistemic operations* activated in the peer-group discussion include: *appeal to consequences* (5), *appeal to probability* (5), *appeal to previous knowledge* (3), *appeal to task data* (2), *appeal to instances* (1), *appeal to experimental goal* (1), *appeal to analogies* (1), *reframing the task* (1), *evaluation* (3), *refer to experimental goal* (1), *refer to consequences* (1). Being closely bound to the nature and content of the domain, the *epistemic operations* shape peers' reasoning pattern towards their final decision for *option A*. The reasoning pattern is developed upon the *possible consequences* of each option's use and their *evaluation* with regard to recombination or cloning *goals*. Furthermore, the process of decision-making for *option A* can be characterized as indirect, since peers mainly negotiate the evaluation of *option B* and it is the emergence of the latter's negative consequences through which they finally arrive at a decision for the former. The *operations of appealing to analogies and appealing to instances* are strong reasoning and argumentative means, since aiming at constructing plausible meaning about new situations they use familiar or well-known ones, which derive from peers' common sense or shared knowledge resources. The analogy mobilized in this case is common sense originating and becomes a useful peer tool in the crucial process of predicting options' consequences. In addition, the *ori-loss* instance employed in the discussion plays a key role in the group's final decision as it specifies the abstract possibility of any fragment's loss and pinpoints its practical significance on a more 'concrete' and familiar level. Nevertheless, the preceding activation of *appealing to probability* is itself critical, since it indicates that peers tend to think of recombination as a dynamic and not fixed rather than a static and always successful procedure and they use this notion to build the criterion on which they ground their decision. Finally, the operation of *appealing to knowledge* is also a significant means of warranting; it is characteristic that peers' reasoning in the process of supporting both options is strongly informed by their background knowledge about plasmid digestion products, sticky ends and *ori*'s role in DNA replication. Furthermore, the activation of *appealing to knowledge* in the discourse indicates peers' engagement in a creative process of mobilizing and applying background knowledge in order to build new target knowledge concerning genetic engineering.

Concerning the **social aspect** of the discussion, the peers' *participation pattern* is *symmetric*, as all peers contribute equally in terms of overall comments and time and no one seems to dominate the discourse for a significant time period. The *interactional mode* of the discourse is *adversarial*, since the joint answer is constructed through peers' objections about the appropriate option (one peer persists in *option B* for a significant part of the discussion, while the others hold for *option A*). It is worth while to stress that the employment of higher-order justification structures and discursive devices seems to be related to the adversarial mode of the discourse, as it rather serves peers' need to raise their own objections or to cope with objections raised by the others. Similarly, the emerging need of convincing peers for the appropriateness of one option while they strongly hold for its alternative may be considered as challenging the activation of strong epistemic means and giving the decision-making reasoning its indirect character (selection of A by rejection of B).

5. Discussion

The findings from the analysis of the peer group discussion clearly suggest that the students, being symmetrically engaged in a fruitful adversarial interaction, produced a highly argumentative discourse upon a set of various epistemic tools and finally achieved their collaborative goal of constructing a joint answer. We assume that embedded in a hypothetical

gene cloning procedure the task becomes a meaningful step to the students' overall mission. Furthermore, we consider the tasks' decision-making character as favoring the construction of arguments, since there are two different alternatives to be evaluated for the exclusive joint selection of one. Thus, the specific task implemented in a group setting seems to be an appropriate context for practicing arguments' construction, developing reasoning patterns through particular epistemic criteria and finally learning about the target property of plasmid vectors. In other words, the task seems to accomplish the aim of students' apprenticeship in scientific ways of reasoning and arguing, set by the theoretical framework of situated-learning considered for the construction of the overall didactic sequence.

Furthermore, it is worth mentioning some of the implications that the findings or the analysis process itself may have in regard with the analytic tools used for the study of the discourse. The coding scheme of the argumentative operations (Pontecorvo et al, 1993; Resnick et al, 1993) including non-typical structural elements of the argument such as oppositions, concessions and challenges, gave us the possibility to explore not only the individual but also the social aspect of arguments' construction. Thus, considering those socially oriented argumentative elements turned out to be useful for identifying the potential role of the 'other' to the construction of one's arguments and also differentiate between individual and co-constructed arguments. For example a justification request carried out through the operation of challenge may finally proved to be a condition that leads to providing grounds for a spontaneously non-justified claim and thus to constructing an argument. Furthermore, coding peer oppositions to claims makes possible to consequently identify if they lead to more complex, sufficient or persuasive justification structures for further grounding the objected claims. Finally, our ability of such dynamic view of the arguments' construction seems to be enhanced by another characteristic of the coding scheme used. The definition of the claim as 'any clause stating a position' and that of the argument as 'any justified claim, concession or opposition', made possible to also identify all intermediate arguments contributed towards the answer and not to be restricted to those which actually constitute it. On the other hand, the coding process revealed the significance of sticking to the precise context of peers' contributions in order to identify meaningfully the argumentative operations. For example, statements appearing to be claims may actually function as justifications in a specific context; the fact that they may be distant from their target premises and not necessarily attached to 'because'- markers makes the task of a reliable coding rather complicated. Concerning the domain-specific coding scheme of the epistemic operations, it is noted that emerging to a large extent from our own data, the scheme's categories permitted us to identify effectively the 'micro' cognitive procedures activated by students and ultimately to synthesize their 'macro' reasoning patterns in the specific context. Nevertheless, it should be stressed that apart from 'appeals' and 'refers', which are absolutely defined in terms of the particular biological content of reference, all the remaining categories may be applied to similar contexts of natural sciences. In addition, it is noted that the distinction between 'appeal to' and 'refer to' proposed by Mason (Mason, 1996) was proved fruitful since the inherent link of the 'appeals' with the warranting process leaves a gap concerning procedures of similar content but non warranting character.

Finally, the employment of Roth's framework (Roth, 1995) in regard with the social aspect of peers' interaction contributed to framing the overall process in terms of 'macro'- descriptions. Particularly, the mode of interaction, which is shaped by the argumentative operations of opposition/concession to claims constituting potential answers to the task, is a significant feature of the interaction, as it might be correlated to the argumentative character of the discourse or its learning products. In fact, this rather applies to the specific discussion where the adversarial

mode adopted by peers seems to be followed by the employment of higher-order justification structures, persuasion devices and epistemically rich reasoning leading to an adequate joint answer. It is underlined that four out of five higher-order justification structures along with the unique persuasion device were used to support or undermine peers' objections to an option. Such finding, if confirmed more globally, could have implications for the construction of tasks aiming at students' practice in scientific ways of reasoning and discourse. It might suggest for example that tasks requiring selection among options, which anyway fulfil one of the conditions reported as leading to warrants (Diaz de Bustanente & Jimenez-Aleixandre, 2000), should be further supported by prompting explicitly peers' adversarial interaction.

Considering the biology education perspective, the task constitutes a context for studying plasmid vectors' property of having unique target sequence per any restriction enzyme. The findings regarding the biological content of the dialogue indicate that towards the construction of adequate new knowledge about the issue in question, the students applied systematically their background knowledge. The latter concerned notions like the prerequisite of sticky ends for rejoining DNA fragments, the probability inherent to the rejoining process, plasmid vectors' property of necessarily having the ori sequence and gene cloning procedure goals. It is worth noticing that the last two notions had been recently constructed by peers in the context of previous tasks of the sequence, but they seem already familiar enough to inform more novel constructions. It is clear from the analysis that the notion of probability as inherent to the recombination procedure - reflected either upon the probable fragments' loss or the probable fragments' rearrangement- is difficult for peers to follow. Thus, it needs to be stressed by the teacher in a whole class discussion for instance, so that students could be able to understand recombination as a rather dynamic than static process, and recognize that it potentially leads to various different outcomes. Grasping this view of recombination is a crucial step for students' meaningful approach to the target property.

Summarizing the above, this study seems to indicate that tasks in an applied biological sub-domain having the specific theoretical and procedural features presented here are potentially effective contexts for the promotion of scientific thinking and discourse and the construction of new knowledge by students. In addition of cross - checking this finding, it would be interesting to explore further the potential relationship between the mode of peers interaction and the character of their discourse in the specific biotechnological domain. In other words, attempting to identify whether collaborative peer interactions can be as effective as adversarial ones in producing argumentative discourse leading to the target knowledge. Furthermore, it is worth attempting to highlight the potential relationship between the tasks' type and the character of peers' discourse comparing for example a task of proposing an experimental procedure to a one of selecting among options in terms of the employment of argumentative reasoning.

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**BIODIVERSITY AND ILL STRUCTURED PROBLEMS:
ADOLESCENTS' REFLECTIVE JUDGMENT**

Marie-Hélène Lavergne, Rodolphe M. J. Toussaint

Université du Québec à Trois-Rivières

C.P. 500 Trois-Rivières, Canada G9A 5H7

marie-helene.lavergne@tr.cgocable.ca, rodolphe_toussaint@uqtr.ca

Abstract

The main objective of education is to allow improvement in students' thinking. In our society, students have access to a huge amount of information, not always accurate. Their main challenge during their school years is to choose appropriate solution for different problems. This research considers King and Kitchener (1994) reflective judgment model with a sample of 32 adolescents aged 16-17 years old. Reflective judgment is based on the way people see knowledge and how they justify their beliefs.

The students were asked to consider complex situations involving a particular concept, i.e. biological diversity. Written answers were analysed with a King and Kitchener grid for *ill structured problems*.

When confronted with problems about biological diversity, these high school students were situated in four of the seven stages of King and Kitchener's reflective judgment model. Our conclusion partly validates King and Kitchener's model for reflective judgment.

1. Introduction

Knowledge in modern society is easily accessible to everyone. Students have access to a huge amount of information, not always accurate. The ability to solve complex problems with an appropriate solution is also one of the challenges they will face during their school years. Stimulating students' thinking should be a very important goal in education.

Specific abilities in problem solving and reasoning must be developed in science classes for the future citizen to keep abreast of evolving knowledge. Biological diversity presents a particular challenge because concepts are constantly evolving and it is difficult to provide definitive and reliable answers in light of incoming information.

In this research, students were exposed to *ill structured problems* (ISP), (King & Kitchener, 1994). ISPs are controversial issues, not entirely defined, and with a high degree of uncertainty. There is no single solution for these problems, but a multitude of possible outcomes.

Three questions guided our study: 1- What conceptions of scientific knowledge do possess the students? 2- What beliefs do they maintain throughout their school years? 3- Does problem solving of ISP allow students to exercise their reflective judgment?

The objectives of this study were twofold: - to apprehend the type of problem solving used by students confronted with *ill structured problems*; - to validate of King & Kitchener's reflective judgment model.

We wanted to probe the students' capacity in using reflective judgment and, secondly at which level of the King and Kitchener's model they were functioning. Finally, what were their conception of knowledge about biological diversity and their level of reflective judgment.

2. Conceptual frame

2.1 Reflexive thinking

The educational mission is to form young autonomous citizens with the capacity to function in a society where science and technology are in a constant evolution and where scientific information is easily accessible. Giordan (1998) suggests that learning is most important in our complex and continually changing modern society. Thus, it is important for those future citizens to make the best use of information in order to make judicious choices. High order thinking skill development for those future citizens in formation turns out essential. Reflective thinking gives the opportunity to improve individual's reflective judgment, giving intellectual autonomy in return. The economical and technological development has completely transformed our production and consumption modes, overwhelming our ecosystems self-control capacities (Giordan, 1998). This evolution in which we are implicated could have impacts, not only on our personal lives, but also on the physical environment in which we are living.

Environmental questions, the main focus of this study, represent challenges and constitute the principal issues for each citizen. The major difficulty encountered is to consider all the concepts inherent of the situation and links between those concepts in order to predict impacts

of our decisions. Obviously, more than one alternative are possible each and every time there is an environmental problem, this fact does not help in decision making.

According to Dewey (1933), true reflective thinking is initiated only when a real problem is acknowledged. This type of problem cannot be resolved by logic alone but considered solved when the person in reflection has identified a solution that closes temporarily the problem. This kind of problem is called *ill-structured problems* (ISP).

Dewey's definition of reflective thinking inspired King and Kitchener in the development of their model for reflective judgment (1994). The model considers people views about knowledge and about beliefs justification. It consists of seven (7) stages, distributed along three levels: pre-reflective, where knowledge is assumed to be absolute and concrete, quasi-reflective, where knowledge is assumed to be absolutely certain or temporarily uncertain, and finally, reflective judgment, where knowledge is constructed and the outcome of a process of reasonable inquiry (King & Kitchener, 1994).

Table 1.

<i>Reflective judgment stages</i>
<i>Pre-reflective thinking</i>
Stage 1: knowledge does exist in an absolute and concrete way and it can be obtained with certainty by direct observation. Beliefs need no justification (ex: " I know what I saw ").
Stage 2: knowledge is certain, or certain but not immediately available (known by everyone). Knowledge can be obtained directly through the senses (like in a direct observation) or from figures of authority and those who think the contrary are wrong (ex: " If it is in the news, it must be true or they would not have put it on ").
Stage 3: absolute answers are assumed to exist but to be temporarily inaccessible, in that case, only personal beliefs may be known, until the true knowledge is obtained by the figures of authority (ex: " when we have a proof we can use to convince everybody, it is knowledge otherwise, it is only a supposition ").
<i>Quasi-reflective thinking</i>
Stage 4: knowledge is unknown in several specific domains leading to an abstracted generalization that knowledge is uncertain and idiosyncratic. Every opinion is good and absolute proof is needed to believe (ex: " We will never know for sure who built the pyramids in Egypt because no one was there ").
Stage 5: knowledge is uncertain, contextualized and subjective (ex: " People think in different ways and thus, approach problems in different way. Other theories can be as true as mine, they are only based on other evidence ").
<i>Reflective thinking</i>
Stage 6: knowledge is constructed by comparison of evidence (ex: " It is very difficult to be certain in life. There are degrees of certainty. There is a point where you are sure enough to take position in a situation ").
Stage 7: knowledge is the result of an investigative process; it is probabilistic and may be generalize across domains.

This structure is based on Piaget and Kohlberg "cognitive and developmental perspective" (King, 1992). Four assumptions are then considered.

First assumption: people actively try to interpret and make sense of their experiences; interpretation from the perspective of the individual often reveals an internal logic for the explanation (King, 1992).

Second assumption: the individual's ways for making "sense" develop over time. Thus, the way we understand and approach the world is different whether we are a young child, an adolescent or an adult. Earlier ways of making sense mature over time, providing the foundation for ulterior ways of making meaning (King, 1992).

Third assumption: interactions with the environment affect the person's intellectual development. Indeed, environmental factors like the kind of intellectual challenges proposed, the quality of the interactions, and the opportunity for practice without fear of failing or being penalized affect the way people learn to reason.

The last assumption: an individual does not think in only one stage of this model; stages are not linear. Individuals tend to use several stages that depend on factors like the way this person feels at the moment of reasoning. The task's difficulty, the distractions of other concerns and the nature of feedback or support this person has received also have an influence on the reasoning performance and the reflective judgment stage demonstrated (King, 1992).

There seems to be a relationship between the reflective thinking stage presented by someone and his age, educational level and epistemic assumptions. King's (1992) research demonstrated that high school students are clustered in a pre-reflective thinking stage, college students in a quasi-reflective thinking stage, while true reflective thinking is generally seen only with graduate students.

2.2 Biodiversity

Biodiversity embraces all life forms found on earth as well as their genes and the ecosystems they constitute. Biological diversity increases when new genes appear, thus creating a new species. It may decrease with the decline of the genetic variation in a species, with species extinction, and destruction of a complete ecosystem.

Biodiversity is usually considered along three levels: genetic diversity, species diversity and ecosystems diversity (Commonwealth Department of Environment, 1997; Postel-Vinay, 2000). Genetic diversity refers to genes variation in different species. This genetic diversity may be partly attributed to the large variety and complexity of earth's different habitats; it is also related to all the conditions essential for survival. Species diversity represents the variety of species found in different biota and is measured by the wealth of species in a given place, their taxonomical and phylogenic abundance and diversity. Ecosystem diversity is based on the huge differences between types of ecosystems, habitats and ecological processes. The concept is, however, rather difficult to define since the frontiers between various ecosystems are not discretely circumscribed.

To take a stand on maintaining biodiversity and preserving the food chains, high school students are required to activate higher thinking skills within the model proposed by King and Kitchener.

Reflective thinking skills are essential in order to understand environmental issues and their consequences. Their acquisition allow people to become more responsible and much more able to adopt a wise position in selecting valid and relevant information for the situation.

3. Methodology

This research was conducted in a real class setting, during a full year, with students in the «*Environmental and sustainable development program*» (Ferron & Samson, 1998). Our interest was focused on how students think when involved in learning activities concerning biodiversity. Complex situations, involving environmental problems, provide students with enough leeway to find the most adapted solution with possibilities to practice their reasoning skills.

We considered the students' representation of biodiversity concepts and we observed emergence of their reasoning. This research is interpretative in its methodology, emergent concepts being derived from the students' argumentation. We did not try to put the information into an existing categorisation, interpretation of their thought leading us to their knowledge structure and their own belief justification.

3.1 Sample

To analyze the level of reflective judgment concerning biological diversity, 5 *ill structured problems* (ISP) were submitted to 32 students (16-17 years old) within an environmental class. Data were collected during the 2000–2001 academic year, with written answers produced individually for each ISP.

3.2 The ill-structured problems

Categories proposed by King and Kitchener in their reflective judgment model served as basis for the elaboration of each ISP. The following themes were chosen for the five ISP:

1. National parks management (see figure 1);
2. Boreal forest management;
3. Protection of endangered species;
4. Global population increase;
5. Black bear; nature laws or human intrusion?

The complex nature of the ISP is related to the fact that to form an opinion and make decision, an understanding of the different concepts involved appears necessary. The students have to make economic, social, ethical considerations, and their own value system (Kline, 1998). Moreover, the biological diversity is so complex that the students have the occasion to exercise their thinking from the first stage through the seventh of King & Kitchener's reflective judgment model.

3.3 Analysis

Analysis of the students' reflections about the ISP provides the opportunity 1) to discover their approach for solving ill-structured problems with no right or wrong answer; 2) to compare the emergent concept categories with King and Kitchener's reflective judgment model.

Content analysis of the written answers was made with the program NUD*IST. The students' reflections were transcribed then coded. Data analysis consists in clustering the students'

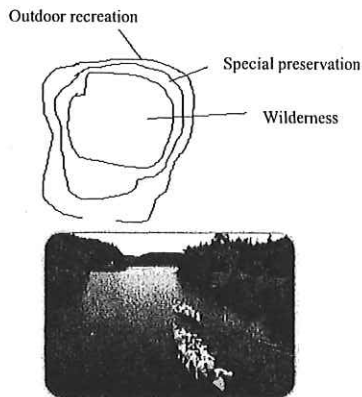
representations according to similarity in meaning. This software gives the opportunity of proceeding to a decontextualization of the data.

The national parks management



Canada Parks / J. Pleau

There are about 39 national parks in Canada, divided in all Canadian provinces. In 1998, an ecological integrity commission for national parks was created to study the integrity of biodiversity in those parks. Canada Parks classified the terrestrial lands and water within those parks in *zones* offering variable degrees of protection. The national parks' zoning system allows Canada Parks to apply the ecological integrity principles in order to protect lands and their resources and minimize man's disturbance. Tourist activities occupied small proportion (0,57 %). The remainder is zoned *special preservation* (3,25 %) and *wilderness* (94,1 %).



Canada Parks / J. Pleau

Special preservation :

These zones hold natural features, threatened or endangered. Access and motorized circulation are not permitted.

Wilderness :

These zones are conserved in a wilderness state. Recreational activities are adapted to the park ecosystems. Outdoor activities are authorized only if they do not conflict with the maintenance of the park wilderness. Automobiles are prohibited and access by plane is allowed, but strictly controlled.

Questions:

Do you think that this management will give the opportunity to preserve the rich biodiversity of those parks?

1- Which positive characteristics would allow us to preserve the parks' biodiversity? Give an explanation for each, in what way does it allow to preserve this biodiversity. Explain your point of view.

2- Which negative characteristics may stop the preservation of the parks' biodiversity? For each characteristic, explain what might hinder biodiversity preservation. Explain your point of view.

Figure 1. *ill structured-problem* for "National parks management"

Semantic criteria were selected for the classification, ideas or propositions being considered in global context (L'Écuyer, 1989). For example, one student wrote : *"They (animals) live like they should, without knowing human domination on nature, since they appeared on earth. Food chain is then better organized and biodiversity is in much better condition"*. In this sentence we deliberately chose : *"They (animals) live like they should, without knowing human domination on nature, since they appeared on earth"* and categorised this statement as a negative human impact on nature. Thus, occasionally a same semantic unit could be coded in different categories, according to different contexts. Another student wrote : *"Moreover, it is because we protect something this way that it would survive all the time. We should let nature by itself and stop trying to control everything. Maybe some species have to simply disappear with no human interferences. I can not answer this"*. In this proposition, this student proposed we let nature do what it has to do, which represents one category. From the same sentence, another category is lack of knowledge which gives uncertainty. Categorisation evolved from what a person meant and we did not try to discover the latent content nor the symbolic or psychological signification of the students' speech (L'Écuyer, 1989). The semantic units were then compared to construct more encompassing categories in which we could find every similarly built semantic unit. We end up with eight categories and some subcategories.

Our sample was sufficient enough, because we rapidly obtained data saturation. Qualitative content analysis is usually significant when categorisation emerged are both, exhaustive and limited (Bardin, 1993; Savoie-Zajc, 2000). After coding three of the five ISPs, no more new categories were found, the first one was sufficiently encompassing to contain all the other semantic units without having to add new information.

4. Findings

In the following, we present eight categories that were formalized from our analysis :

1) Sources of danger

Human actions through their institutions are judged as a source of danger for the environment. Nature itself sometimes causes problems due to the complexity of the variables. Students also pointed the lack of knowledge as another source of danger.

"...pulp and paper companies' only interest is in their growing market and production but the forest does not grow bigger (in a territorial point of view) so, one day they won't be able to get this resource." (Karl / ISP₁)

2) Helping sources

Students see the Institutions (National parks, laws, schools) as a good source of help for the nature. They also raised the obligation for the humans to do something to prevent the planet's destruction. Some students see nature itself as capable of caring for every living creature.

"I think that we should leave nature alone. For 3,8 billions years, nature itself can have kept with this task. Nature knows how to create dominated species rotation, it has conceived a food chain that suits everyone and it has given to each and everyone a function on earth." (Maxime / ISP₂)

3) Evolution takes time

Evolution over time is an important factor to consider when studying an environmental problem, and this allows for some uncertainties about the solutions to be chosen from.

" Who knows how a protected species could have lived in another environment than the one the earth has offered it ? anyway who knows if the earth could have evolved in another direction than this one ? These are questions that, I am sure, have not been answered by scientists, because no one can know in advance what has been reserved for us. " (Amélie / ISP₂)

4) Experts' report

The students tend to use experts' opinions as highly reliable to help them form their own opinion.

" Since I am not a specialist myself, I can not be sure that my opinion is correct. In the same way that no one can be sure either. " (Cynthia / ISP₁)

5) Social environment

The social environment is suggested as a source of influence when people have to make decisions about a problem.

" I based myself on what I saw on television or what I learned at school or what I heard about the subject. I also based my point of view on the others' point of view, that helped me to understand some points that I had never thought of in this way before. " (Mélodie / ISP₁)

6) Preconceptions

Some students use preconceptions to justify their position without ever questioning those conceptions.

" Protection costs a lot of money, preservation too, and I am not sure society is ready to invest billions of dollars to protect species they have never seen. " (Rosalie / ISP₂)

7) Idiosyncratic position

Some of the students consider knowledge as an idiosyncratic concept.

" Yes, because every opinion is good in accordance with everyone's judgment. We cannot describe an opinion as wrong, because we judge an opinion from our thoughts, our values, and meaning that everybody has his own opinion. " (Judith / ISP₁)

8) Truth

Others believe with absolute certainty that truth does exist and everybody should stand for it.

" Yes, one and only one : the survival instinct. That is simple, clear and logical. Why look far away when the answer is so simple. " (Cynthia / ISP₃)

5. Interpretation

Dichotomic observation

To understand an environmental problem, students try to identify the culprit for the ecological unbalance. For example, they see human beings in general as an important threat for different aspects of environmental balance. Species extinction is related to human activities and could be caused by nature itself. Their reasoning stops there. So, pre-reflective judgment is characterized by this dichotomic vision of ISP (King & Kitchener, 1994) where individuals separate knowledge in two categories : right and wrong answers. Each problem has a unique solution. This dichotomic vision is prevalent in the pre-reflective judgment.

Recognition of others views

For complex situations, they refer to experts' solutions. Experts are reliable people, possessing knowledge so, their judgment must be reliable. Students are not ready to evaluate a complex situation on their own, by analysing alternatives for example, in order to build their own conclusions. However, many students did question the expertise of some specialists. Their position against credibility of experts is products from a divergence of opinion with them. They did not offer argumentation to justify their doubt. They only rejected an opinion that did not follow the same direction as theirs. For King and Kitchener (1994), ability to consider others' views for a complex situation shows a higher stage of reflective judgment, a quasi-reflective judgment or a reflective judgment.

Pre-conceptions stability

These research results show that students with a pre-reflective judgment (three first stages of the King et Kitchener's model) used their pre-conceptions to solve complex situations where only their views prevail. These conceptions come from their family circle (parents, friends, teachers, experts...), and are therefore reliable and difficult to modify. This stability let us think about what Toussaint (2002) calls the stability of first representations where even when students are confronted with facts that contradict their naive conceptions, they still retain their preconceived ideas.

The seven categories of King & Kichener' model are partly validated considering that some students used their own observations to make their opinion. Knowledge is seen as concrete and there is an absolute correspondence between what a person believes to be true and what is true (Stage I). Some students justify their position by using figures of authority: teachers, parents, etc (Stage II). Some justify their position by using experts' point of views about the subject and raise the fact that everybody has the right to detain a personal opinion even if it is not the same as theirs (Stage III). Others explained the differences between solutions by the idiosyncratic way people construct their opinion, referring to personal values and individual knowledge (Stage IV). The higher stages (V to VII) were almost not detected in the written answers. Our findings are consistent with King & Kitchener inasmuch as thinking for the high school students is usually at the pre-reflective or early quasi-reflective stages.

6. Discussion

The main objective of this research consists in a better understanding of 16-17 years-old students' reasoning when they are confronted with environmental complex situations. We wanted to evaluate their reflective thinking level according to King and Kitchener's model (1994), by looking at their vision of knowledge and justifications for their point of view in order to partly validate the model. Furthermore, we also tried to find out what understanding they have of the environmental concepts surrounding each problem in order to contrast this understanding with their reflective judgment level. Finally, we wanted to evaluate if an action, like solving ill-structured problems (ISP) based on the understanding of biological diversity allow students to use their reasoning to improve their reflective thinking.

While analysing students' reflections on problem solving, we realised that some students could present a first level reasoning at one time, and present a superior level (second or third)

of reasoning at another time. It is then possible for one person to use different level of reflective thinking at different moments.

It appears that some students see the idiosyncratic character of knowledge only in theory. When they are confronted with opinions different from theirs, they are radical, without consideration for other viewpoints.

Several students feel that knowledge contains some elements of ambiguity and uncertainty, but they do not always write it very clearly. The writing context may have imposed a limit on the clarity of their thinking. If the data have been collected through an interview for example, we would have had provided the opportunity for clarification of their thoughts. It is possible the classroom context could have limited students' reasoning. Restricted time allowed for problem solving, other students' proximity created a climate similar to the one of examination testing, this may have restricted their spontaneity. The school context in which we made this study, however, confirms that it is possible to conduct this kind of experimentation with students.

The reasoning mode generally used by students excludes themselves from the problems. They blamed experts, company leaders or the government for all the environmental problems. The problems are analysed with an external vision that limits them in their capacity to perceive the real complexity of the situation. When students exclude themselves from the problem, the situation becomes simple and only one vision is possible. This is a characteristic of the pre-reflective stage.

The moral responsibility that we found in the students' reasoning leads us once again to believe that they distinguish all the facets hidden behind every complex situation. They describe two alternative situations : 1) humankind is responsible for every destruction, and 2) nature itself is also responsible for these changes. They wish for actions to be undertaken in order to help the environment only when human beings are responsible, but not when it is nature itself that decided a change was needed. They do not distinguish the entanglement of both situations that cannot be managed separately. They keep this reasoning in justifying their belief system. They do not detect the complexity behind all the different positions adopted by different people on a same problem.

The students see nature concept as much as a source of help as a limit to its stability. Nature is solid and capable of adaptation to changes, but they also see its vulnerability, sensing in this way, intuitively, that every action done on nature may have more unforeseen consequences.

Their conception of biodiversity focuses on animals only and do not include plants. This perception of biodiversity denotes a lack of global analysis of the situation that is coherent with a pre-reflective judgment. Indeed, the reflective stage is achieved when every facet of the problem is seen.

Using ISP, like the one used in this research, provides the opportunity for students to practice their thinking skills in order to develop their reflective judgment. We were able to understand and analyze their conception about each ecological system and to make inference about their reasoning skills.

Results show that adolescents are able to reason about complex situations. However, the type of problems they face during their school years does not fit the type of problems that allows

high order thinking skills. Other thematic situations (genetic manipulations, cloning, world resources water or food sharing) could be used as sources of complex situations for reflective thinking exercises.

The brief duration of this research does not allow us to verify if the new knowledge is applied in deliberate action toward the environment. This study confirms however that making students reason about complex situations provides the opportunity to practice their thinking skills and to make transfer to analogous situations. They develop critical thinking skills and their environmental awareness which could have a positive impact on their behaviour towards environment. In turn, this could increase their desire for implication in environmental causes. This awareness of their own impact on nature could also improve their desire of implication in an environmental comity for example, or simply to recycle or compost.

Empowering students to practice their thinking could give them the opportunity to improve their understanding of scientific concepts in general. Thus, they will develop a more critical regard by analysing all aspects of a question. They will not tolerate only one possible answer, they will look for other possibilities, and they will look at the problem under different aspects before they stand for the most adapted solution for the situation. They will be able to think before they act.

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LEARNING BIOLOGY

**“PROTEINS HAVE THE BASES URACIL, THYMINE, ADENINE, GUANINE,
CYTOSINE”**

**CONCEPT MAPPING AS A TOOL TO CLARIFY TWO BIOCHEMICAL
CONCEPTS.**

Jutta Lumer, Friederike Picard & Manfred Hesse
Institute of Didactics in Biology, University of Münster (Germany)
picardf@uni-muenster.de

Abstract

Already in 1996 it was demonstrated how poorly the comprehension of transcription and translation is even among students which graduated from German high schools (Lumer 1996). These results show that one of the main reasons of this lack is an insufficient knowledge of the molecular structure of proteins and nucleic acids.

Therefore, we developed a concept map task which helps students to repeat and strengthen their conceptual knowledge about proteins and nucleic acids and which also allows to reveal and correct several students' misconceptions. To prove the effectiveness of this task, biology teacher students were asked to describe the molecular structure of proteins and nucleic acids in their own words – before and after performing the task. Analysing the students' written answers we show that besides a concentration on those contents presented in the maps there is a strong decrease of misconceptions, but nevertheless no change in the amount of false technical terms and inaccurate formulations.

1. Introduction

Since the last decades not only the knowledge of the molecular processes of life has been increased to an indescribable extent, but also the public interest in those subjects has become stronger every day. Especially biotechnology concerning genetics like cloning, genetic engineering and fingerprinting are discussed in the media. To take part in these public debates a basic comprehension of the molecular processes – above all transcription and translation – is imperative.

1996 Lumer proved how poorly this comprehension is even among students which graduated from German high schools (= Gymnasium) (Lumer 1996). Her results indicate that one of the main reasons of this lack is an insufficient knowledge of the molecular structure of proteins and nucleic acids. Especially a clear distinction between these two is a frequent difficulty (Lumer & Hesse 1997a+b, Lumer et al. 1998). Seemingly the students know a large amount of details (e.g. that translation proceeds in the 5' → 3' direction, or how many hydrogen bonds exist between thymine and adenine), but do not understand the basic facts about proteins and nucleic acids.

On the basis of these results we developed a task which on the one hand helps students to repeat and strengthen their conceptual knowledge about proteins and nucleic acids by concentrating on these basic facts, and to avoid mixing up these two concepts. On the other hand this task can reveal and correct several students' misconceptions which might have been overlooked. Therefore, the students were asked to build concept maps which represent their own knowledge about the molecular structure of proteins and nucleic acids.

Our research question was: Is this concept map task a helpful tool to improve students' (written) explanations concerning the scientific concepts "proteins" and "nucleic acids"?

In detail: 1) Will an increase or a decrease of correct statements be recognised? 2) Does the amount of used technical terms change? 3) Will the amount of errors (distinguished in inaccurate formulations, false terms and misconceptions, see 4.3) de- or increase?

2. Concept map tasks in the teaching process

Concept maps have become a common method in teaching and research. In the last 15 years a series of publications proved that concept maps are a helpful tool to recognize, summarize and connect the significant information of a subject (e.g. Mikulecky et al. 1989, Heinze-Fry & Novak 1990, Okebukola 1990, Esiobu & Soyibo 1995, Jüngst 1995, Sungur et al. 2001 and Zieneddine & Abd-El-Khalick 2001). This can promote a meaningful learning of concepts and their relations (Novak 1990). Concept maps are related to semantic memory theories which suggest that a net-shaped presentation of conceptual contents corresponds adequately to what is so far known about the way how concepts are stored in the human memory (Aebli 1989). Following this, the meaning of complex concepts can be represented by other concepts (= junctions) and relations (= connections) between them.

Concept maps can therefore be used for several needs in the teaching process (Kinchin 2000):

- By choosing the "basic" concepts needed to give a sufficiently short, precise and terse description of a subject represented in a concept map the teacher can be assisted in preparing curricula and lessons.
- During a course or a lesson a concept map can be constructed by linking single pieces of information step by step; this gives students an orientation of their own learning process.

- Using (self constructed or given) concept maps the students receive a helpful guidance to adhere to the selected concepts; this sort of consistency is absolutely essential for students in the process of acquiring basic knowledge (Mikulecky 1989, Roth 1990, Sungur et al. 2001).
- This also provides a good base for practising scientific language and repeating information (Schmid & Telaro 1990, Roth & Roychoudhury 1993).
- Concept map tasks can help teachers to detect non appropriate interpretations of material by the students (Behrendt et al. 1997).

3. Concept map tasks in a chemistry course for biology teacher students

The concept map task which is discussed here supports the consolidation of the knowledge of the concepts “proteins” and “nucleic acids”. This task has been designed with reference to our positive experience with a similar task for high-school classes concerning “the path from the gene to the trait” (Lumer et al. 1998).

The task dealing with the molecular structure of proteins and nucleic acids has been applied in a chemistry course for future biology teachers. The aim of this course is to activate or establish a knowledge of basic chemistry contents which are in our opinion indispensable for learning biology. Subjects are for example water and solutions, oxidation and reduction, acids and bases, and important organic molecules such as organic acids, lipids, carbohydrates, proteins and nucleic acids.

During this course the students, which usually do not have any experience with concept maps, are carefully trained to deal with this kind of representation of information. After one concept map (“lipids”) has been introduced to the students, they are asked in one of the following lessons to fill in the junction words in another concept map (“carbohydrates”).

In a last step the students have to construct concept maps by themselves (“proteins” and “nucleic acids”) using given junction words and relations (see figure 1 and 2). At the end of this task the different proposals are discussed and corrected – if necessary.

Therefore, it has to be distinctively stressed that constructing “the one and only perfect map” cannot be a desirable aim. Neither do we want the students to learn one of their proposed maps by rote. We hope that by constructing their own maps the students are forced to penetrate the logical conceptual structure. In other words, having an appropriate result (=correct map) is only one part of the task, the other one is “to get there”, which means to think about the meaning and use of the given words and relations.

Our positive experiences during the last two years convinced us that our assumption was correct. Because by discussing the students’ proposals many misconceptions have been revealed and inaccurate formulations have been corrected. By means of examining our suggestions we started to evaluate the effectiveness of the concept map task this year.

4. Research design

4.1- Sample

All students who took part of this study want to become high school biology teachers for the grades 5 to 10. Those who have chosen other subjects than chemistry as their second subject have to pass a special course “chemistry for biologists” in their first years. Those students who passed the assessment test in February 2002 and took part in the chemistry course in April 2002 were tested (n=14; 7 female, 7 male; 6 first term, 5 third term, 3 fifth term).

Considering that there were only 14 students this year to work with we decided not to split this small group into an experimental and a control group. Because of the fact that the course programme is slightly changed every year it is not appropriate to use former or future course members as a control group.

4.2- Collecting the data

- 1) Preparing themselves for an assessment test, the students use given and/or self chosen schoolbook-texts which contain information about the molecular structure of proteins and nucleic acids.
- 2) The students are asked to describe the molecular structure of proteins and nucleic acids in their own words. (= part of the assessment test)
- 3) Six weeks later those students which passed the assessment test and took part in the chemistry course (n=14) are introduced to work with concept maps (as described above) and perform the task. (= part of the course)
- 4) Two weeks after this the students are again asked to describe the molecular structure of proteins and nucleic acids in their own words. (= part of the final test)

4.3- Analysing the data

The analysis of the students' answers included:

- a) counting the used technical terms, the correct statements and the errors,
- b) analysing the type of errors (misconceptions, false terms and inaccurate formulations),
- c) distinguishing between those terms, statements and misconceptions "inside" and "outside" the maps.

The differentiation between misconceptions, false terms and inaccurate formulations can be described as the following:

Inaccurate formulation: the student gives a correct statement concerning terms and contents, but the formulation he or she uses is not scientifically adequate, e.g. "proteins can be portrayed in the secondary, tertiary, quarternary structure" instead of "proteins have a secondary, tertiary and quarternary structure".

False term: the student describes the scientific facts correctly but uses a false technical term, e.g. "quarters structure" instead of "quarternary structure".

Misconception: the student gives an incorrect description of the scientific facts, e.g. "Prolin is responsible for the structures of proteins".

Although we know that it is quiet problematic to classify students' conceptions as "misconceptions" we prefer to use this term in this case. The more frequently used terms "alternative conceptions" or "prior knowledge" are based upon the assumption that

- 1) students construct their own "scientific" concepts by interpreting phenomena of their everyday life, and
- 2) that those (meaningful) concepts consist respectively are arranged in a "logical structure", which fit into the students' prior experiences. (Gröger 1996)

The misconceptions we are confronted with in this study have a slightly different character:

- 1) a) Although we did not investigate the origin of the misconceptions systematically we assume from several discussions with our students that these misconceptions are rather caused by teaching experiences than by everyday life experiences.

1) b) According to our observations during the last ten years we believe that many students do not construct biochemical concepts (e.g. “proteins” and “nucleic acids”) to explain biochemical phenomena (e.g. protein biosynthesis), but to pass the next test.

2) As long as tests are mainly demanding a repetition of rote learned phrases than asking for an application or transfer of knowledge the students’ concepts do not need any logical structure. It often seems as if the students remember words and phrases which are somehow related to “proteins” and “nucleic acids” by chance as soon as one of the key words of these subjects are mentioned. For example one of our students first claims that proteins have got only one carboxyl group, one amino group and one R-group; but further on she writes: “Proteins are made of 20 amino acids.”

In our view those statements should not be described as “alternative ideas” which can be “seen as acceptable ‘intermediate conceptions’ to built upon” (Taber 2001) but as “misconceptions”.

All results are to be tested statistically by using the t-test (technical terms; correct statements) respectively the Wilcoxon- χ^2 -test (errors).

5. Typical misconceptions

Before presenting the results we would like to give some further examples of the statements made by students in the 1st test; they show the kind of misconceptions existing. The later can also be regarded as typical because they already appeared in our former investigations (Lumer & Hesse 1997a+b, Lumer et al. 1998):

- no clear distinction between the different substances proteins and nucleic acids (1 student): *Nucleic acids can be distinguished by the rest. [...] Proteins have the bases uracil, thymine, adenine, guanine, cytosine.*
- confusion about the monomer-polymer-hierarchy of proteins (6 students), e.g. *Every peptide has an amino group (NH₂), a carboxyl group (COOH) and a rest.*
- no clear distinction of the “secondary, tertiary and quaternary structure” (6 students), e.g. *The tertiary structure contains many chains of amino acids.*
- no reference to the hierarchical relation between secondary, tertiary and quaternary structure (13 students)
- misconception about the differences of DNA and RNA (2 students), e.g. *DNA has got one sugar less [than RNA].*
- no reference to the fact that even the molecular units of RNA are nucleotides (13 students).
- misconception that also RNA has a double strand and a (double) helix (7 students), e.g. *DNA and RNA are built like a rope-ladder.*

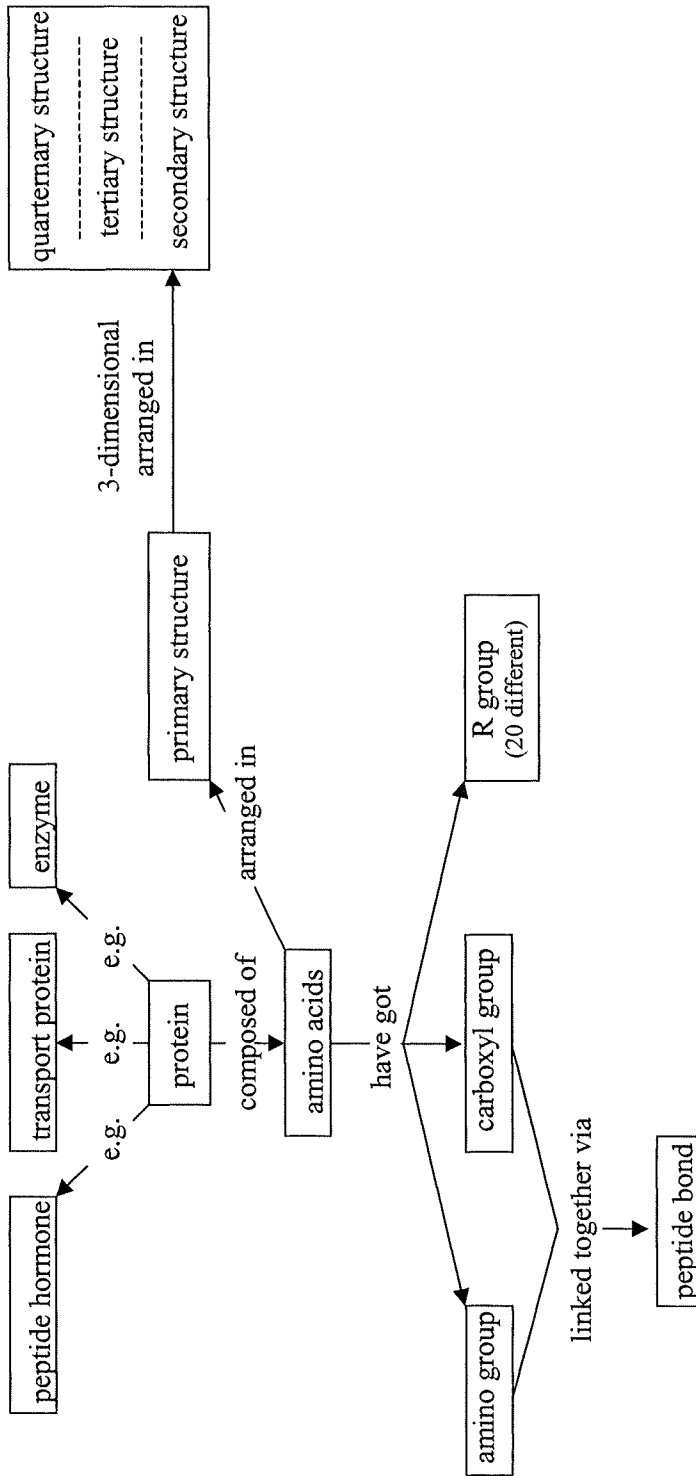


Figure 1. Example of students' concept map of "proteins"

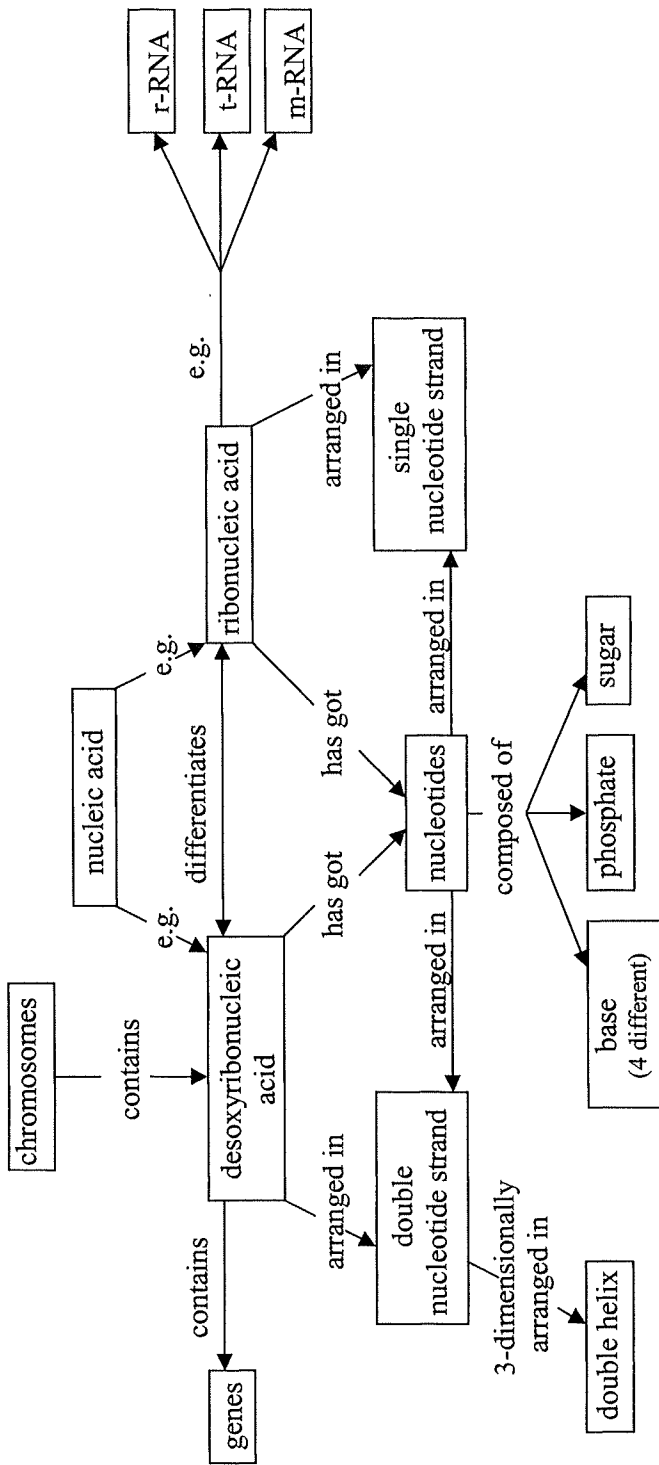


Figure 2. Example of students' concept map of "nucleic acids"

6. Results

6.1- Technical terms

The total amount of technical terms seems not to change, but analysing the data in detail there are variations:

a) those technical terms, which appear in the maps (=“map terms”) show a highly significant increase ($\alpha=0,002$), but the “non map terms” decrease ($\alpha=0,000$) is even stronger; (see diagram 1);

b) especially the technical terms concerning „nucleic acids“ demonstrate the increase of “map terms” ($\alpha=0,002$);

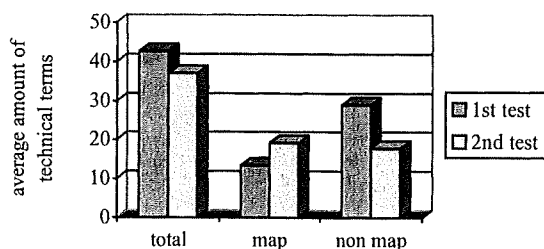


Diagram 1.

c) those concerning “proteins” demonstrate a stronger decrease of “non map terms” ($\alpha=0,000$);

6.2- Correct statements

The total amount of correct statements seems also not to change, but analysing the data in detail there are similar variations like in technical terms:

a) a highly significant increase ($\alpha=0,002$) of those correct statements, which appear in the maps (=“map statements”), but a distinct decrease of “non map statements” ($\alpha=0,004$); (see diagram 2)

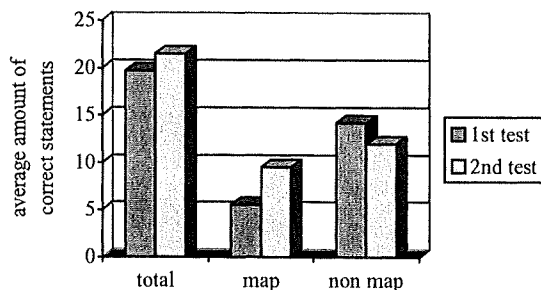


Diagram 2.

b) here also the correct statements concerning “nucleic acids” demonstrate a stronger increase of “map statements” ($\alpha=0,003$);

c) and especially those concerning “proteins” demonstrate the decrease of “non map statements” ($\alpha=0,003$);

6.3- Errors

The amount of all errors decrease distinctively ($\alpha=0,005$), but the three categories of errors show a different change:

a) while there is a highly significant decrease of misconceptions ($\alpha=0,002$), the small decrease of false technical terms and inaccurate formulations is not significant (see diagram 3);

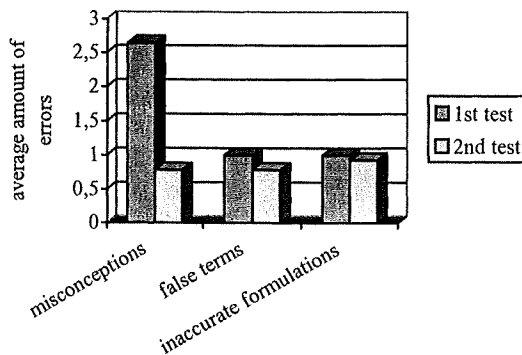


Diagram 3.

b) especially those misconceptions which can be corrected by knowing the map-structures (“map misconceptions”) show a highly significant decrease ($\alpha=0,004$), but also the other misconceptions (“non map misconceptions”) decrease significantly ($\alpha=0,023$); (see diagram 4)

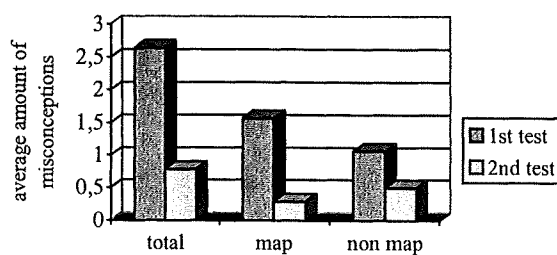


Diagram 4.

c) there is a higher significance concerning “proteins” (“map misconceptions”: $\alpha=0,014$; “non map misconceptions”: $\alpha=0,033$) than “nucleic acids” (“map misconceptions”: $\alpha=0,046$; “non map misconceptions”: no significant decrease).

7. Discussion

The first aim - to promote students' concentration on those contents which are represented in the maps - seems to be achieved. This is observed with different tendencies in "proteins" (stronger decrease of non map contents) and "nucleic acids" (stronger increase of map contents), because concerning "nucleic acids" there is a strong increase especially of those terms and statements which deal with the chemical and three dimensional structure of RNA; concerning "proteins" there is a strong decrease of those which deal with functional (and not structural) aspects.

Although the intended concentration on the basic facts is observed we cannot unequivocally interpret this as an effect of the task. This could also be just a "time effect", because the 2nd test has been made two months after the 1st test, but only two weeks after performing the task. We cannot exclude that the students just forgot more of the non map contents and remembered the recently repeated map contents better.

In opposite to this we think that the dramatic decrease of map misconceptions can be interpreted as a distinct effect of the task. Like the decrease of non map misconceptions correlates with the decrease of non map contents, one would also expect an increase of map misconceptions - if the students wrote more about the map contents, just because those have been repeated recently. But the opposite is observed!

The most important corrections are:

- a distinct separation of the two substances proteins and nucleic acids
- a distinction of the monomer-polymer-hierarchy of proteins
- noticing the hierarchical relation of the terms "secondary, tertiary and quaternary structure"
- a distinction of the different structure of DNA (double nucleotide strand; double helix) and RNA (single nucleotide strand; no helix)
- a perception of the three different types of RNA (m-, t-, r-RNA).

Thus, we are convinced that the here discussed concept map task is a helpful tool to detect and correct students' misconceptions concerning the molecular structure of proteins and nucleic acids.

Until now we cannot prove whether this positive influence can be recognized over a long period - like Cliburn (1990) proved in his study - but the performance of former students in other courses suggests that the so acquired conceptual knowledge about proteins and nucleic acids is quiet stable.

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LEARNING DIFFICULTIES IN ECOLOGY.

Alexandra Magro¹, Laurence Simonneaux¹, Didier Favre² and Jean-Louis Hemptinne¹

¹Ecole Nationale de Formation Agronomique, BP 87 – F-31326 Castanet Tolosan Cedex, France ; ²Lycée d'Enseignement Général Technique Agricole de Tours Fondettes, La plaine, 37230 Fondettes, France
alexandra.magro@educagri.fr

Abstract

In a previous paper on the lack of motivation for ecology by most pupils of agricultural schools in France, Magro *et al.* (2001) suggested that this problem exists because teaching is not changing at the same pace as the “scientific knowledge”. Furthermore, they have shown that teaching is based on descriptions and definitions and is therefore not very concrete.

In the present work, the authors want to know whether pupils are able to understand the underlying mechanisms of ecological processes and acquire methodological skills for solving practical problems, as they are supposed to following the objectives and purposes outlined in the *curricula* forewords.

Seventy-four pupils having overcome successfully the final national examination of the agricultural secondary schools were asked to answer a questionnaire. It appears that they were very keen to give definitions or describe but unable to solve a practical problem and understand what the attributes of ecology as a science are. In what concerns practical ecological problems, pupils show that their prior teaching did not endow them with a theoretical framework for reasoning. However, they seem intuitively able to logically think about the problem.

1. Introduction

Media frequently report about political measures based on scientific information that have huge social consequences. This is the case for the debate on genetically modified organisms, laws determining the opening and closing dates of hunting seasons or the re-introduction of predators like wolf or bear. Therefore, education must train people to develop a critical understanding of such issues and make sound decisions through, for instance, changing their consumer habits or election of their representatives.

Ecology is central to the understanding of environmental processes (Hart, 1978, Hale, 1986). There is, therefore, a large consensus about the fact that ecological literacy is a fundamental part of the total education package (Golley, 1993). However, the last year public opinion reactions to the EU decisions of reducing quota to avoid the collapse of fisheries are not different from those recorded 25 years ago when the Canadian government largely reduced cod quotas and finally closed Newfoundland fishing grounds in the early 90s (Kurlansky, 1999). Today, citizens still seem unable to decipher these complex issues.

There are different opinions on the origin of the general inability to correctly analyse ecological topics. Roberts (1997) argues that “students perceptions of ecology are often about creepy-crawlies and counting daisies on the school field, hardly appealing to their own interests” and seen as nonsense for the understanding of environmental issues. Unfortunately, this lack of relationship to practical everyday life is frequent in science education and might explain the disinterest of young people for science in most countries (Delpech, 2002).

In order to stimulate students’ interest and teach ecology more efficiently many authors propose strategies like situated learning, fieldwork or computer simulations (e.g. Hale, 1993, Lutterschmidt & Schaefer, 1997, Heimerich, 1998, Fernandez-Manzanal *et al.*, 1999 or Randler & Bogner, 2002).

Magro *et al* (2001) observed that the teaching of ecology in the agricultural schools in France was traditionally focused on the concept of ecosystem. Pupils learned about abiotic factors, that organisms can be sorted out in trophic levels. They also learned that ecosystems evolve and can be of different sizes. This teaching is descriptive. The biological diversity is not taken into account because organisms are only quoted as examples of the kind of species that can be found in various trophic categories. Magro *et al.* (2001) also observed that teachers neglected for many years to consider the individuals and the fact that modern ecology is the scientific study of the interactions that determine distribution and abundance of organisms (Krebs, 1994). Therefore, teachers were probably not aware that ecologists need to know how individuals live to understand the dynamics of their populations and how such populations interact with other species in communities (Begon *et al.*, 1996). For Magro *et al.* (2001), this explains why the teaching of ecology was cut off from the real life and poorly appealing to pupils. They believe that this has to be changed before adoption of the pedagogic approaches recommended by Hale (1993), Lutterschmidt & Schaefer (1997), Heimerich (1998), Fernandez-Manzanal *et al.* (1999) or Randler & Bogner (2002).

In our opinion, a second factor might contribute to the learning difficulties in ecology. “Ecology” and derived words are associated with subjects outside the scientific field. They are loaded with subjective values, namely ethics and aesthetics. Therefore, children starting to learn ecology may have strong alternative representations about what is ecology. Baker & Slingsby (1999) believe that this meaning problem is even common at teachers level “The relationship between teaching about environmental issues and ecology as science can sometimes appear confused“. We defend the idea that a descriptive approach of ecology, centred on ecosystem, will not allow people to avoid making confusions.

This paper aims at testing the hypothesis that teaching of ecology with a strong focus on ecosystem,

- will train pupils in a way that will allow them to easily recall definitions and describe ecosystems components;
- will not prepare pupils to understand the ecological mechanisms underlying the relationships between the components of an ecosystem and as a consequence will not prepare them to solve practical problems, contrary to the objectives and purposes outlined in the *curricula* forewords;
- will not give pupils the idea that ecology is a science.

2. Research design and Method

Seventy-four pupils were asked to answer a written questionnaire three months after having successfully overcome the final national examination of agricultural secondary schools. These pupils represented 35 different secondary schools.

The questionnaire had three items:

1. A 319 words text, describing the recent decline of the sea otter (*Enhydra lutris*) in the Alaskan Sea. This text was based on Stevens (1999). It has an introduction on sea otters and their natural history in the Aleutian Islands. Then, it deals with the sea otter's population crash and explains that this reduction in abundance is the result of the predation by killer whales (*Orcinus orca*). Killer whales usually feed on Harbor seals (*Phoca vitulina*) and Steller sea lions (*Eumetopias jubatus*) but had to change their diet as a consequence of the rarefaction of these pinnipeds provoked by a lack of fish. Fish was in turn rare because fishing grounds were overexploited.
2. An 648 words annex presents the natural history of sea otters, Harbor seals, Steller sea lions and killer whales: general description of the animals (weight, food preferences, territorial range, preferred habitat) and demographic parameters (longevity, age at sexual maturity, number of births per year and during their total life time).
3. Four questions about concepts which are part of the pupils *curricula*:
 - 3.1. Give a definition of food web.
 - 3.2. Build the food web of the Alaskan Sea following information contained in the text.
 - 3.3. Why do killer whales reduce populations of sea otter and not populations of Harbor seals or Steller sea lions they were preying on before?
 - 3.4. The initial text mentions fishery overexploitation. Researchers in ecology got interested at this problem because (choose one of the two following sentences):
 - ! They want to know how to manage fish populations in order to avoid fish depletion.
 - ! They believe that Nature belongs to everybody and its equilibrium is sensible so that it should not be modified because consequences are unpredictable.

The first two questions are typical of the National examination. In the first question pupils have to recall verbal information in order to define a food web. The second question requires pupils to analyse a text, extract information and draw a net of trophic relationships.

The third question is on population dynamics, which is part of the *curriculum* followed by the 74 pupils. Contrary to what is usually done during National examinations, this question is practical. In order to answer it, pupils have to deal with information on the lower integration level, i.e., individuals. In fact, as Krebs (1994) says, in general, a scientist dealing with a particular level of integration seeks explanatory mechanisms from lower levels of integration.

For helping their reasoning, pupils were encouraged to read the annex on the natural history of the different actors of the story.

Finally the fourth question is on misconceptions about ecology. This question was constructed to see if pupils were able to distinguish the attributes of ecology as a science (objective, predictive and experimental) from ecology as it is usually presented in the media, that is a social/philosophical/political attitude responding mainly to subjective values, ethical and aesthetics.

Assessment of the answers is done as follows:

Question 1

The usual national examination criteria are used.

The correct answer is “The totality of the trophic relationships that link different populations (or species)”.

Key words:

“Totality”, because it is not only a trophic chain. Synonyms are also accepted.

“Trophic relationships” because it only takes into account the food relations.

“Populations”, because the actors of the food web are groups of individuals of the same species. Other words like “species” or “groups of living beings” are also accepted.

“Consumers” or “producers” give right to half the points.

Question 2

The correct answer is presented in Figure 1.

The six populations of the food web must be quoted; points are taken out for each missing element.

The six populations must be correctly linked; a point is taken out for each missing or non-correct link.

A legend must be presented to indicate the meaning of the links (arrow means “being eaten by” or “eater of”).

Killer whales must be at the intersection of the two food chains.

The role of men must be mentioned, either by considering him as part of the trophic chain or by mentioning it in another form.

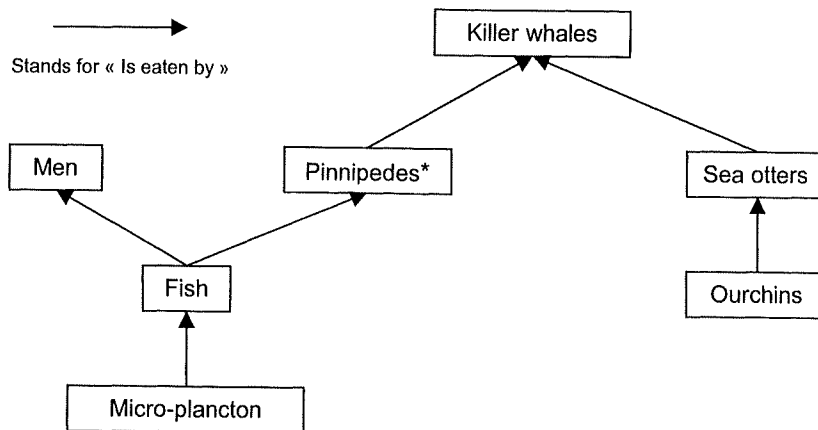


Figure 1. Food web of the Alaskan Sea. * Instead of Pinnipedes, Steller sea lions and Harbor seals could be mentioned separately.

Question 3

The pupils are expected to build their answer using the simple following equation.

$$N_{t+1} = N_t + \text{Births} - \text{Deaths} + \text{Immigrants} - \text{Emigrants},$$

where N_t is the number of individuals in the population at time t and N_{t+1} is the number of individuals in the population at time $t+1$. The expression of the same idea in words is also accepted.

The correct explanation of the disappearance of the sea otters is based on the fact that they are smaller than seals and sea lions, have a shorter longevity but a similar yearly fecundity. Killer whales must therefore catch three times as many otters than their usual prey. Sea otters are unable to compensate for the predation rate. The assessment of pupils' answers takes into account the fact that none, one, two or three key elements are quoted by the students.

Question 4

The correct choice is the first one.

The second option assumes the general conventional wisdom that Nature should not be touched because consequences are always unpredictable. This is in contradiction with ecological sciences. In many cases, mankind can sustainably harvest natural populations if the importance of catches is correctly determined by an accurate knowledge on population dynamics. This option also states another common view that "equilibrium is sensible" which is not necessarily correct: each natural system has its own resistance and resilience capacities and changes might also depend on how the system is disturbed. We expect that pupils having studied ecology as it is defined by Krebs (1994) should be aware of these facts.

The distributions of frequencies to all the question answers were subjected to Pearson's tests for goodness of fit.

4. Results and discussion**4.1- Question 1: Definition of a food web**

Three months after their final examination, only 8 % of the pupils were still able to define accurately a food web; 58% gave a rather acceptable definition (Figure 2). The frequency distribution of the answer is not uniform ($\chi^2 = 32.55$; 3 d. f.; $P < 0.001$).

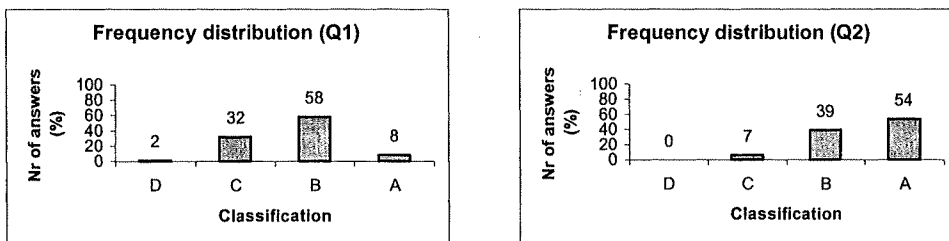


Figure 2. Frequency distribution of the answers to questions 1 (definition of "food web") and 2 (tracing of a food web described in a given text). A= answer 75-100% correct; B= answer 50-74% correct; C= answer 25-49% correct and D= answer 0-24% correct.

4.2- Question 2: The food web of the Alaskan Sea

After reading the text inspired from Stevens (1999), 54% of the pupils gave a good representation of this food web and 7% failed (Figure 2). The distribution of frequencies of the answer is not uniform ($\chi^2 = 36.48$; 3 d. f.; $P < 0.001$). It is noteworthy that although few students were able to correctly define a food web, most of them succeeded in establishing the trophic relationships between the species mentioned by Stevens (1999).

4.3- Question 3: “Why do killer whales reduce populations of sea otter and not populations of Harbor seals or Steller sea lions, they were preying in before?”

About 35% of the pupils failed to solve the problem and only 12% were able to mention all the elements of response (Figure 3). However, none of these latest backed their answer by the basic equation of population dynamics or a similar model. In addition, the observed distribution of frequencies is not significantly different from a uniform distribution ($\chi^2 = 6.14$; 3 d. f.; $P > 0.05$).

The case of the 53% of the students who tried to formulate their answer using one or two key elements of the annex raises two questions. Firstly, it might reveal an experimental bias because they were all encouraged to use the annex. If it is so, the score reveals that students tended to behave as they thought they were expected to by their teachers. Secondly, and more optimistically, it might indicate that 53% of the students have a propensity for a scientific reasoning. With an appropriate teaching, a substantial fraction of these students will probably reinforce the 12% that formulated a rather correct answer.

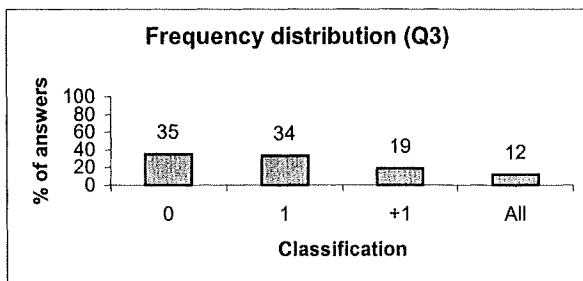


Figure 3. Frequency distribution of the answers to question 3 (population dynamic's problem). 0= No answer or non-understandable answer; 1= answer mentions one element of response - “weight”, “longevity”, “reproduction”; +1= answer is composed of more than one element; all= answer mentions all the elements of response.

4.4-Question 4: “What is ecology?”

Although the 74 pupils studied ecology for at least 2 years, 57% of them still see ecology as it is usually understood in the media, i.e. a social/philosophical/political attitude responding mainly to subjective values, ethical and aesthetics and 7 % have no clear idea about the subject (Figure 4)! The frequency distribution of the answers is not uniform ($\chi^2 = 35.17$; 3 d. f.; $P < 0.001$).

However, we consider that this question should be more deeply studied, e.g. by asking the pupils to explain the reasons of their choice. Further studies are going to be made in order to completely assess these aspects (Favre, pers. com.).

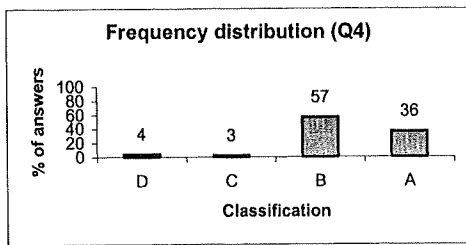


Figure 4. Frequency distribution of the answers to question 4 (the attributes of ecology as a science). D= No answer; C= choose both alternatives; B= choose the alternative of ecology as it is usually understood in the media; A= choose the alternative of ecology as a science.

5. Conclusions

The present paper aimed at testing several hypotheses about the consequences of teaching ecology through an approach based on the ecosystem concept.

Our results confirm the fact that the above-mentioned approach does train pupils to remember definitions and solve stereotyped problems. Besides the fact that we believe that definitions are not relevant to the understanding of natural mechanisms, our results indicate that this kind of learning does not last for long.

In what concerns the second hypothesis - the ecosystem approach will prevent pupils to understand the ecological mechanisms underlying the relationships between those components, not enabling them to solve practical problems - the answer is less straightforward.

The fact that 64.9% of the pupils (Figure 3) are able to come out with some sort of an answer could mean that our hypothesis is rejected. However, none of the 74 pupils was able to answer in a methodical way, that is, by referring to a theoretical model. In our opinion, this means that their previous teaching did not give them the skills to do so. In that case, our hypothesis would not be rejected and our results would mean that pupils do have an intrinsic ability to reason. A teaching approach that would focus on the study of individuals in order to allow a subsequent understanding of the mechanisms underlying upper level phenomena, as the one we defend, would then easily be followed by pupils and allow them to reason within a theoretical framework.

Finally, the last hypothesis is accepted: when they leave the secondary school, the majority of the pupils do not know exactly what is ecology. Only 36% of them agree that it is a science.

The results of the present work, as well as those from a previous paper (Magro *et al.*, 2001), encouraged us to carry out a didactic approach based on the study of individuals. This approach takes an evolutionary perspective, and is routed in nowadays environmental problems. This approach is being put into practice by 11 teachers, which take part in the GRADE team (Groupe de recherche appliquée en didactique de l'écologie), managed by our research group at ENFA. The success of the new approach, in what concerns pupils' learning and interest, is being assessed. Production of educational materials is also being developed.

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**THE DEVELOPMENT OF SITUATIONAL INTERESTS
IN AN INFORMAL LEARNING ENVIRONMENT – A VISITOR EVALUATION
STUDY IN AN EDUCATIONAL EXHIBITION ON INDIVIDUALITY**

Annette Schmitt-Scheerso¹, Helmut Vogt² and Clas M. Naumann¹

¹Zoologisches Forschungsinstitut und Museum Alexander Koenig (ZFMK), Bonn (Germany)

²Universität Kassel, Abteilung Didaktik der Biologie (Germany)

a.schmitt.zfmk@uni-bonn.de

Abstract

Museum exhibitions have a great potential as learning environments, but classical exhibitions with neutral showcases often fail to realise their goal of public education. They are now gradually being replaced by interactive learning environments. The purpose of this visitor evaluation study was to identify the design factors that influence the effectiveness of an educational exhibition focussing on the development of situational interests.

For this study, a biological educational environment was developed taking modern didactic principles into account. Both general public and students were observed during their visit to this exhibition. At the end of the exhibition, these visitors had to choose between two possible ways (“Exit” or “Continue”) and were asked to fill out a questionnaire afterwards.

The results of the study demonstrate that this specific learning environment fulfils its intended purpose of triggering situational interests and avoiding non-interests. All the visitors were willing to enter further person-to-object-engagements (i.e., they chose to continue) and gave a positive evaluation of the exhibition. Interactive media were extremely successful.

1. Introduction

Museum exhibitions have a great potential as learning environments, but it is necessary to re-examine their educational role according to a theory of learning (Shettle, 1973). Classical exhibitions with neutral showcases often fail in their mission of public education. Interactive learning environments in line with current developments in the experimental psychology of learning and motivation are now replacing this type of exhibition. These new-style exhibitions are not merely the objects of contemplation but also offer possibilities for participation, and they encourage people to become engaged, to come into contact with the objects and the subject matter. The purpose of this visitor evaluation study was to identify the design factors which influence the effectiveness of an educational exhibition with a focus on the development of situational interests.

2. Theoretical framework

2.1- Theory of interest

The theoretical framework is a model based on the “theory of interest” (Krapp, 1999): An interest represents a specific relationship between a person and an object. The object of interest can refer to a concrete thing, a topic, a subject matter or an abstract idea or concept. The realisation of an interest requires a situation-specific interaction between the person and the object (= person-object engagement). Within the concepts there is a differentiation between two kinds of motivational states based on interests: the “individual interest” as an already established personal interest, and the “situational interest” which is created by conditions or incentives of the learning situation. A situational interest can be the initial state of a longer lasting individual interest. Different formal criteria define the types of interest: cognitive aspects, emotional characteristics, and value-related qualities. The *cognitive aspects* concern the amount of knowledge with regard to the object of interest as well as the readiness to acquire new knowledge and to enlarge the competences related to the specific domain. The *emotional characteristics* refer to positive emotional states (e.g. joy) during an interest-based activity, as well as to feelings of competence, autonomy and social relatedness (Deci & Ryan, 1993). The *value component* refers to the assumption that any interest has the quality of personal significance. The first contact with an object plays an important role for the further development of the person-object relation. A positively and emotionally satisfactory interaction will lead to the emergence and stabilization of interests.

Research on situational interest has shown that an interest-triggered learning activity leads to better learning results (e.g. Hidi & Anderson, 1992; Schiefele, 1996). From this perspective, it seems worthwhile to reflect on situational interests as important educational goals.

2.2- Theory of non-interest

If there is no interest towards a specific object, Upmeier zu Belzen & Vogt (2001) distinguish between two states: indifference and non-interest. In the state of indifference the person has not yet had contact with a certain object and thus experiences no emotional or rational attachments towards the domain of the object. In the case of non-interest two different forms are distinguished: disinterest and antipathy. In the case of disinterest, the person has only a fragmental transitory knowledge about the domain of the object and has slightly negative feelings about it. An antipathy is the result of previous contact with a certain object and negative experiences during this interaction. The person actively avoids any further engagement with this particular object.

2.3- Influence of the learning environment on the formation of interests

Various studies have demonstrated that the formation and change of interests can be considerably influenced by the arrangement of the learning environment (Krapp, 1999). Hein (1998) surveyed a wide range of visitor studies in museums around the world and concludes that the principles of constructivism can be applied to learning in museums. Semper (1990) focuses on four themes in education theory which are especially related to the learning activities in museums: curiosity or intrinsically motivated learning; multiple modes of learning; play and exploration in the learning processes; the existence of self-developed world views and models among people who learn. Surprisingly little systematic attention has been paid to the role of curiosity and intrinsically motivated learning on the part of students or the general public. But intrinsic factors – such as curiosity, enjoyment in learning and mastery of challenge – also form potential motivational tools.

3. Hypotheses

- The didactic-methodical design of a biological exhibition has a positive effect on a visitor's disposition to enter a specific person-to-object engagement.
- Situational interest can be triggered by the specific use of different media in the context of an exhibition.

4. Methods

To verify these hypotheses, a biological exhibition on the subject of "Individuality" was developed and designed taking account of the following didactic principles:

- The information was carefully structured and presented in a "multi-level form" (i.e. each level successively provided more details and additional information).
- The subject matter was presented in ways which are related to the personal experiences of the visitors and which prompt them to ask themselves questions and to look for conclusions.
- A variety of well selected media was used (a hand-out, texts, a computer programme, visualisation media, several "hands-on" exhibits to involve visitors more actively).
- Different kinds of entry points were provided and different kinds of stimuli were used to attract a wide range of learners.
- Social learning was stimulated (most media could be used by several people at the same time and encouraged discussions between the visitors).

The study was conducted in Bonn's Museum Koenig (Museum of Natural History) during the "Museumsmeilenfest 2001", a four-day event which attracts a lot of visitors. In addition, students ranging in age from 10 to 12 years were drawn from three secondary school classes to make sure that this important group of museum visitors was sufficiently represented. The visitors were systematically observed by researchers during their visit to the exhibition and asked to fill out a partly standardized questionnaire afterwards (n = 200). In accordance with the criteria used to define interests, information on *cognitive*, *emotional*, and *value-oriented aspects* during the visitors' engagement with the different exhibits was obtained from these questionnaires as well as background information about the visitors. To find out if the visitors wanted to enter into further person-to-object-engagements after their visit, they had to choose between two possible ways – "Exit" (corresponds to an avoidance of a further engagement) or "Continue" (willing to enter into a further engagement) (Fig.1).

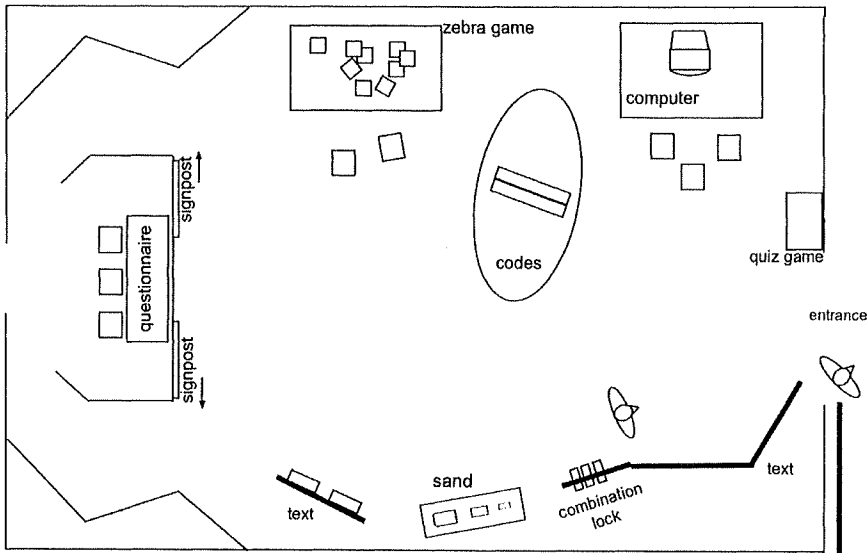


Figure 1. Plan of the exhibition on "Individuality".

5. Results

5.1- Demographic characteristics of the visitors

The age distribution of the visitors showed quite a number of people between 31 and 60 years of age (mostly parents who visited the exhibition together with their children). The largest proportion of the visitors were students under the age of 17 (51 %) (Fig.2). This age distribution is in accordance with the general visitor situation of the Bonn Museum of Natural History (in-house visitor study).

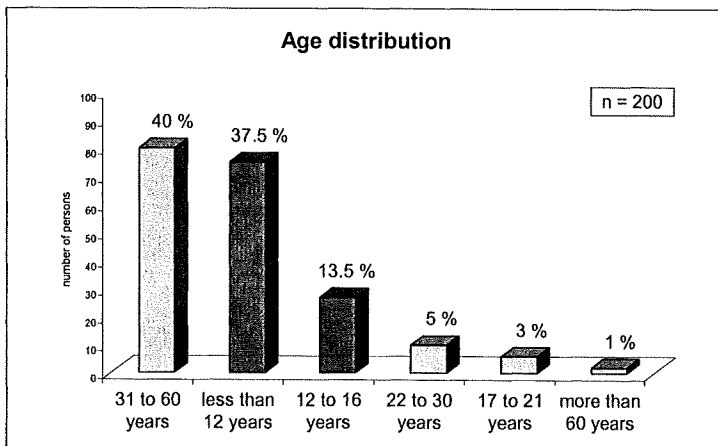


Figure 2. Age distribution among visitors to the exhibition

5.2- Interest-related information

The results of the study demonstrate that this specific learning environment had a favourable effect on the development of visitors' interests. All the visitors wanted to enter into further specific person-to-object engagements: nobody chose the "Exit", and 88 % of the visitors specified in the questionnaires that they would like to learn more on the topic (Fig.3). This result thus shows that no one of the visitors will avoid a further engagement with this specific domain.

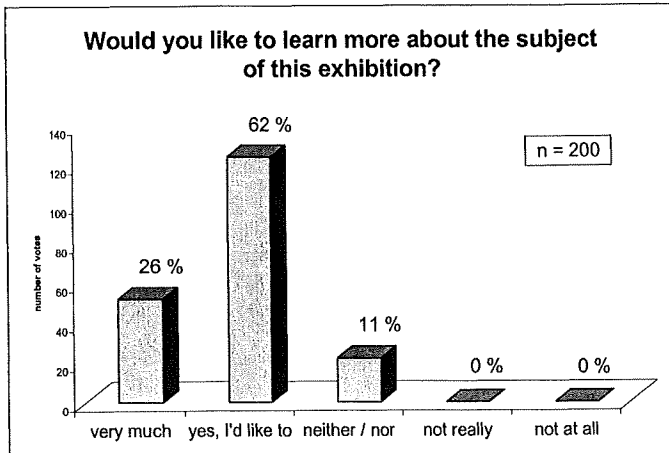


Figure 3. Readiness to enter further person-to-object engagements

The exhibition as a whole was evaluated positively by all the visitors; none gave a negative response (Fig.4).

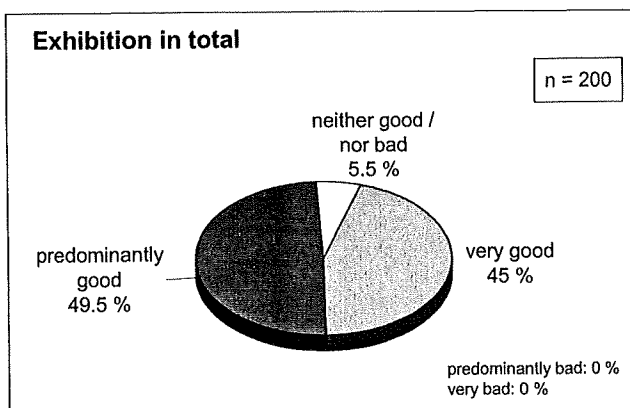


Figure 4. Visitors' evaluation of the exhibition in general

Some media were extremely successful: nearly half of the visitors chose the computer as their favourite medium in this exhibition (Fig.5).

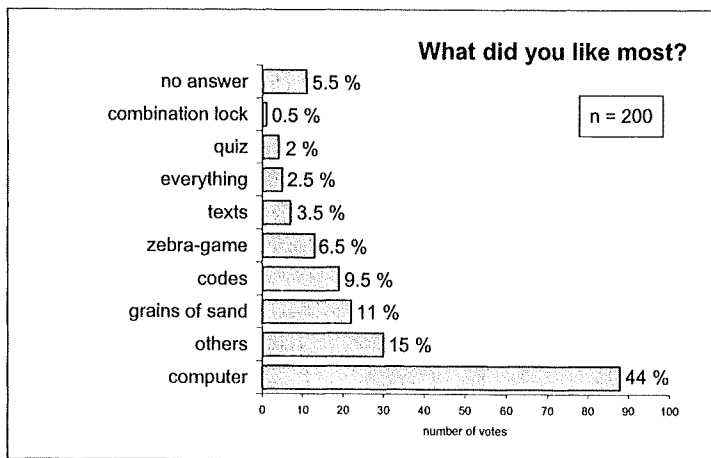


Figure 5. Visitors' favourite media in the exhibition

The computer by itself was rated as “mainly good” or “very good” by eighty-one per cent of all the visitors (Fig.6).

Fifteen per cent of the visitors specified what they liked most in the exhibition (“others”; Fig.5). Several answers were related to the exhibition design, for example “big variety of media”, “interaction”, “good illustrations” or “general method of explaining the phenomena”.

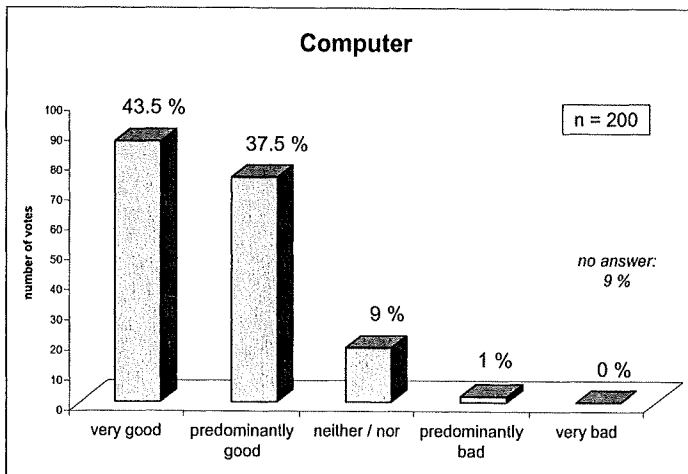


Figure 6. Visitors' evaluation of the computer programme (part of the exhibition)

Another medium – a group of glass showcases filled with different amounts of grains of sand to illustrate a large number – was also very much appreciated by the visitors (90.5 % of the visitors judged it as “very good” or “mainly good”; Fig.7).

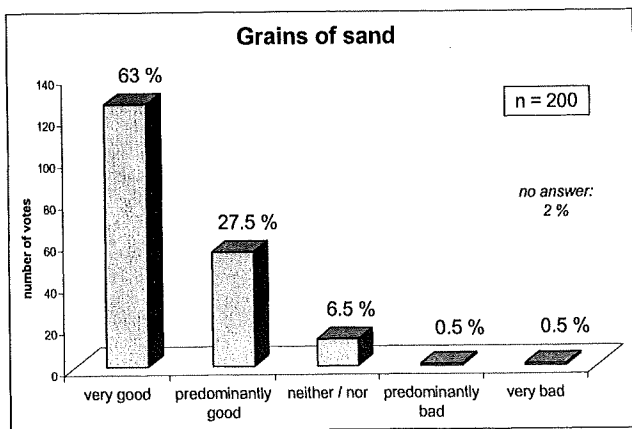


Figure 7. Visitors’ evaluation of the “grains of sand” (visualisation media to illustrate a very large number)

The visitors responded favourably to the suitable length of the texts (Fig.8) as well as their comprehensibility (Fig.9).

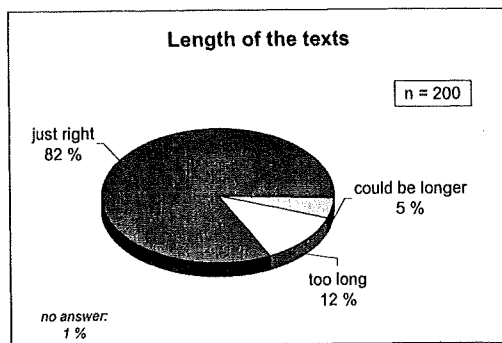


Figure 8. Visitors’ evaluation of the length of the exhibition texts

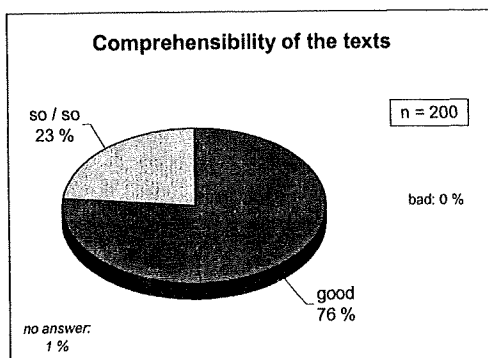


Figure 9. Visitors’ evaluation of the comprehensibility of the exhibition texts

They also appreciated the opportunity to obtain further information if they wanted to (Fig.10).

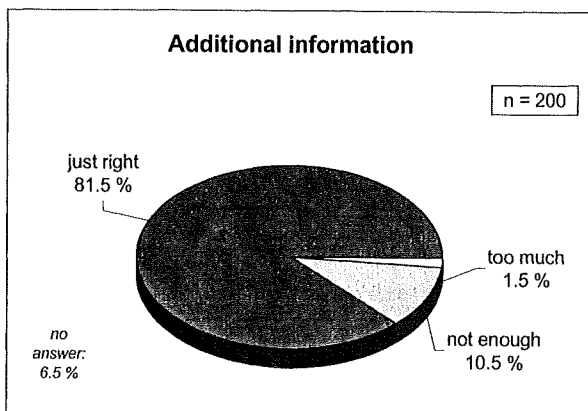


Figure 10. Appreciation of the opportunity to obtain further information in addition to the basic texts

About two-thirds of the visitors used the hand-out (a quiz that guided through the exhibition). They stayed longer in the exhibition than the others and therefore had more chance to come into contact with the objects and to broaden and deepen their knowledge and understanding (Fig.11).

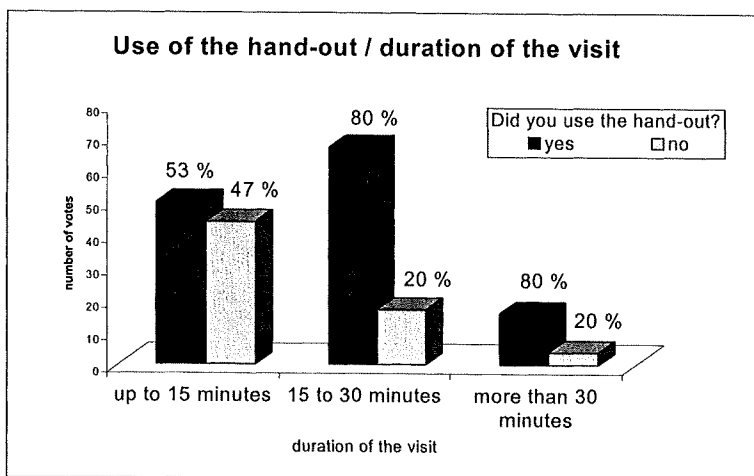


Figure 11. Correlation between the use of a hand-out quiz and the duration of the visit to the exhibition

6. Conclusion

The results of the evaluation study demonstrate that this specific learning environment fulfilled its intended purpose of triggering situational interests and avoiding non-interests. At the end of the exhibition all visitors wanted to continue, no one chose the option to go to the "Exit". The answers obtained from the questionnaire confirm this exceptionally clear result:

All the visitors gave a positive response to the exhibition as a whole and 88 % of them specified that they would like to learn more about the subject matter. This result is related to the criteria of cognitive aspects used to define different types of interest (see above). In the case of non-interest, the visitors would have avoided a further engagement with this specific object.

In particular, interactive media such as the computer were extremely successful in initiating situational interests. Referring to the criteria of emotional characteristics (see above), the positive evaluation concerning this media shows that the visitors liked to use the computer program and felt positive about this activity. Similarly, Hilke et al. (1998) have detected that computers are often more popular than any other exhibit in the display. This kind of media encourages people to become engaged and to communicate with each other, as it was observed by the researchers during this study as well (see above, methods). Engagement and communication are central principles of the constructivist learning theory: learning is seen as an active process, and cooperation – the interaction between learners – plays an important role.

Another element of the exhibition which seems to be particularly effective in triggering situational interest is the "grains of sand" (used for the illustration of a very large number). The visitors evaluated this visualisation medium extremely positively, and the observers noticed that the people communicated with each other and called their companions to show them this specific media. With the aid of such visualisation media and well-structured information, an emotionally satisfactory interaction with the subject can be achieved for a wide range of learners with different comprehension levels (emotional aspects, for example feelings of competence).

The study shows that it is highly effective to connect current learning-theory and exhibition design. Research can be applied to facilitate meaningful educational experiences in informal learning environments. Since this specific arrangement fulfilled its purpose in a museum – a place where self-directed learning is characteristic – the same didactic principles can be expected to work even more effectively within the formal education system. Exhibitions have the opportunity to connect with many different learning modes, and the role of playing and exploring with objects and ideas as part of the learning process is an important feature of education in free-choice learning environments.

By communicating scientific knowledge and understanding, by arousing curiosity and interest, natural history museums fulfil their educational role and form a bridge between the formal science-education system and the wider society.

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STUDENTS' INTEREST IN „SYSTEM EARTH“ WITH SPECIAL CONSIDERATION OF BIOLOGICAL ASPECTS

Horst Bayrhuber, Lore Hoffmann (IPN), Ingrid Hemmer (Catholic University of Eichstaett),
Michael Hemmer (University of Muenster), Päivi Taskinen, Sylke Hlawatsch
and Marion Raffelsiefer (IPN)

IPN-Leibniz-Institute for Science Education at the University of Kiel
bayrhuber@ipn.uni-kiel.de

Abstract

Empirical studies show that interest-driven learning leads to higher quality learning strategies. Interest is defined either as a lasting disposition of an individual independent of situation or as a quality, which is dependent of situation. Interest as a lasting disposition of an individual can develop out of situational interest. Three dimensions of interest can be distinguished: interest in a specific content, interest in a specific context associated with the content, and interest in a specific activity connected to the context-bound content. Two research questions are asked in this project: To what extent are students interested in certain geoscientific contents if these are taught within specific contexts? To what extent are students interested in certain activities when dealing with the earth as a system? On a general level, the results show on average a medium interest in almost all contents. Regarding contexts, Individual, Society as well as Values and Norms are of relatively high interest. When analysing the data in more detail it becomes obvious that students' interest in a special content changes significantly with the context it is associated with. Further, the students show different interest in the same context depending on the contents it is combined with. From the students' point of view, the selected areas concerning System Earth were covered in biology and geography lessons, and almost not at all in chemistry or physics lessons.

1. Introduction

Dealing with the earth as system is relatively new in German schools and that for two reasons: First, this topic requires an interdisciplinary approach integrating biology, chemistry, physics and geography as well as economics and ethics. Up to now earth was almost only disciplinarily addressed by geography. And in this connection the skills of thinking in systems, of model development and of critically reflecting natural scientific methods of geosciences were not sufficiently taken into consideration (Hlawatsch et al., 2003; in preparation).

For the topic system earth is new, it is not clear to what extent students are interested in. In order to create a learning environment that fosters the development and stabilisation of students interest in this topic it is necessary to gather information about the characteristics and structure of their interests in this area. As one basis for the development of teaching materials, we wanted to gain knowledge of the structure of interest, e.g. in different contents as well as contexts associated with contents.

Before we describe the results of this study we would like to make some remarks regarding

- the construct interest and
- the design of the study.

2. The construct interest

In pedagogical and psychological terms, interest as a theoretical construct describes the quality of the relationship between an individual and an object. Interest directs thoughts and intentions towards the object in question. It stimulates *cognitive* dealings with objects of learning and has an *emotional* component (Krapp, 2002; Krapp, Hidi & Renninger 1992; Prenzel 1988).

Empirical studies show that interest-driven learning leads to **higher-quality learning strategies**. Knowledge is developed, elaborated, rather than being acquired mechanically, by rote-learning (Schiefele, Krapp & Schreyer 1993; Schiefele, Krapp & Winteler, 1992). Interest-driven learning leads to **greater knowledge acquisition** and **longer-term retention** (Hoffmann, 2002; Hoffmann, Häußler, 1998).

More recent approaches differentiate between **individual and situational interest** (Krapp et al., 1992; Renninger, Hoffmann & Krapp, 1998): Individual interest is defined as personality-specific property, a relatively stable preference, e.g. for an object of learning (disposition to behavior and activity). Situational interest is defined as situation-specific, motivational state of being interested triggered by the interesting or stimulating quality of the object of interest and its environment. It is further assumed that situational interest can arise for a certain object without preference, that is without individual interest. But normally interest-driven activities represent a combination of current individual interest and situational interest, whereby the ratio of individual to situational interest varies, depending on the object and the situation.

It is further assumed that attractive subjects and a stimulating learning environment can lead to situational interest, even if individual interest is not present. It is also assumed that stable individual interest can develop through repeated contact with the subject. The stimulating quality of learning environments is significant especially when students are first confronted

with a subject or if individual interest has not yet developed (Krapp et al., 1992). This applies to a number of the topics in our System Earth project .

Generally spoken, interest in a subject is determined not only by the content of the subject, but also by the context in which it is placed and the way in which it is dealt with by the individual. Thus, interest can be seen as a **three-dimensional construct** (Häußler & Hoffmann, 1998):

- interest in a particular content or *topic*,
- interest in a particular *context*,
- interest in a particular approach or *activity*.

3. Design of the study

3.1- Sample

We surveyed 333 students, approximately half male, half female, aged 17 to 19, in grades 11 to 13 at schools in the federal states of Bavaria, North Rhine-Westphalia and Schleswig-Holstein. The survey was conducted in May and June 2001 (see Table 1).

Table 1. Sample and design of the study

Sample:	333 students (171 males; 162 females)
Grades:	11 to 13
Age:	17 to 19
Region:	Three German federal states: Bavaria, North-Rhine-Westphalia, Schleswig-Holstein
Period:	May to June 2001

3.2- Structure of the questionnaire

We developed a questionnaire focusing on the above mentioned three dimensions of interest: topic, context and activity (Raffelsiefer et al., 2001). The items were developed by an interdisciplinary group of researchers who are specialized in Didaktik of Biology, Didaktik of Geography, Geology, Didaktik of Physics and Psychology. The question if the items are suitable for students was checked with the help of teachers. The questionnaire was divided in two parts.

a) First part of the questionnaire

The first part consisted of 88 items systematically **combining eleven topics of System Earth and eight contexts** associated with these topics (see Table 2). The definition of topics and contents depended upon curricular reasons. Topics are themes of modules of the project System Earth, contexts represent general perspectives of dealing with topics in learning. For example, the spheres of earth can be looked upon from the perspective of system theory (C4), history (C6), geoscientific methodology (C8) or seen from another angle.

Table 2. Topics and contexts included in the study

Topics		Contexts	
T1	Spheres of earth	C1	Individual concern
T2	Carbon cycle	C2	Significance for society
T3	Rocks and minerals	C3	Social responsibility
T4	Fossil resources	C4	Earth as a complex, dynamic system
T5	Soil	C5	Geoscience research
T6	Gas hydrates	C6	History of earth
T7	The ocean	C7	Regions of earth
T8	Drinking water	C8	Methods of geosciences
T9	Earthquakes		
T10	Climate change		
T11	Changes in biodiversity		

The way we developed the items we will illustrate by the example of Changes in biodiversity (T11). As we regarded 8 contexts (C1 to C8), we developed 8 items (see Tab. 3). The same applies to all other topics.

Table 3. Items on the topic Changes in biodiversity; topic context combinations

My interest in finding out more about this is	<i>very high – high – medium – low – very low</i>
T11C1	How many endangered species live in my hometown?
T11C2	How important is maintaining a high biodiversity for healing diseases?
T11C3	Are certain animals more worth protecting than others?
T11C4	How do exhaust fumes from Great Britain influence the diversity of life in Scandinavian lakes?
T11C5	Under what conditions does a diversity of living creatures develop?
T11C6	Why did such a variety of species develop during the Cretaceous Period (145-67 million years ago)?
T11C7	Why is the number of species of trees less in Germany than in North America, although the climatic conditions are similar?
T11C8	How can the number of species in a lake be identified?

b) Second part of the questionnaire

The second part of the questionnaire elicited data about the students' interest in the eleven topics, eight contexts and six groups of classroom activities when each is **taken individually**, that is **not** combined in this part. In this connection we will only say something about topics and activities.

Topics. In our project, the various topics are related to biology, chemistry, geography and physics, but they are not always processed in relation to the wider system. For this reason, the second part of the questionnaire contained two items for each of the eleven topics. The first item in each case was overtly related to a certain science discipline, i.e. subject oriented. The second was related to the conception of system, i.e. system oriented. Tab. 4 presents two examples of items concerning the topic Changes in biodiversity: a subject-oriented item and a system-oriented one. In addition there are shown the questions which went with each item, and the five-point rating scale.

Table 4. Subject oriented and system oriented items on the topic Changes in Biodiversity

T11a subject-oriented The bio-diversity differs greatly in the various environments on earth	
T11b system-oriented In the course of the earth's history there were numerous cases of periodical mass mortality; the causes of which are only partially known.	
Questions to each statement (T11a as well as T11b)	5-point rating scale
a. How high is your interest in finding out more detail?	very high ...very low
b. How much coverage of this topic has there been in one of the following subjects during your school career? (Biology, Chemistry, Geography, Physics)	a lot ... none at all
c. How much have you dealt with this during your spare time?	a lot ... not at all
d. How do you rate your knowledge about this topic	very high ... non-existent

Activities. We collected the data about students' interest in six groups of activities only separately. For a consistent combination of contents, contexts and activities would have generated 528 items, not all of them sensible. Table 5 describes the six groups of activities with examples of items from the questionnaire.

Table 5. The six groups of activities included in the questionnaire each supplemented by at least one example of item

A1 Passive acquisition of information e.g. listening to a lecture, looking at pictures, watching a film	A4 Independent checking of a hypothesis e.g. independent planning of an experiment to check an assumption
A2 Independent search for information e.g. evaluating scientific data	A5 Communicative learning e.g. asking geoscientists questions
A3 Practical learning e.g. collecting data on field trips, evaluating geoscience experiments	A6 Evaluating and discussing e.g. assessing the results of geoscience research, discussing implications of geoscience findings for society

4. Results

a) Students' interest in topics in combination with contexts

Figure 1 represents the interest the students expressed in the eleven topics in combination with the eight different contexts. The bars T1 to T11 show the mean values of the responses for each area topic, grouped together irrespective of the various topic-context combinations.

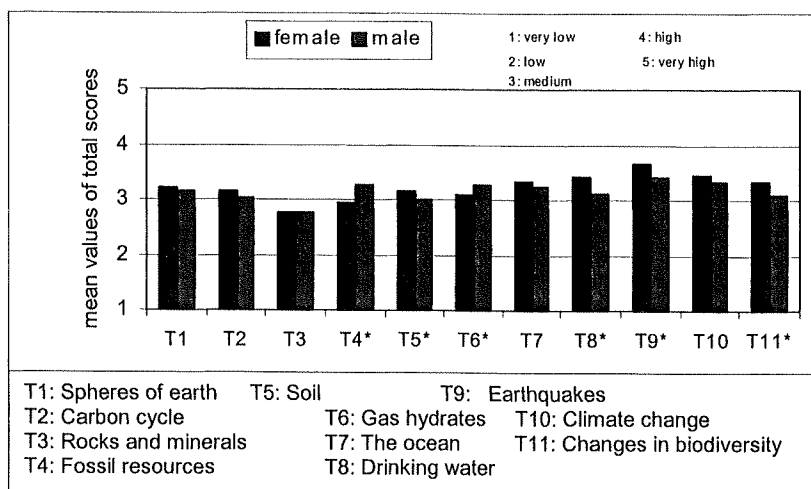


Figure 1. Interest in eleven topics of System Earth; mean scores per topic over all topic context combinations (*: $p \leq 0,01$, for T5 $p \leq 0,05$)

The results show a medium level of interest in almost all contents. The lowest level of interest is in Rocks and minerals, while Changes in biodiversity stimulates a relatively high level of interest (see T9). For about half of the topics, there were no gender differences. Females showed on average a significantly stronger interest than males in Soil, Drinking water, Earthquakes and Changes in biodiversity. Males, on the other hand, were on average significantly more interested in Fossils, Natural resources and Gas Hydrates.

We can obtain a more differentiated picture if we view the special topic-context combinations for each topic as the two following examples show. We will illustrate this for the topics Rocks and minerals (Fig. 2) and Changes in biodiversity (Fig. 3).

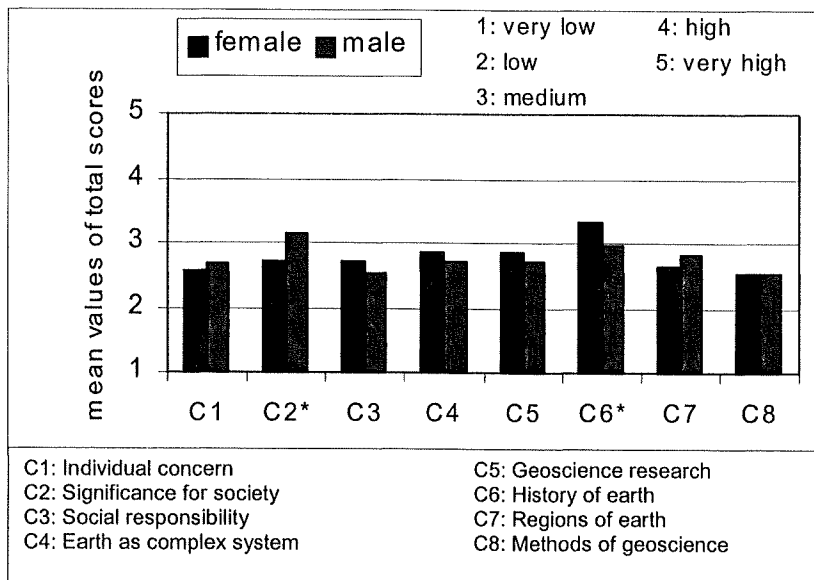


Figure 2. Students' interest in Rocks and minerals (T3) in combination with contexts (C1 to C8); mean values of total scores (*: $p \leq 0,01$)

Concerning **Rocks and minerals**, on the whole a relatively uninteresting field, females and males expressed a medium level of interest only when the topic was set in the context of earth history (C6). Males showed a medium level of interest in combination with the socio-economic context (C2).

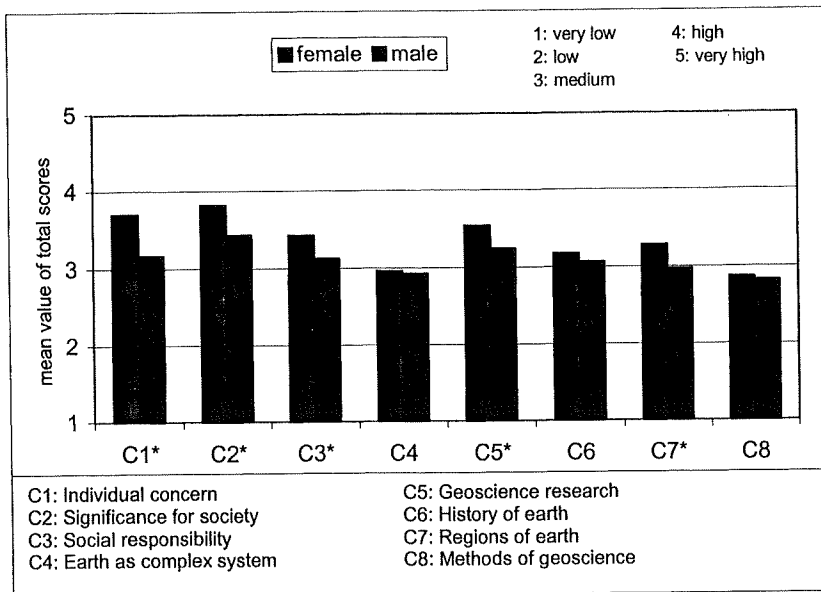


Figure 3. Students' interest in Changes in biodiversity (T11) in combination with contexts (C1 to C8); mean values of total scores (*: $p \leq 0,01$, for C3 and C7 $p \leq 0,05$)

Changes in biodiversity is a topic in which both males and females expressed overall a relatively high level of interest. This was influenced particularly by the contexts focusing on the effects for the individual (C1), significance for society (C2) and social responsibility (C3) and geoscientific research (C5).

Figure 4 is a synthesis of fig. 2 and 3. It obviously shows that interest in Rocks and minerals is significantly lower in practically all topic context combinations than the interest in Changes in biodiversity, and this applies to both males and females. Only the context *earth* as a complex dynamic system (C4) and Methods of geosciences (C8) stimulate a similarly (low) level of interest in both topics.

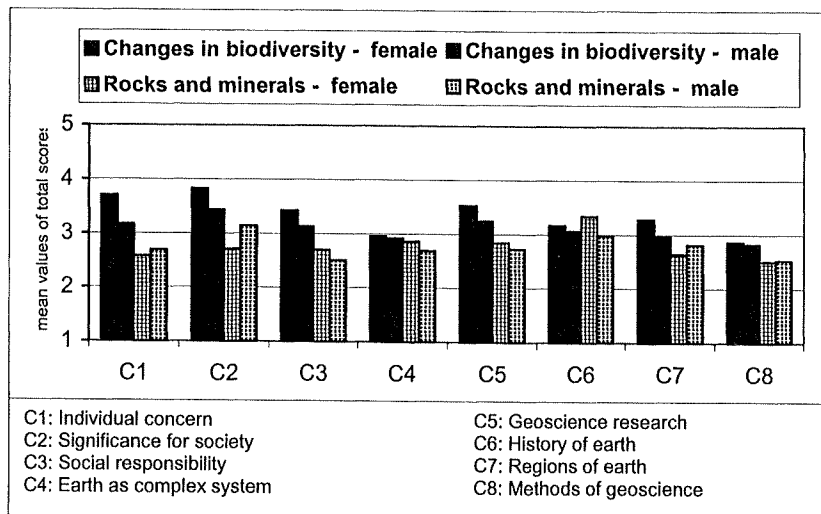


Figure 4. Students' Interest in Changes in biodiversity (T11) compared to interest in Rocks and minerals (T3); mean values of total scores

b) Contexts, topics and activities as separate dimensions

Contexts. Figure 5 represents the contexts 1 to 8 and the female/male levels of interest. The bars for C1, C 2 and C3 are clearly higher for both sexes. In other words, interest is highest in those contexts in which the concerns of and responsibility for the individual and society are central. In addition, male students, significantly more so than female students, are interested in methods of geoscience (C8), while female students showed a higher interest in the context of *Social Responsibility* (C3).

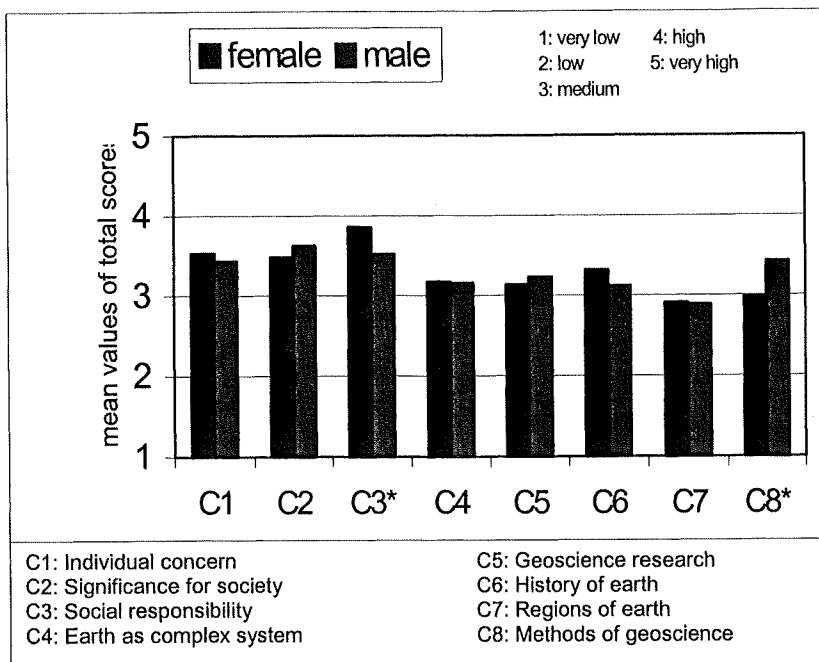


Figure 5. Students' interest in contexts (not combined with topics; *: $p \leq 0,01$)

Topics. As we mentioned earlier we formulated a subject-oriented and a system-oriented item for each area of topic. The aim was to ascertain which of these two basic aspects related to the individual topics would arouse the most interest. The results do not yield a uniform picture (see fig. 6).

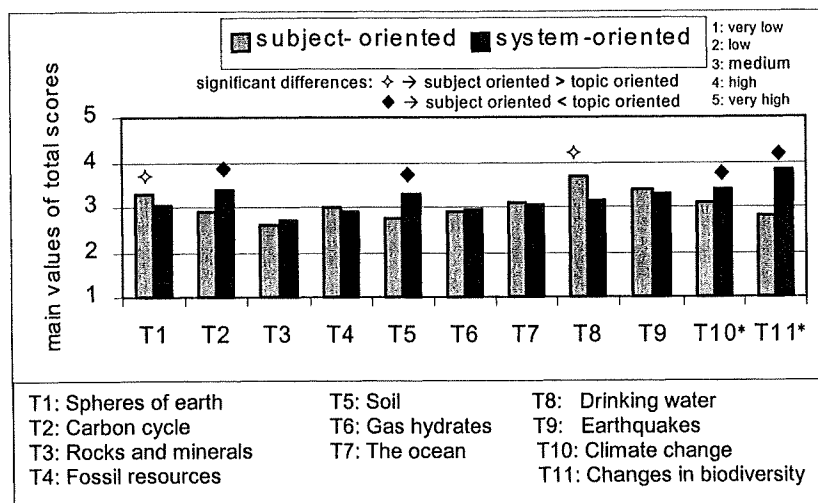


Figure 6. Students' interest in the subject vs. the system oriented aspect of the 11 topics (*: $p \leq 0,05$)

For two topics (T1 and T8), the subject-related item on average received a significantly higher rating than the system-oriented item. In four of the topics (T2, T5, T10, T11) the ratings for the system-oriented item were on average significantly higher than the ratings for the subject-related item. The remaining five topics (T3, F4, F6, F7, F9) showed no mean differences.

Activities. How, then, would students best like to deal with System Earth topics in the classroom? Which are the favorite activities? In fig. 7 one response is given to that question, on the basis of our findings.

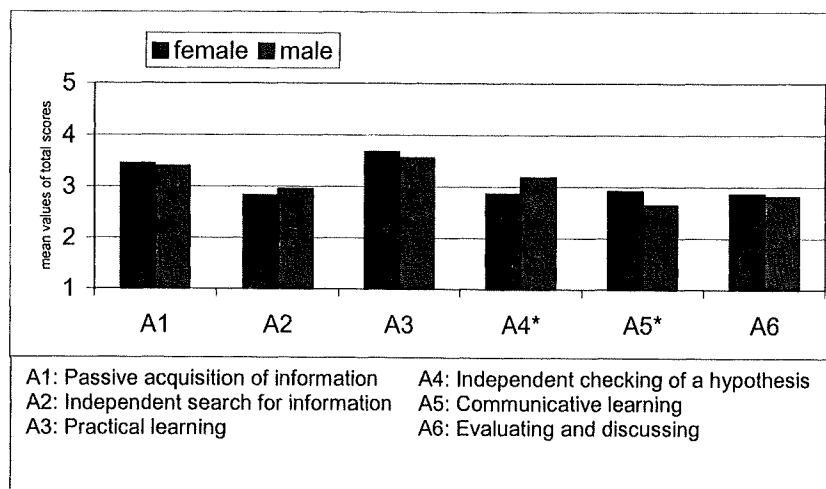


Figure 7. Students' interest in groups of activities (*: $p \leq 0,05$)

The students expressed a relatively high level of interest in **the passive acquisition of information (A1)**, e.g. listening to a lecture, looking at pictures, watching a film. The same applies to **practical learning approaches (A3)**, such as geoscience experiments and data collection on field trips. The interest expressed in these categories (A1, A3), was significantly higher than for all the other activities.

c) Leisure activities and evaluation of knowledge

In addition to interest levels, we also asked the students to which extend they dealt with the subject oriented as well as system oriented aspects of the 11 topics **in their leisure time**. The results are covered by the red bars in fig. 8. We also asked them to rate their own **level of knowledge** about the field. The answers to this question are covered by the green bars.

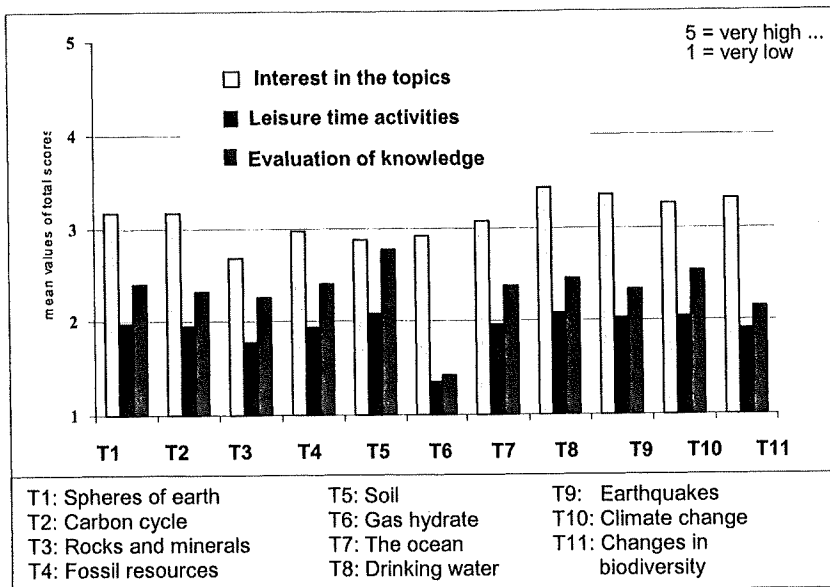


Figure 8. Students' interest in the 11 topics compared to their leisure time activities and subjective knowledge levels about these topics; results of subject oriented and system-oriented items taken together

Leisure time activities and subjective knowledge levels can be used as indicators for the level of interest on the part of the individual. Our findings suggest that both aspects hardly ever feature in the students' leisure activities and that very little knowledge is already at their disposal. We therefore assume that the interest expressed in the topics (yellow bars) on the questionnaire is rather situational, induced by the individual items, than already stable individual interest.

d) Coverage of earth as system in different school subjects

We asked the students how detailed the coverage of a field had been in biology, chemistry, geography or physics instruction during their school career. It emerged that contents within the topic System Earth had been dealt with relatively frequently in geography and to some extent in biology. In chemistry and physics, on the other hand, practically nothing of these topics had been covered. This is shown by fig. 9.

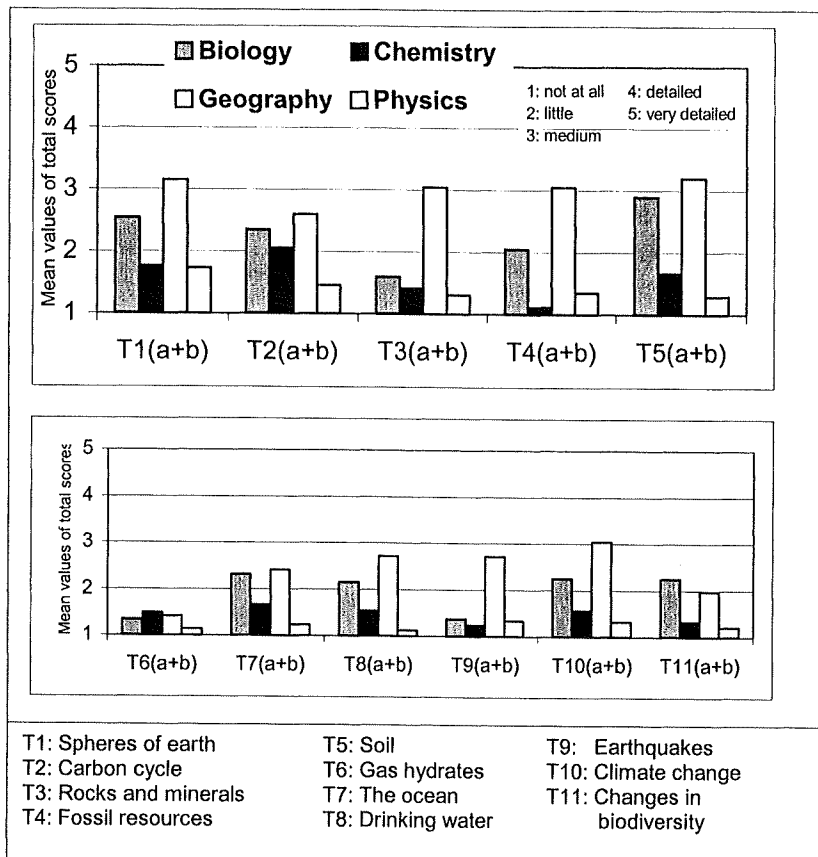


Figure 9. Coverage of the 11 topics in teaching; results of subject oriented (a) and system oriented (b) items are taken together

The results contrast starkly with the considerable significance of chemistry and physics research within the geosciences. The interest expressed by the students in the various subject-oriented aspects (see fig. 10) correlates positively with the frequency of coverage in teaching: The students expressed significantly higher interest in the biology- and geography-related aspects than in the chemistry- and physics-related ones.

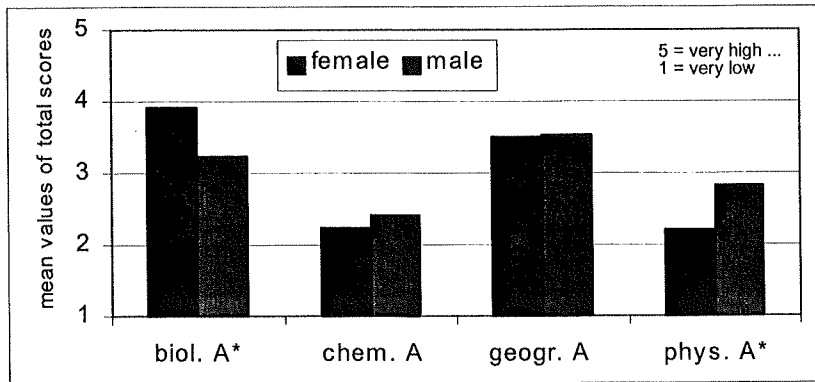


Figure 10. Interest in various subject-oriented aspects on “System Earth” (*: $p \leq 0,001$)

5. Discussion and Outlook

As a result of this study we know the topics, for which it would be difficult to generate situational interest and the learning environments in which this feat was possible. However each topic comprises a lot of specific contents and each context can be defined by a number of different perspectives. For this reason, e.g. the actually used items on the topic carbon cycle are only a small selection of all possible items. Or the context significance for society can have the meaning significance for health of the population, for economy etc. Therefore, the results give only a general insight into students' interest in system earth. For a more precise description of students' interest an additional and more detailed analysis is necessary. Nevertheless the results of this study are an important basis for the development of teaching materials in the innovative project System Earth in Germany. Further analyses will be carried out in connection with the evaluation of the effects of the innovative materials. In this connection the development and stabilization of students' interest will be investigated.

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PROBING CHILDREN'S UNDERSTANDINGS OF THE NATURAL WORLD

Carolyn Boulter, Sue Dale Tunnicliffe and Michael Reiss

Institute of Education, University of London, 20 Bedford Way, London WC1H 0AL, UK
c.boulter@ioe.ac.uk, s.tunnicliffe@ioe.ac.uk, m.reiss@ioe.ac.uk**Abstract**

Previous work by various researchers into young people's understanding of the natural environment has been carried out using a wide range of techniques. These have included interviews, questionnaires, group discussions and the production of drawings. Generally such techniques are then used to provide generalisations about young people's understandings of the natural environment. Our research goes beyond this existing work in two ways. First, it uses a range of techniques (oral, photographs and drawings) for eliciting understandings of specific natural objects using a sample from three age groups (ages 5, 10 and 14 years) of young people rather than just picking one particular technique. Secondly, it investigates these young people's understandings both in school and in the field – at Botanic Gardens, Field Study Centres, Museums or Zoos – in order to determine the effect of these contexts upon pupils' understandings of the range of objects in the natural world. Here the data obtained from year 5 pupils in one school who visited the Natural History Museum, London are examined to discern what they may enable us to say about the expressed models and hence children's own knowledge and understanding of the natural world.

1. Introduction

When teachers or researchers ask subjects about their understandings of anything, subjects respond by presenting 'representations' (Bruner, 1964). These representations may be words or mathematical symbols, drawings, physical constructions, or even gestures. In the language of Buckley *et al.* (1997) and Gilbert & Boulter (2000) such representations can be viewed as the expressed models – that is, representations of phenomena placed in the public domain. These expressed models are assumed to be generated from mental models – i.e. the private and personal cognitive representations held by subjects. The only way for a researcher to understand a subject's mental model of a particular phenomenon is by eliciting one or more of their expressed models of that phenomenon. At present, teachers we believe are generally not alert to the significance of the mode in which information is presented to pupils and used to elicit a response, nor to the ways of responding to pupils' representations. Moreover, the physical link with an object and the probe used to elicit the mental models about it are of great importance in learning (Guichard, 1996) and most pupils need to have access to a concrete aid such as a diagram, drawing or photograph to assist their thinking and recall (cf. Giordan, 1996).

There are many ways of gathering information about subjects' understandings of scientific phenomena – see White & Gunstone (1992) for a wide-ranging review. However, despite the richness and variety of the methods used by science educators, it remains a fact that most of these methods rely on subjects either talking or writing about science. Such methods include oral interviewing of students (Osborne & Gilbert, 1980; Tunnicliffe & Reiss, 1999a), gathering students' written responses using, for example, a drawing or photograph as a probe (Leach *et al.*, 1995), recording students' spontaneous conversations (Tunnicliffe & Reiss, 1999c), interviewing about instances (Osborne and Freyberg, 1985) and getting students to construct written concept maps (Novak & Gowin, 1984). Another fruitful, and non-verbal, approach has been to ask subjects to draw certain objects (e.g. Guichard, 1995; Tunnicliffe & Reiss, 1999b). Caravita and Tonucci (1987) combined drawings and interviews and Carivita *et al.* (1999) have studied pupils' interactions with a computer in enhancing learning about the environment.

The relatively few data that exist suggest that when young children view live animals, they identify certain striking features of the organisms. In particular, they mention anatomical features such as the dimensions of the animal, its shape and its colour, and comment especially on its front end, on its legs, on other disrupters to its outline and on any unfamiliar organ (Tunnicliffe, 1995). These striking features become the defining ones for the children in constructing their mental models of animals and are applied to different kinds of animals. Less work has been done on pupils' understandings of plants than of animals and what work has been done has mainly concentrated on pupils' understandings of such processes as growth and photosynthesis (Barker & Carr, 1989; Russell & Watt, 1990; Osborne *et al.*, 1992). However, a considerable literature exists about children's understandings of the natural and physical environment (e.g. Strommen, 1995) and about the naming and classification of plants (e.g. Askham, 1976; Brown, 1983; Plotkin, 1994). Particularly relevant for our study are Schneekloth (1989), who has written about a widespread tendency in some cultures for vegetation to be regarded as insignificant background, as 'nothing', and Simmons (1994) who looked at the way in which eight to nine year-old urban Chicago children perceive nature.

Our supposition is that the learning about natural objects revealed by a young person's expressed model depends on the physical context (whether the individual is in a classroom or out-of-doors) and the manner in which it is probed, e.g. orally or with the use of drawings or photographs. As far as we are aware this has not been investigated to date.

1.1- Key objectives.

The objectives of the research are therefore to explore the way in which the revealed understandings which young people have of certain objects in the natural environment depend both on the type of research instrument used and on the context in which their understandings are probed. Secondly we wish to inform future studies of people's understandings of the natural world (including scientific phenomena) by determining the extent to which revealed understandings are 'robust' with regard to methods of data collection.

Our interest therefore has a strong methodological basis. We concentrate on objects (e.g. 'an oak tree') and their representations rather than processes (e.g. 'decay') because an understanding of a process first requires an understanding of the objects involved in that process. Moreover, other work (Gilbert & Boulter, 2000) indicates that teachers sometimes attempt to explain processes to pupils before their pupils have an adequate understanding of the constituent objects.

2. Research design and methods

2.1- Origins of this study.

The case study reported in this paper is part of a bigger study exploring children's understandings of the natural world which is addressing questions about the effect of age, probe type and context upon the expressed understandings of pupils. This case study of one of the 13 schools involved in the project seeks to describe the ways in which pupils in year 5 express their models orally within an interview, the effect of the visit to the Natural History Museum on these expressed models, and the ways in which these pupils draw the objects presented.

The same methodology has been used with all the schools and is described below.

2.2- The development of the probes.

Eight natural objects were decided upon through consideration of those objects with which the children would be familiar, those likely to be in their home or school environment and likely to be represented or present on the out-of-school visit. We also decided that the objects should be of different kinds (e.g. not all animals) so that it would be possible to consider them relating to each other in a variety of ways, e.g. in a food chain. In this way it provided an opportunity for subjects to express their mental models not only of the object itself but of the level at which they understood it.

The understanding of levels as an important aspect of biological understanding has been developed through work with student teachers (Boulter *et al.*, 2001). Recent interest in the application of general systems theory as a conceptual framework for thinking about science (Gulyaev *et al.*, 2002) proposes the same approach. In essence we take the organism as the central level and develop levels above and below based on a nested scale so that the ecosystem comes at the top level, then its constituent communities, then populations which are composed of individual

organisms. Below the organism level come organs in systems, which are made of tissues, comprising cells and organelles which are made of atoms and molecules. (See Table 1 for definitions.) Taking these considerations into account, our objects for England are daisy, grass, oak tree, pigeon, squirrel, ant, pond, cloud. A mushroom was added at the beginning of the process of presenting representations as a cue object to ease the pupils into talking.

Table 1. The levels of organisation in the environment used in the analysis of the transcripts of the pupils' responses to the probes

Biological levels	Descriptions and examples
Ecosystem, e	Communities interacting with one another and the chemical and physical factors of the non-living environment. E.g. Leaves catch the Sun's energy and it is used by the leaf to make food; The water cycle
Community, c	Populations of species living and interacting in an area at a particular time E.g. Oak tree food web; Groups of animals living together in grass
Population, p	Group of individual organisms of the same species living within a particular area E.g. Red squirrels; Black ants
Organism, o	A living (or once living) individual of a species E.g. The oak tree; A dog
Organ system or organ, or	Tissues grouped together into functional units which make up systems E.g. The heart; A leaf
Tissue, t	A group of physically linked cells or related fluids specialised for a particular function E.g. Muscle; Blood
Cell or organelle, cl	Basic unit of structure and functioning in organisms or a component of its internal structure E.g. Muscle cell; Chloroplast
Molecule or atom, m	Smallest unit of chemical elements or combination of two or more atoms of the same or different chemical elements held together by bonds E.g. Oxygen; Carbon dioxide

The representations chosen for presenting to pupils in school were those most commonly used in previous research, namely orally, as a drawing or as a photograph. The drawings and photographs of the nine objects were commissioned from professionals and then trialed with a sample of three boys and three girls at the different ages. Considerable alterations were required to the drawings, some of which caused confusions in the trial.

2.3- Selecting the samples.

Overall in the project we worked with nine primary and four secondary schools to allow us to obtain data from five year 1 classes (5 year olds), four year 5 classes (10 year olds) and four year 9 classes (14 year olds). The work reported in the case study which is the focus of this paper was

obtained from year 5 pupils. As in all the studies, the teacher was asked to select a sample of six pupils to represent the range of abilities in the class, and, if possible, to include both boys and girls. These sample pupils were followed on their out-of-school visit to the Natural History Museum. The pupils were taken in the museum to exhibits of similar objects to those about which they were interviewed in school. The pupils, in front of each object or representation of the objects such as a pond or painted clouds in a diorama, were questioned about the objects previously presented to them in school using open questions such as 'What do you know about X?' and 'Tell me more about Y'.

The class was visited back in school at a suitable time after their out-of-school visit. On this occasion, the sample pupils were first asked about their understanding of each object (presented orally). They then were asked to draw the objects, being told that they could add words to their drawings if they wished to so do. Throughout, all interviews were audio-tape-recorded using high-quality, low-visibility equipment suitable for use both in the field and indoors. All audio-recordings were transcribed.

In the case study analysed here, the data come from a year 5 class in a school situated in a new town 30 miles from London. The visit was to the Natural History Museum, London where the pupils looked at exhibits that contained objects similar to the examples presented in the pre- and post-visit probes. For instance, the pigeon was represented by a taxidermically preserved passenger pigeon, a squirrel by Pallas's squirrel in the mammal corridor, a pond by a puddle in the diorama, and an oak tree by a model and painting of trees in the African dioramas. Clouds were represented by those painted in the backdrop of the dioramas, which also included grass on the ground. Daisies were talked about in the Evolution Gallery where there is an exhibit focused on dog daisies. Ants were looked at in the Creepy Crawlies Gallery where there is an exhibition of live ants as well as diagrams and labels about ants. A *Plesiosaurus* mounted on the wall was used as the 'warm up' object.

Both the pre- and post-visit interviews used 'words' as the probe. The transcribed tapes were read and re-read, and issues about coding were discussed with the research team and resolved.

3. Analysis

3.1- Analysis of a case study school.

There are various ways of analysing conversations and narratives (reviewed by Tunnicliffe & Reiss, 1999c). Here, coding and initial analyses of pupil utterances were carried out employing systemic networks. These generate quantitative data from qualitative input and so will allow statistical analyses to be carried out later; for example, comparing the utterances of pupils who differ with respect to age, gender or physical setting (Bliss *et al.*, 1983; Tunnicliffe, 1995). Comparatively little research has been undertaken on different ways of analysing children's drawings (cf. Cox, 1997; Gilbert, 1997). Here, drawings are considered as expressed models (Gilbert & Boulter, 2000) and we examine the parts of the objects represented and their spatial relationships to each other together with any behavioural features represented.

4. Results

4.1-The pre-visit interviews.

To illustrate the sort of data obtained, here are two extracts from the pre-visit interviews. The two year 5 classes from which the pupils were selected had studied the water cycle three weeks before the interviews. The school also had a pond in the environmental area. Pine trees surround the school. (Each full stop preceded by a space or another full stop indicates a pause of one second; an underlining means that two people are talking at the same time; R stands for Researcher and P for pupil.)

4.1.1- Pupil 5 (male): probe = squirrel.

R *A Squirrel.*

P *Uhm. They are smaller than the American and there's only a few red squirrels left in England. They have massive quite big fluffy tails and the rest of their body is really small for eating conkers and that. They love nuts specially uhm they are called conkers and they bury them in another garden.*

R *So you've seen them, these squirrels?*

P *I had two cats and they used to chase squirrels.*

R *Have you still got the two cats?*

P *Dead.*

R *Oh. No answer for that. Are you going to tell me any more?*

P *Err no I don't know. I've got a lizard.*

R *Where has you keep that?*

P *My Dad's flat.*

R *Not in the back garden?*

P *Huh*

R *Night is too cold. Anything else about squirrels?*

B *Squirrels. They have these lovely big black eyes and they don't . see ... well I don't really see them blink . so they are focusing a lot. Can't think of anything else no.*

R *OK.*

4.1.2- Levels used by the pupils and general interpretations.

The levels, as defined in Table 1, used by the pupils in the pre-visit interviews are shown in Table 2. It is clear that most comments are at the level of organism or organ system / organ. In addition, there are a number at the level of community and population but very few at the other levels (ecosystem, tissue, cell / organelle, molecule / atom). It is notable, though, that the cloud elicits comments at the two extremes: ecosystem and molecule / atom.

The analysis shows that these 10 year old pupils refer to organisms the most (37%), followed by parts of the organism (33%), such as the bushy tail of the squirrel and the acorns of the oak tree. Few references (2%) were made to ecosystems and these were all in the context of clouds. Likewise at the other end of the spectrum of levels of organisation only 2% of the references were to molecules, most of which were in the context of the water cycle. Thus, as in work conducted which analyses spontaneous conversations of pupils at zoos and when presented with plants (Tunncliffe, 1996, Tunncliffe, 2001), the name of organism was the most frequently heard reference. The organism level is the initial one mostly commonly referred to by these pupils, followed by salient features (organs) of the organisms.

Table 2. Results of analysis of the transcripts of the pre-visit interviews using words as the probe before going to the Natural History Museum, London

(NB definition of categories is given in Table 1)	Totals (n = 242 category comments)							
	e	c	p	o	or	t	cl	m
Daisy	0	0	8	9	18	0	0	0
Grass	0	3	7	4	1	0	0	1
Oak tree	0	5	4	10	19	0	0	0
Pigeon	0	5	5	10	13	0	0	0
Squirrel	0	3	7	13	15	0	0	0
Ant	0	3	5	14	13	0	0	0
Pond	0	3	5	30	0	0	0	0
Cloud	4	0	0	0	0	0	0	5
Totals								
ecosystem	4							
community		22						
population			41					
organism				90				
organ system/ organ					79			
tissue						0		
cell/organelle							0	
molecule/ atom								6

Reading the transcripts revealed some trends in the pattern of pupil responses in addition to the numerical analysis. Pupils draw on their mental model, previous knowledge and first-hand experiences of the objects. Public understandings are evident from the pupils' comments and these are often not the same as scientific understandings. Pupils have a tendency to inform us of information which to them is related to the probe and elicited from the word being said to them and pupils interlace their response with information about their own involvement and that of others with the objects.

4.2-The visit dialogues.

On the visit, the pupils were interviewed in a group, rather than individually. Table 3 shows the levels revealed by the transcripts of these interviews. While there are fewer relevant pupil utterances (n = 65 compared to n = 242), the shape of the data is similar in that most comments are again at the level of organism and organ system. It is possible that comments at the level of organism predominate to an even great extent (52% compared to 37% on the pre-visit probes – Table 2). When being interviewed it was apparent that once one pupil had voiced a comment and there was agreement amongst the group, no one else repeated the comment.

Table 3. Results of analysis of the transcripts of visit to the Natural History Museum, London

(NB definition of categories is given in Table 1)	Totals (n = 65)							
	e	c	p	o	or	t	cl	m
Daisy			1	4	2			
Grass			1					
Trees			1	3	2			2
Pigeon			1	4	3			
Squirrel		1	1	5	7			
Ant			2	11	5			
Pond			1	7				
Cloud	1							
Totals								
ecosystem	1							
community		1						
population			8					
organism				34				
organ system/ organ					19			
tissue						0		
cell/organelle							0	
molecule/ atom								2

4.3-The post-visit interviews.

The post-visit interviews, which again used oral probes, produce findings that are very similar to the pre-visit interviews. The pupils were friendlier as this was the third meeting and they had all travelled by train to the museum in the company of the researcher and spent the day together. On the day of the post-visit interviews England had recently been defeated in the Football World Cup. The interviewees were conducted in the afternoon on a very hot day and the pupils, particularly the boys, appeared rather subdued and tired. Here is an extract from a post-visit interview.

4.3.1- Pupil 1 (male): probe = clouds.

R *What about clouds?*

P *Clouds are made up of water vapour and when there is too much vapour in them it turns back into water and it drops as rain and it goes into the sea and it goes back into vapour again like the water cycle. They are quite puffy sometimes. They are white, really common during the summer.*

R *Are they always white?*

P *Not all the time. When they get really heavy they turn grey and they drop their rain.*

R *Uhm.*

P *And uhm*

R *Do they stay still all the time?*

P No they move about because they get moved in the air.

R What by?

P Wind.

R Anything else about clouds?

P No.

R OK, thank you.

4.3.2- Levels used by the pupils and comparison with the pre-visit interviews.

The levels used by the pupils in the post-visit interviews are shown in Table 4.

Table 4. Results of analysis of the transcripts of the post-visit interviews using words as the probe after visiting to the Natural History Museum, London

(NB definition of categories is given in Table 1)	Totals (n = 233)							
	e	c	p	o	or	t	c	m
Daisy	0	1	5	8	13	0	0	0
Grass	0	1	8	6	16	0	0	0
Oak tree	0	1	3	7	15	1	0	0
Pigeon	0	0	7	4	15	0	0	0
Squirrel	0	3	3	10	21	0	0	0
Ant	0	3	4	11	12	0	0	0
Pond	0	2	2	50	1	0	0	1
Cloud	3	0	0	0	0	0	0	4
Totals								
ecosystem	3							
community		11						
population			32					
organism				98				
organ system/organ					83			
tissue						1		
cell/organelle							0	
molecule/atom								5

Again, from reading and re-reading the transcripts, a number of points emerge. As in the pre-visit interview, pupils talk about the objects in various ways mentioning structural features and locations in particular. The most frequent level is again organism (42% compared to 37% on the pre-visit interviews). Only two pupils referred to the visit, and these references followed prompts from the researcher. The pupils access their mental models and mention certain aspects of the organisms, often the same as they mentioned in the pre-visit interview. This suggests that the effect of the visit and the exposure to the concept for the third time has reinforced the mental model held by the pupils but not added to their knowledge and mental model. The context of the visit and the effect of an out-of-school trip has not altered the content of the comments of the pupils when given the same probe after the visit. Human involvement appears in evidence again, as well as references to activities they have undertaken or seen elsewhere such as on television or

in school, particularly in school grounds. As on the pre-visit, certain objects elicit an especially high number of comments about organs. In particular, the squirrel leads to lots of mentions of nuts, seeds, twigs and leaves. The pond is again a major source of comments about whole organisms.

4.4-The pupils' drawings.

There were six drawings produced by this set of pupils (one per pupil). The main features noted in these drawings were also noted in other drawings from other schools. Most of the drawings *either* provide an 'exhibit view' in which the items are related to each other and viewed from the side as in a museum diorama, *or* consist of a 'visual inventory' (a 'list') of individual drawings of the objects with no connections to the other objects. A few pupils produce a 'bird's-eye view' (although not in this sample). Pupils were free to label their drawings if they so wished. We refer to pupils who do label as 'labellers'.

The following observations emerged from considering the drawings of these pupils and echo those features shown by other drawings from other groups of pupils. Ponds are shown fringed with stones and often have lily pads on them, fish in them or ducks on them (Figure 1). Daisies are shown as one plant without leaves (Figures 2 and 3). Only one type of fungus (the pupil's interpretation of the word 'mushroom' is shown and this often resembles a toadstool, frequently recognisable as fly agaric. (Figures 1 and 3). Grass is often represented by a serrated short line (Figures 1 and 2 but note Figure 3). Pigeons are usually either depicted on the ground (Figures 1 and 2) or in a tree (Figure 3). Occasionally the bird is shown in the air with its legs hanging down. Squirrels are shown associated with trees – usually running up the trunk of a tree or sitting on a branch (Figure 3).



Figure 1. Post-visit drawing by pupil 1 (male). An 'exhibit view' combining all items in a picture represented like a diorama.



Figure 2. Post-visit drawing by pupil 5 (male). A 'labeller' with a 'list' of individual drawings.

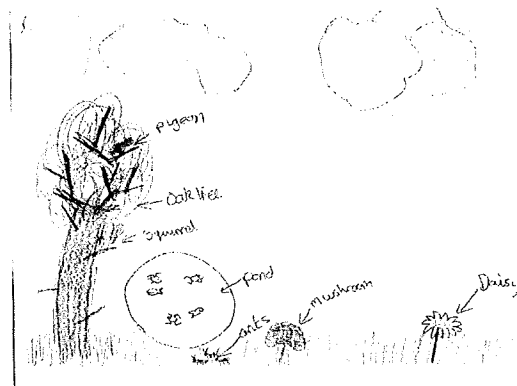


Figure 3. Post-visit drawing by pupil 6 (female). A 'labeller' with an 'exhibit view'.

Ants are usually shown the ground and are very small. However, pupils who provide inventories (Figure 2) appeared to draw larger pictures but rarely accurately (Figure 2). Often ants were shown with only four legs. Clouds are usually shown as outline blobs and are not producing rain. Trees are shown with surprisingly little differentiation: a blob on a thick trunk was the usual representation with little if any differentiation of the foliage and branches (Figures 1, 2 and 3).

If the content of the drawings for each pupil is compared with their comments made at the pre-visit and post-visit interviews (Table 5) it can be seen that the pupils who draw an exhibit view represent the community aspect of the probed object. The labeller draws his objects in isolation. As in the visit group interviews, the organisms etc are represented in far less detail than when discussed individually face to face.

Table 5. The contents of the drawings compared with the contents of the interviews of those pupils

	PRE-VISIT			POST-VISIT			DRAWINGS analysed in similar manner to interviews. e.g. pigeons = population; ants in grass with other organisms = community; dairy showing petals, disc and stalk = organs			Comments
	Pupil 1	Pupil 5	Pupil 6	Pupil 1	Pupil 5	Pupil 6	Pupil 1 Exhibit view	Pupil 5 Lister and label-ler	Pupil 6 Exhibit view and label-ler	
Daisy	1o 3or	1p 1o 4or	1p 5or	1p 2o 2or	1p 2o 3or	1p 2or	o 3or	o 3or	o 2or	P5 drew 3 parts of daisy (=3or). P6 drew flower and stalk.
Grass	2c 1p 1o	1c 1o 1o	1p 1m	2p 3o 1or	2p	1p 1or	o c	o	o c	P1 drew grass round edge of pond. P5 drew a short image of grass. P6 drew grass as habitat of community.
Oak tree	2c 1p 6o 5or	1p 4or	1p 1or	1p 1o 1or it	2or 1t	1o 3or	c 3o or	o	c 3o or	P1 drew squirrel in tree and acorns. P6 drew branches and two organisms in the tree = community.
Pigeon	3c 1p 4o 2or	1c 1p 1o 4or	1o 4or	1p 4or	1p 1o 3or	2p 2o 1or	o	o	oc	P1 put pigeon in sky – alone. P6 placed pigeon in tree – part of tree community.
Squirrel	1c 2p 3o 4or	1c 3o 3or	1p 2or 1o	1p 1o 4or	2o 4or	1c 1o 2or	o c	o 4or	o c	P1 squirrel in a community of tree. P5 squirrel holding nut and with bushy tail and incisors and eyes. P6 as above
Ant	1c 2p 3o 4or	1p 2o 5or	1p 1o 3or	1c 4o 3 or	1p 1o 4or	2o	o c	o	3o p c	P1 ant in a community. P6 drew 3 ants (population) in grass in community.
Pond	3p 9o	1c 4o	1p 5o	1p 4o	17o 1or	1c 8o	drew 5o c	drew	Drew 5o c	P1 placed 3 frogs and 2 fish in a community in pond.
Cloud	1e 2m	1e 1m		1m 1e			Drew	Drew	Drew several	P1 drew cloud in appropriate 'community' setting. P6 placed several clouds in sky in appropriate context.
Totals										
eco-system	1	1	0	1	0	0	0	0	0	No ecosystems shown.
comm-unity	9	4	0	1	0	2	5	0	7	Pupils 1 and 6 indicated communities through their drawings but not in interviews.
pop-ulation	10	4	6	7	5	4	0	0	1	Populations were embraced within communities in drawings.
organ-ism	29	12	8	15	23	14	13	6	17	As in visit interviews, organisms were shown usually once, hence a lower incidence.
organ system / organ	17	20	15	15	17	9	4	7	3	Fewer than mentioned in pre- and post-visit interviews. Some obvious features shown, e.g. nut in pupil 5's drawing.
tissue	0	0	0	0	1	0	0	0	0	Nothing indicated.
cell	0	0	0	0	0	0	0	0	0	Nothing indicated.
mol/atom	2	1	1	1	0	0	0	0	0	Nothing indicated.

The act of drawing appears to allow the pupils to make more connections between the organisms unless the pupil is a child who lists with drawings the probe subjects, in which case interconnections between the probes are not indicated.

5. Issues and initial conclusions

5.1- Interview and visit issues.

The interviews had to be conducted at mutually acceptable times. For this case study, the pre-visit interviews were conducted in a morning and the post-visits in a hot afternoon. The differing conditions and time of day may be one explanation for the lowered number of comments made post-visit. Moreover, factors and events outside of school, the World Cup for Football in this case, apparently affected the mood of the pupils. More fundamentally, despite agreeing interview protocols the researchers still found it difficult to avoid occasional leading questions.

Furthermore, the school had chosen pupils for whom in some cases it was felt the extra attention would be beneficial. Indeed Pupil 2, a boy with learning and language / speech problems, was so motivated by being included that his school work developed. The head teacher felt sure that the attention and boost to his self esteem that he received through being part of the project had led to this improvement. Reticent children required varying approaches to encourage them to speak.

Finally, the out-of-school visit proved problematic with regard to the recording of conversations. In part this was due to all the background noise and attempting to record group rather than individual pupil conversations. Some comments from pupils standing further from the researcher may have been lost.

5.2- Initial conclusions.

Pupils talk about their memories and existing knowledge of the objects represented by the probes. They describe the organisms and the salient anatomical and behavioural features, which they recall. They refer to appropriate memories such as the school pond, seeing a squirrel in their garden, and so on. They mention molecules and ecosystems when they remember them. This was particularly the case with clouds and the water cycle, which they had been taught a few weeks before the first interview. The visit to the museum, in which the group interview revealed similar but less often mentioned categories, did not appear to enhance their recall of the organisms. This was rooted very firmly in their recall, employed in the pre-visit interviews. However, the drawings for those pupils who draw spontaneously 'exhibit' style pictures enabled the pupils to show the organisms in relationship to each other and the pond and clouds, whereas the 'lister' showed little connection between the probe subjects. The out-of-school visit in this case has little apparent influence on the pupils' revealed understandings.

This project, illustrated here by one case study, uses a combination of modelling theory and systemic networks to analyse and interpret the data in novel ways. These are beginning to reveal the depth and diversity of pupils' expressed models of the natural world. They indicate that these models are readily expressed in discussion especially in the interviews. Drawing liberates other thoughts and connections. While a major focus of our work is methodological, it is clear that many pupils have a tremendously rich understanding of most of the objects about which we questioned them. While many of these understandings do not agree with accepted scientific

understandings, we would hesitate to describe the pupils' understandings as 'misconceptions'. In many ways, the children's understandings reflect either personal experience (e.g. 'I had two cats and they used to chase squirrels') or communal myth making (e.g. 'If you are lucky there's might be some frogs around the pond because if you have lily pads they might like jumping around and swimming in the pond'). Furthermore, the data so far reveal that children's understandings of the natural world are by and large acquired from places other than school and that the pupil's first hand observations are important.

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HOW DO STUDENTS USE CRITERIA IN COMPARISONS?

Marcus Hammann and Horst Bayrhuber

Leibniz-Institute of Science Education, IPN (Kiel — Germany)

hammann@ipn.uni-kiel.de

Abstract

Criteria are a constituent element of scientific comparisons. This study analyses how students use criteria in a free-sorting task that requires grouping the same set of organisms in two different ways. In contrast to previous studies, which concentrated on students' alternative conceptions of animal kinship, this study focuses on students' methodological competence in comparisons. The ability to use *a single* criterion for the groups forming one classification system is considered an indicator for this competence. This indicator is used because scientific classifications are characteristically purpose-oriented and organized around a single criterion. Only one third of the students of this sample (age 11-12) used criteria consistently insofar as their classification systems formed coherent and integrated wholes with groups closely related by a single criterion. Two thirds of the students used more than one criterion for forming the groups of one classification system or both classification systems. The students' methodological problems were not found to be restricted to a specific set of animals or to the students' choice of particular criteria. Evidence is presented that alternative conceptions about the use of criteria in comparisons rather than alternative conceptions about animal kinship account for the students' methodological problems in classification tasks.

1. Introduction

The comparative method, a major mode of scientific inquiry in the biological sciences (Mayr 1982, Ridley, 1983, Rieppel 1988, Harvey & Pagel 1991), revolves around the use of criteria. Logically, criteria constitute comparisons, which are defined as a three-partite relation, in which the relata – the objects to be compared – enter into a relationship established by using a criterion (Janich 1993). Epistemologically, criteria provide insights and help to answer the question or hypothesis that started the comparison (Eichberg 1972). From the perspective of science theory, comparisons yield reliable and reproducible insights only if the purposes of the comparison and the choice of criteria are explicitly stated and justified (Gutmann 1996). Recently, Janich & Weingarten (1999) have reconstructed the comparative method from the perspective of science history and shown that Carl von Linné (1707-1778) laid the groundwork for the comparative method by using criteria which he deliberately abstracted from the objects to be compared.

Criteria are not only the defining component of comparisons; choice of criteria also determines the result of comparisons. Being multi-dimensional by nature, similarity is hard to define without reference to criteria; any two given organisms can be found similar and different in many respects depending on the perspective chosen. A dolphin and a shark, for example, are similar in terms of their body shape (adaptation to similar environments), but dissimilar in terms of their physiology or taxonomy. Since biological similarity is informed by the two causal mechanisms of adaptation and evolutionary descent, it is necessary to reflect on the criteria that provide the basis for similarity judgments. Distinguishing between different types of similarities (homology, analogy) brought major advances in knowledge in the history of classification (Wuketits 1977, Harvey & Pagel 1991).

Deliberate use of criteria is crucial in scientific classifications, which are purpose-oriented and organized around a single criterion. Choice of criteria in classifications is determined by the aim of the classification. In taxonomic classifications, criteria are used in order to form groups of organisms related by kinship. They differ from ecological classifications, for example, in which organisms are grouped according to their adaptations to the environment. Many other classifications exist, for example classifications based on biochemical and physiological processes (e.g. ectotherms and endotherms), reproductive processes (e.g., asexual and sexual processes) and the relationship to human beings (e.g., domestic, wild, and farm animals).

Everyday life is permeated by classifications of natural kinds and artificial objects. Often, people use classifications without thinking about their aims and the criteria on which they are based. Panchen (1992), for example, argues: “the individual person is unlikely to be aware of the structure of the classification he or she is using” (1). Students in biology classes may thus be familiar with important biological categories, but they may not know how to classify because they are unaware of the structure of classifications and the fact that a single criterion is necessary for forming the groups of one classification system. Accordingly, this study aims at assessing the students’ methodological skills in a free-sorting task.

2. Theory

Studies on the comparative method have neglected the role of criteria in comparisons. Kĳazimov (1968) and Brezmann (1986), for example, found that students are more likely to mention differences than similarities in comparisons, but excluded the role of criteria from their studies. They defined comparisons as a two-partite relationship, i.e. a relationship between the objects to be compared and not as a three-partite relationship, i.e. a relationship

between objects established by a criterion. In this study, by contrast, comparisons are defined as a relationship between objects involving criteria.

Until the mid-nineties, classification tasks have been used to assess the students' lack of taxonomic knowledge (Jungwirth 1971, Ryman 1974, Trowbridge & Mintzes 1985, 1988, Mintzes & Trowbridge 1987, Braund 1991). An important finding of these studies is that students' taxonomic knowledge is often deficient and that students tend to interpret similarity between organisms as a sign of kinship although similarity may be caused by adaptation to similar environments. Students who misclassify the dolphin as a fish exemplify this problem. Recently, studies in classification have shifted from assessing the students' taxonomic knowledge to investigating students' alternative conceptions about animal kinship (Kattmann & Schmitt 1996, Kattmann 2001). This was possible by using the method of free-sorting. The authors found that students "prefer to classify creatures along the criteria of habitat and locomotion" and that they "continue using these criteria after learning the categories of biological taxonomy" (Kattmann 2001, 141). Students formed the groups "aquatics", "flyers", "creepers", and "terrestrials" as well as taxonomic groups, which was seen as an indication of the existence of alternative conceptions about animal kinship. In this study, the authors analyzed the criteria used *by groups* of students. *Individual* students' use of criteria in the classification task was not assessed. Thus, it remained to be investigated if individual students had used a single criterion in their classification systems – with potentially some students using a single (e.g. taxonomic) criterion and other students using a single (e.g. ecological) criterion – or if individual students had shifted criteria and used taxonomic criteria in conjunction with criteria of habitat and locomotion in *the same* classification system.

Individual students' use of criteria was assessed in a study that investigated how students classified a set of animals in at least two different ways (Hammann 2002, Hammann & Bayrhuber 2003). The students (age: 12) frequently used several criteria in one classification system, for example, ecological criteria, taxonomic criteria and criteria describing the relationship to human beings. Also, students formed both one-criterion systems and various-criteria systems in the alternative classification task (for a definition of these terms cf. 5.1). The findings revealed methodological deficits in students' classification performance. Even though the students were given free choice of criteria, they were unable to conceive of their classification systems as an integrated whole unified by the use of a single criterion. Students were thus unaware that biological classifications must fulfill the requirements set for scientific classifications, i.e. use of a single criteria for the groups of one classification system.

3. Research Questions

The overall aim of this study is to assess students' methodological skills in comparisons at an early learning stage. For this, it is necessary to know *if students are able to form one-criterion systems in an alternative classification task (research question 1)*. This question is pertinent because the student's methodological competence in free-sorting tasks of organisms should be measured against the standards set for scientific classifications. Based on our own findings in a study of a different sample (Hammann 2002, Hammann & Bayrhuber 2003), it is possible to hypothesize that students have problems using a single criterion for all the groups of the classification system. Three sets of animals are used in order to investigate if the students' anticipated methodological problems are restricted to a specific set of animals or to the student's choice of particular criteria.

Second, it will be investigated *if students use a variety of criteria only when they try to form taxonomic classification systems or if unsystematic use of criteria is a more general tendency*

in students' comparisons and occurs also in classification systems without taxonomic groups (research question 2a). This question is posed because taxonomic categories are learned in introductory high school classes, but students may have problems applying them because their taxonomic knowledge is not broad enough. A lack of taxonomic knowledge may thus be responsible for methodological problems in classification tasks. Although we found that the students' tendency to use a variety of criteria in classifications systems is not restricted to classification systems with taxonomic groups when students classified a set of eleven fish, this may have been due to the specific material used (Hammann 2002, Hammann & Bayrhuber 2003). Also we pose the question if methodological problems occur only because students use the criteria of habitat and locomotion in conjunction with taxonomic criteria, so that we will investigate *whether or not students' alternative conceptions about animal kinship (Kattmann & Schmitt 1996, Kattmann 2001) can account for the anticipated unsystematic use of criteria in various-criteria classification systems (research question 2b).*

Third, if this study confirms our previous findings (Hammann 2002, Hammann & Bayrhuber 2003) that students form both one-criterion systems and various-criterion systems in the alternative classification task, and if alternative conceptions about animal kinship (Kattmann & Schmitt 1996, Kattmann 2001) cannot account for unsystematic use of criteria, the attempt must be made to explain *why one and the same students form both one-criterion systems and various-criteria systems (research question 3).* It can be hypothesized that students shift criteria because either they may not know how to relate all the organisms to the criterion initially chosen, or because they do not intend to use a single criterion for the classification system.

4. Research method and testing materials

The test used in this study required students to group the same set of animals in at least two different ways and to give the groups descriptive names (see Appendix). This type of free-sorting task was previously tested (Hammann 2002, Hammann & Bayrhuber 2003) and represents a variation of the method used by Kattmann & Schmitt (1996) who asked their participants to group a set of 25 animals in *one* classification system. For this task, students have to think of the organisms from different perspectives, choose one criterion for one classification system (and use it for all groups of this system), and choose another criterion for the other classification system (and use it for all groups of that system.)

Three different sets of animals were used, so that each student had to group three sets of animals in at least two different ways and submit a minimum of six classification systems. This requirement was set to rule out chance – some students may deal with some sets of animals better than others – and to be able to assess a spectrum of graded methodological abilities.

The first material consists of a set of 15 animals presented to the students without names as color pictures: snake (1), penguin (2), flying squirrel (3), frog (4), fly (5), fish (6), hummingbird (7), kiwi (8), bat (9), spider (10), beetle (11), tiger (12), butterfly (13), parrot (14) and whale (15). The second material consists of a set of 25 animals presented to the students in writing. It is the same set of organisms used by Kattmann & Schmitt (1996): dog, cat, butterfly, earthworm, wasp, hen, snail, spider, snake, fox, fly, seal, beetle, hamster, duck, crab, lion, herring, swallow, frog, mouse, elephant, jellyfish, lizard, starfish. Lower-grade students' familiarity with these animals has been tested by Kattmann & Schmitt (1996). The third material consists of a set of eleven fish presented to the students as color pictures without names. It is the same set of organisms used in a previous study with different students

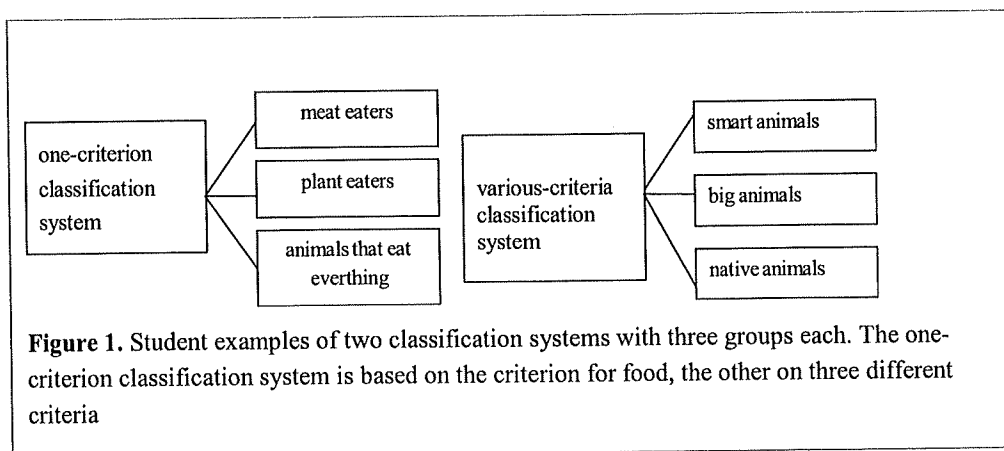
(Hammann 2002, Hammann & Bayrhuber 2003): carp (A), flounder (B), tuna (C), loach (D), moray (E), shark (F), bream (G), swordfish (H), ray (I), brook lamprey (K) and pike (L). These materials were used in order to (a) compare student performance to the findings of Hammann (2002) and Kattmann & Schmitt (1996), (b) investigate if students' methodological deficits are restricted to a certain selection of organisms, and (c) induce students to select different criteria for the organisms in material 3 in order to investigate if students' methodological deficits are restricted to a certain choice of criteria. For reason (c) material 3 consists of a group of organisms whose taxonomy and ecology (habitat and locomotion) is expected to be less familiar than the organisms in materials 1 and 2.

5. Data analysis

5.1 Types of classification systems

Students' use of criteria was assessed by analyzing group names and by ascertaining if one criterion or if multiple criteria were used for forming the groups of one classification system. Generally, two kinds of classification systems were distinguished: "*One-criterion systems*" are classification systems, in which all the groups of the classification system are based on the same criterion. For example, the criteria used for forming the groups "animals with fur", "animals with feathers", "animals with skin", and „animals with a carapace" can be attributed to the criterion of anatomy (cf. Fig. 1 for another example).

"*Various-criteria systems*" are classification systems, in which at least one criterion used for group formation is in conflict with the other criteria. For example, a classification system with the groups: "water animals", "insects", "animals with scales", "animals with fur" and "animals with feathers" is a *various-criteria* system because the criteria of habitat, taxonomy, and anatomy are used (cf. Fig. 1 for another example).



5.2 Types of student responses

Based on the distinction between two types of classification systems (cf. 5.1), three types of students were defined: students that formed exclusively *one-criterion systems*, students that formed exclusively *various-criteria systems*, and students that formed both *one-criterion systems* and *various-criteria systems*.

5.3 Analysis of various-criteria classification systems

Comparisons in free sorting tasks require the ability to (a) select one criterion and (b) use it for all the groups of the classifications system. In order to take into account both components, an index was formed by subtracting the percentage of groups formed by using diverging criteria from the percentage of groups formed according to one criterion. Example: in a classification system that consists of 6 taxonomic groups (60%), 2 groups based on the criterion of habitat (20%) and 2 groups based on anatomical details (20%), the index is 0,2. This index takes into account the total number of groups formed in one classification system and describes the ability to use criteria in classification tasks more adequately than an index based on counting the criteria per system, which gives credit to ability (a) only.

6. Sample

The sample consisted of 248 students, 154 female (62%) and 94 male (38%). 12 students (5%) were 10 years old; 127 students (51%) were 11 years old, 101 students (40%) were 12 years old, and 8 students (3%) were 13 years old. 152 students (61%) were in grade 5, 96 students (39%) were in grade 6. The sample was drawn from two high schools in Kiel, Germany. Testing took place during one class period (45 min) in the classroom.

7. Findings

7.1 General characteristics of student responses to Material 1

Tab. 1 presents some general characteristics of student responses to the three materials, in particular the ratio between one-criterion systems and various-criteria systems and the mean number of criteria used in various-criteria systems.

Table 1. General characteristics of student responses to the three materials

	Material 1 (15 animals)	Material 2 (25 animals)	Material 3 (11 fish)
Total number of students who responded to the material	246	246	246
Total number of classification systems formed by the students	567	520	504
Total number (%) of one-criterion classification systems formed	322 (57%)	275 (53%)	273 (54%)
Total number (%) of various-criteria classification systems formed	245 (43%)	245 (47%)	231 (46%)
Total number of organisms classified in one-criterion systems formed	4790	6722	2957
Mean number of organisms (STD) classified per one-criterion system	14,97 (STD 1,559)	24,44 (STD 2,707)	10,81 (STD 0,96)
Total number of organisms classified in various-criteria systems	3592	5883	2491
Mean number of organisms (STD) classified per various-criteria system	14,66 (STD 2,77)	24,01 (STD 4,265)	10,78 (STD 2,06)
Mean number of criteria (STD) used by students per various-criteria system	3,26 (STD 1,18)	3,33 (STD 1,28)	3,08 (STD 1,05)

Tab. 2a and Tab. 2b present the types of criteria used in one-criterion systems and various-criteria systems.

Table 2a. Criteria used in one-criterion classification systems

Number of one-criterion classification systems with the criterion of ...	Material 1		Material 2		Material 3	
	N	%	N	%	N	%
Taxonomy	104	32,3	74	26,9	17	6,2
Locomotion	28	8,7	15	5,5	6	2,2
Habitat	66	20,5	88	32,0	37	13,5
Food	29	9	24	8,7	23	8,5
Ecology	3	0,9	2	0,7	26	9,5
Anatomy	61	18,9	50	18,2	123	45,5
Relationship to human beings	18	5,6	10	3,6	37	13,5
Reproduction	7	2,2	5	2,0	0	0
Other	6	1,8	7	2,5	4	1,6
Total number of one-criterion systems	322	100	275	2,61	273	100

Table 2b. Criteria used in various-criteria classification systems

Number of organisms in groups formed according to the criterion of ...	Material 1		Material 2		Material 3	
	N	%	N	%	N	%
Taxonomy	1079	30,0	1755	29,8	345	13,8
Locomotion	893	24,8	698	11,8	61	2,4
Habitat	622	17,3	1811	30,8	137	5,4
Food	104	2,8	228	3,9	79	3,2
Ecology	113	3,1	137	2,3	202	8,1
Anatomy	553	15,4	911	15,5	1193	47,9
Relationship to human beings	113	3,1	191	3,2	0	0
Reproduction	57	1,6	42	0,7	313	12,6
Other	57	1,6	93	1,6	47	1,9
Unspecific	29	0,8	17	0,3	114	4,6
Total number of organisms classified in various-criteria systems	3592	100	5883	100	2491	100

7.4 Discussion

Students' classification systems are fairly homogeneous for materials 1, 2, and 3 in terms of the ratio of one-criterion systems to various-criteria systems, the average number of criteria used per various-criteria system, and the care that was taken to group all the organisms presented to them. There are, however, differences between the students' responses to the materials regarding the choice of criteria. Whereas the classification systems for materials 1 and 2 resemble each other in terms of choice of criteria and confirm the findings that students tend to use the criteria of habitat and locomotion (Kattmann & Schmitt 1996, Kattmann 2001), students shifted to different criteria for material 3 in their one-criterion systems (cf. Tab. 2a) and various-criteria systems (cf. Tab. 2b). This had been anticipated because materials 1 and 2 consist of animals of more familiar taxonomic groups. Also these animals live and move in easily discernable habitats. Specialized knowledge, however, is required to classify fish taxonomically (e.g. bony fish, cartilaginous fish, lampreys) or according to habitat and locomotion (e.g. fast-swimming fish of the open water, slow-maneuvering fish of the reed zone, undulating fish on the ground). Thus, students shifted to different criteria when they classified the fish and used anatomical criteria, for example. The fact that students used different criteria for material 3 is a desired effect, which allows for assessing whether or not students' methodological skills are bound to the use of certain criteria.

8. Findings for research question 1

8.1 Types of classification systems

Tab. 3 presents the types of classification systems submitted for materials 1, 2 and 3. Student responses to the three materials resemble each other, with approximately one third of the students forming only one-criterion systems, one-third of the students forming only various-criteria classification systems, and another one-third of the students forming one-criterion systems as well as various-criteria systems for each of the materials. However, if student responses to all three materials are considered (cf. last column in Tab. 3), the percentage of students submitting only one-criterion classification systems (for three materials) drops to 14%, the percentage of students producing only various-criteria systems (for three materials) declines to 10% and the percentage of students who form one-criteria systems and various-criteria systems (for three materials) rises to 62%.

Table 3. Types of student responses to the different materials

	Material 1		Material 2		Material 3		Material 1,2 and 3 combined	
	N	%	N	%	N	%	N	%
Number of students who submitted ...								
... exclusively one-criterion classification systems	73	29	70	28	78	32	34	14
... exclusively various-criteria classification systems	70	28	75	30	69	28	25	10
... both one-criterion classification systems and various criteria classification systems	93	38	84	34	80	33	153	62
... incomplete materials	9	4	9	4	8	3	35	14
Missing data	2	1	9	4	10	4	0	
Total	247	100	247	100	245	100	147	100

8.2 Discussion

With approximately one third of the students in each of the categories (students with one-criterion systems, students with various-criteria systems, and students with both one-criterion systems and various-criteria systems), none of the materials – judged by collective student response – was more challenging methodologically than the other. Severe methodological deficits are revealed by the considerable percentage of students who are unable to use a single criterion in one of the classification systems or both. Only one third of the students was able to form exclusively one-criterion classification systems for each of the materials. Since the materials contained different animals and since the students used different criteria for material 3 than for the materials 1 and 2, methodological problems are not restricted to grouping a specific set of animals or using certain criteria.

This is not to say that individual students classification skills are independent of the material. If individual student responses to all three materials are looked at, it becomes obvious that it is much more difficult to classify three sets of different animals in one-criterion systems than just one set of animals. Also, only 10% of the students formed various-criteria systems for all three materials. As a result, the number of students who formed both one-criterion systems and various-criteria systems for materials 1-3 (combined) increased. These students will be looked at in detail in the part of this paper that focuses on research question 3.

This study confirms our previous findings, which analyzed the classification performance of students (n= 113, age: 12 years) who classified material 3 (Hamman 2002, Hamman & Bayrhuber 2003). The methodological deficits were even more pronounced in that study, with only 7% of the students forming exclusively one-criterion systems, 47 % of the students forming exclusively various-criteria systems, and 46% of the students forming both one-criterion systems and various-criteria systems.

Whereas misclassifications of untypical representatives of a category can be attributed to deficient knowledge about the organisms (e.g., Mintzes and Trowbridge 1987, Braund 1991), students' use of more than three different criteria when forming the groups of one classification system is an indication of a methodological problem. Judged against the standards set by science theory for using the comparative method (cf. "Introduction"), many students use criteria in comparisons less systematically than they should. They disregard of the role of criteria in classifications, and are unable to conceive of their classification system as an integrated whole unified by the use of a single criterion.

9. Findings for research question 2

9.1 Types of various-criteria classification systems

The following typology was used in order to analyze if students use various criteria only in classification systems with taxonomic groups (research question 2a) and if the students' tendency to use criteria of habitat and locomotion in conjunction with taxonomic categories [i.e. alternative conceptions about animal kinship as described by Kattmann & Schmitt (1996) and Kattmann (2001)] account for unsystematic use of criteria (research question 2b):

- Type 1: classification systems with **taxonomic groups** and **groups formed by using the criteria of locomotion or habitat** (but no other criteria)
- Type 2: classification systems with **taxonomic groups** and **groups formed by using the criteria of locomotion or habitat and groups formed by using other criteria**
- Type 3: classification systems with **taxonomic groups, and groups formed by using other criteria** (but not with groups formed by using the criteria of locomotion or habitat)
- Type 4: classification systems **without** taxonomic groups, but with groups formed by using various criteria

This typology was created because classification system types 1-3 contain taxonomic groups, whereas classification system type 4 does not. Thus, types 1-3 and type 4 will be compared for answering research question 2a. Classification systems types 1 and 2 contain taxonomic groups in conjunction with the criteria of habitat and locomotion, whereas types 3 and 4 do not. Types 1-2 and types 3-4 will be compared for answering research question 2b.

Comparison between types 1-3 and type 4: The students formed a considerable number of various-criteria systems for materials 1, 2 and 3 without taking recourse to taxonomic criteria (cf. Tab. 4, type 4). In 31% (material 1), 25% (material 2) and 41% (material 3) of the various-criteria systems, no taxonomic criteria were used. Conversely, taxonomic criteria were used in 69% (material 1), 75% (material 2) and 59% (material 3) of the various-criteria systems.

Comparison between types 1-2 (combined) and types 3-4 (combined): In materials 1 and 2, the students used taxonomic criteria in conjunction with criteria of locomotion or habitat (types 1 and 2 combined) in over 60% of the various-criteria classification systems. In contrast, only 5 % of the students' various-criteria classification systems for material 3 are characterized by this combination of criteria. Conversely, taxonomic criteria were not used at all or did not occur in conjunction with the criteria of locomotion or habitat in 30-40% of the various-criteria systems for materials 1 and 2 and in 95% of the various-criteria systems for material 3 (types 3 and 4 combined).

Another contrast concerns various-criteria systems type 3. In 7% respectively 6% of the various-criteria classification systems for materials 1 and 2, taxonomic criteria occurred in conjunction with other criteria, but not with criteria of locomotion or habitat. However, a large percentage (54%) of the various-criteria systems for material 3 is characterized by this combination of criteria, i.e. by an exclusion of the criteria of locomotion or habitat.

Table 4. Types of various-criteria classification systems

	Material 1		Material 2		Material 3	
	N	%	N	%	N	%
Type 1: classification systems with taxonomic groups and groups formed by using the criteria of locomotion or habitat (but no other criteria)	56	23	64	26	2	1
Type 2: classification systems with taxonomic groups and groups formed by using the criteria of locomotion or habitat and other criteria	95	39	104	43	10	4
Type 3: classification systems with taxonomic groups and groups formed by using other criteria (but not with the criteria of locomotion or habitat)	18	7	15	6	125	54
Type 4: classification systems without taxonomic groups , but with groups formed by using various criteria	76	31	62	25	94	41
Total	245	100	245	100	279	100

9.2 Discussion

The comparison between various-criteria systems with taxonomic groups and various-criteria systems without taxonomic groups shows that unsystematic use of criteria is not restricted to classification systems with taxonomic groups. Although the analysis of combinations of criteria confirms that taxonomic groups are formed in conjunction with groups based on the criteria of habitat and locomotion (cf. Kattmann & Schmitt 1996, Kattmann 2001), other combinations of criteria also occur and unsystematic use of criteria is neither restricted to the effort to group animals taxonomically nor limited to a certain choice of criteria (habitat, locomotion) in any of the three materials used in this study. Thus, alternative conceptions about animal kinship (Kattmann & Schmitt 1996, Kattmann 2001) may contribute to the unsystematic use of criteria described in the previous section, but do not account for it. This is particularly obvious for material 3, in which half of the various-criteria classification systems contains taxonomic criteria in conjunction with other criteria, but not with criteria of locomotion or habitat. Also, students did not form any taxonomic groups in a large percentage of their various-criteria systems (type 4) in all three materials, which underlines that unsystematic use of criteria is not determined by deficient taxonomic knowledge. Deficits in the students' methodological knowledge are rather responsible for the students' use of multiple criteria in one classification systems.

10. Research question 3

In order to answer the question, why students form both one-criterion systems and various-criteria systems, the various-criteria systems of the 178 students who submitted 2 classification systems for each of the three materials (cf. Tab. 3) were analyzed according to the method described in 5.3. As argued before, it can be hypothesized that some of the 153 students, who formed both one-criterion systems and various-criteria systems, shift criteria because either (a) they may not know how to relate all the organisms to the criterion initially chosen, or (b) because they do not intend to use a single criterion for the classification system. In order to test these hypotheses the mean index for their various-criteria systems will be compared to the mean index of various-criteria systems formed by 25 students who submitted exclusively various-criteria systems for all three materials. If the mean index for various-criteria systems of the 153 students who formed both one-criterion systems and various-criteria systems is significantly higher than the mean index of various-criteria systems formed by the 25 students who did not form any one-criteria systems, hypothesis (a) is adequate. If the opposite is true, hypothesis (b) is confirmed.

10.1 Findings for research question 3

For the 25 students, who formed exclusively various-criteria systems for the materials 1-3, the mean index for various-criteria systems is -0,09 (STD 0,15; Min: -0,34; Max: 0,21). For the 153 students, who formed various-criteria systems as well as one-criteria systems, the mean index for various-criteria systems is 0,09 (STD 0,26, Min: -0,55; Max: 0,83). The T-Test showed that the difference between these two groups is significant [$F(2,173)=5,26, p<.01$].

However, since the index for the 153 students who formed both various-criteria systems and one-criterion systems shows a wide range, which limits comparability, this group was divided into 72 students whose mean index for various-criteria systems is below or equal zero and 81 students whose mean index for various-criteria systems is above zero. For these, the following mean indexes for various-criteria systems were found: For the 72 students whose mean index for various criteria system was equal or below zero, the mean index is -0,14 (STD 0,13; Min:-0,55; Max: 0). For the 81 students whose mean index is above zero, the mean index for various-criteria systems is 0,25 (STD 0,25; Min: 0,01; Max 0,83).

The mean indexes for various-criteria systems of these two groups of students were compared to the mean index for various-criteria systems of the 25 students, who formed exclusively various-criteria systems for the materials 1-3 (already listed, see above). The ANOVA showed highly significant differences between the three groups of students [$F(2, 108)=108,79; p<.001$]. Comparisons between the three groups of students (Tukey HSD) revealed, that no significant difference exists between the mean index of the 25 students who form exclusively various-criteria systems and those 72 students, who are able to form both one-criterion systems and various-criteria systems, but whose mean index in the various-criteria systems is equal to or below zero ($p>.05$). Accordingly, the significant findings of the ANOVA go back to the highly significant difference ($p<.001$) between the mean index of the 25 students who form exclusively various-criteria systems and those 81 students, who form both one-criterion systems and various-criteria systems and whose mean index in the various-criteria systems is above zero.

For the 72 students whose mean index for various criteria systems was equal or below zero, no correlation could be found between the number of one-criterion systems (materials 1-3) and the mean index for various-criteria systems (Spearman coefficient: -0,5). For the 81 students whose mean index is above zero, a weak correlation could be found between the number of one-criterion systems (materials 1-3) and the mean index for various-criteria systems (Spearman coefficient: 0,29).

10.2 Discussion

The mean index for various-criteria systems is used for describing the students' ability to choose one criterion and use it for all the groups of one classification system (cf. 5.3). This ability differs considerably in those students, who form both various-criteria systems and one-criterion systems. The main finding of this part of the study is that the ability to form one-criterion systems is not a very good predictor for using criteria systematically in various-criteria classification systems. Proof was found that students who form both one-criterion systems and various-criteria systems use criteria in various-criteria systems as unsystematically as students who are not able to create any one-criterion systems.

This interpretation is supported by the fact that no significant difference was found in the comparison of the use of criteria in various-criteria systems formed by students who submitted exclusively various-criteria systems and by half of the students who formed both various-criteria systems and one-criterion systems. For the latter students, the explanation could be verified that methodological deficits are responsible for their classification problems because their various-criteria classification system do not reveal the intention to use a single criterion for group formation. Probably, these students managed to form one-criterion systems

because they had learned these classification systems and reproduced them. This knowledge of learned classification systems, surprisingly, did not affect their use of criteria in various-criteria systems, which was unsystematic and characterized by frequent shifts.

Proof could also be found for the explanation that other students formed various-criteria systems (although they were also able to form one-criterion systems) because they did not know how to relate all the organisms in the set to the groups formed by them. These students have a significantly higher mean index in their various-criteria systems than students who are unable to form any one-criterion systems. The interpretation that these students use criteria more consciously and systematically is also warranted because for these students, there is a positive correlation between the number of one-criterion systems created in response to materials 1-3 and the mean index for various-criteria systems.

11. Summary

A large percentage of students in this study used criteria unsystematically. Students frequently used various different criteria in one classification system and formed one-criterion systems as well as various-criteria systems in an alternative classification task. Thus, previous findings about methodological deficits of students in comparisons were confirmed (Hammann 2002, Hammann & Bayrhuber 2003). As a consequence for biology instruction, it is necessary to teach students how to use criteria in comparisons. Such a methodological treatment must convey to the students that comparisons are guided by criteria and that scientific classifications are organized around a single criterion.

Unsystematic use of criteria was not found to be restricted to classification systems with taxonomic groups or to the combination of taxonomic categories and criteria of locomotion and habitat. Accordingly, deficient taxonomic knowledge (e.g., Trowbridge & Mintzes 1985) and the students' preference for criteria of locomotion and habitat (i.e. alternative conceptions about animal kinship, as described by Kattmann & Schmitt 1996 and Kattmann 2001) contribute to the unsystematic use of criteria but do not account for it. In contrast, students possess alternative conceptions about the use of criteria in classifications and tend to use various different criteria when they form the groups of one classification system.

Proof was found that students use conflicting ways of using criteria in comparisons. A considerable number of students formed both one-criterion systems and various-criteria systems for the same set of animals, but the ability to form one-criterion systems did not necessarily affect the ability to use criteria systematically in various-criteria systems. Students may have simply reproduced learned classification systems, when they formed one-criterion systems, but they did not possess methodological knowledge about how to classify. From this follows that teaching students biological classifications – without an explicit methodological treatment about the use of criteria in comparisons – does not necessarily affect performance in classification tasks. Particular attention must be paid to teaching biological categories *and* knowledge about the role of criteria in classifications.

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APPENDIX

Task description

First Name: _____ Last Name: _____ (Initial) Age: _____

Grouping animals in different ways

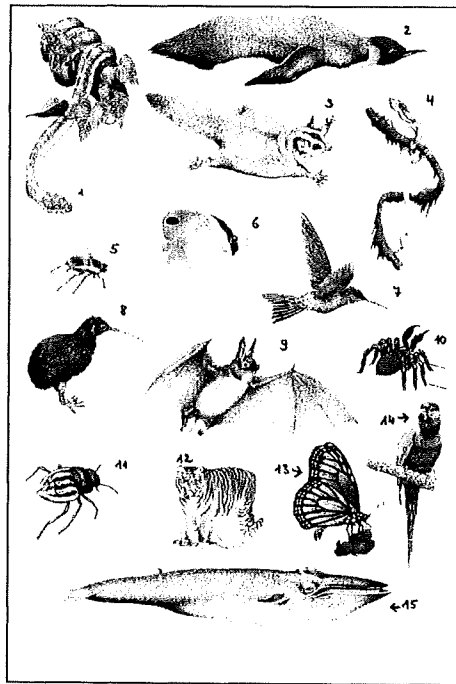
Animals can be grouped in different ways. Form groups for the following animals and give the groups descriptive names.

Proposal 1:
Your task is to group the fish A-L and to give the groups descriptive names. You can decide how many groups you want to form and how many fish belong to a group. (It is also possible to form groups that consists of only one fish) All groups must have names

Proposal 2:
Here, your task is to group the Fish A-L in a different way than in proposal 1. This means that you have to think about a different way of grouping. Don't forget to give the groups descriptive names

For further proposals: proposal 3, proposal 4, ... use the back of this page

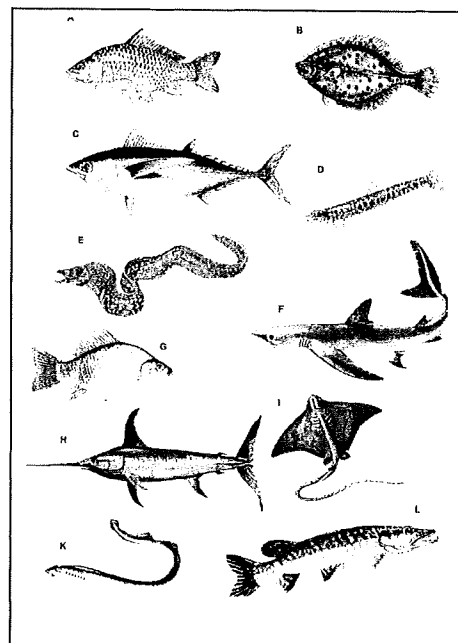
Material 1



Material 2

- | | | |
|--------------|---------------|--------------|
| 1) dog | 2) cat | 3) butterfly |
| 4) earthworm | 5) wasp | 6) hen |
| 7) snail | 8) spider | 9) snake |
| 10) fox | 11) fly | 12) seal |
| 13) beetle | 14) hamster | 15) duck |
| 16) crab | 17) lion | 18) herring |
| 19) swallow | 20) frog | 21) mouse |
| 22) elephant | 23) jellyfish | 24) lizard |
| 25) starfish | | |

Material 3



19-YEAR-OLD STUDENTS' REFLECTIONS OVER THEIR UNDERSTANDING OF ECOLOGICAL PROCESSES

Gustav Helldén,

Department of Mathematics and Science, Kristianstad University, Sweden
gustav.hellden@staff.hkr.se

Abstract

The present paper reports on findings from a study of twenty-eight 19-year-old students' thinking about the development of their own understanding. The study builds upon data from a longitudinal study of the students' conceptualisations of ecological processes. Each student was interviewed on different occasions from age 9 to 15. During the analysis of the interviews, characteristic individual features in the students' conceptions can be followed year by year. In order to know more about the origin of these features and the students' thinking about the development of their understanding, they were interviewed again at 19 years of age. The students listened to the interviews with them as 11- and 15-year-olds. They were asked to make comments on what they said in the interviews, how they thought they had developed their understanding, and what had been of greatest importance in the development of their understanding. The students could often recognise statements in the interviews resulting from experiences from an early age. The majority of students could describe concrete experiences that had contributed to the development of their understanding. The students showed varying abilities to reflect on how their understandings had changed through the years.

1. Background

1.1 A longitudinal study

Over a period of many years of teaching biology to students aged 13-19, I became aware that they had difficulties describing how certain aspects of ecological phenomena take place. For example, they appeared to have problems to give an accurate interpretation, at their own educational level, how biomass builds up and breaks down. I also found that some interesting details in the students' explanations of these processes appeared at different ages among the students. This ascertainment made me still more interested in the development of students' ideas. In order to know more about students' conceptual development, I found that I had to stretch the duration of my research project and study the same subjects over time. Short time studies cannot capture the whole picture. By following individual students' conceptual development we can as researchers get information about the nature of the learning process, learning pathways and the influence of everyday experiences on pupils' long-term learning. Without such studies, we cannot make valid knowledge and value claims about pupils' long-term conceptual development. In spite of this need, comparatively few research projects have been longitudinal in nature (White, 2001).

Novak and Musonda (1991) have reported a twelve-year longitudinal study of students' understanding of science concept learning. Lichtfeld (1996) and Johnson (1998) have carried out a study of students' conceptual development concerning their understanding of the particulate nature of matter during a three- and four-year period. By following students over several years, Bonnie Shapiro (1994) and Michael Reiss (2000) have done long-term studies of individual students' learning in science, their experience of science lessons, and about the environments where science was taught. When my long-term study started in 1988, no results from the above mentioned studies had been reported. The longitudinal study at Cornell University (Novak & Musonda, 1991) was of great importance for the analysis of my interviews because I built initially upon the same theoretical framework as the Cornell study, Ausubel's theory of meaningful learning.

In order to learn how to help students to develop deeper understandings and more scientifically accurate explanations of some ecological processes I carried out a longitudinal study of students' conceptualisation of such processes between 9 and 15 years of age. The ecological processes comprised conditions for life, decomposition and the role of the flower in plant reproduction (Helldén, 1995, 1998). A couple of hours after the last interview at 15 years of age, the students were also interviewed about the views of the development of their own understanding (Helldén, 2001).

1.2 Prior findings and current objectives

The significant findings to emerge from the longitudinal study were (1) The students had great difficulties explaining the processes that involved transformations of matter. (2) An early introduction to the concept of the water cycle at school had an important implication for the students' understanding of other cycles in nature. They used the water cycle model to explain other phenomena, and their explanations became more scientifically accurate. (3) Anthropomorphic reasoning was an important element in several students' attempts to understand and describe the different processes. (4) Early life experiences seemed to be very important for the students' future conceptual developments.

It is possible to identify personal themes in the pupils' descriptions that appeared year after year. Such themes can have a structural nature – a way of explaining a phenomenon – but

these themes can also concern the content (Helldén, 2000). These themes seemed to be a result of personal experiences that were hidden from the researcher. Why not ask the pupils themselves about such features? I also wanted to know their views about their learning and what they thought had influenced the development of their understanding in order to get more insights into the development of the students' understanding.

Other researchers like Bonnie Shapiro (1994) and Michael Reiss (2000) have got such insights by observing science lessons in combination with interviews and other kinds of conversations with the students. Shapiro not only observed the students but let the students talk to her, and the students enjoyed sharing their science experiences with her. She felt that she was a member of the fifth grade class. Shapiro talked to the students about their science experiences both as a group and as individuals. She reviewed the videotaped science lessons together with each student. Through observation of science lessons, conversations with students and interaction with students in a naturalistic school setting, Shapiro obtained valuable information about students' science learning.

Reiss followed a group of students from 11 to 16 years of age by observing more than fifty percent of their science lessons and by making notes on what was going on during the lessons without any communication with students. He also collected data while observing students in corridors and in the school grounds between lessons. Students and parents were interviewed in their homes while teachers, learning support assistants and student teachers were interviewed at school. Reiss' goal was to get a complete picture of how students experienced science lessons and why some of them enjoyed science lessons and learnt from them while others did not.

I did not have any data like Bonnie Shapiro and Michael Reiss but transcribed interviews with students from 9 to 15 years of age. The interviews contain interesting features often as recurrent themes in the students' descriptions of the ecological processes that could be the results of personal experiences. In order to get deeper insights into the students' conceptual development, I wanted to know more about why students said what they did.

Therefore, after I had completed the analysis of the students' conceptualisation of the ecological processes I decided to interview them again. At the end of the students' last semester in upper secondary, I let them as 19-year-olds, listen to the interviews I have conducted with them at 11 and 15 years of age and make comments on their descriptions of the ecological processes.

Questions that emerged from the longitudinal study that became the focus of inquiry for the current study were:

- 1: What were the students' views of their understanding of the processes?
2. What kind of experiences were of greatest importance for their conceptual development?
3. How can answers to these questions contribute to a richer understanding of the students' conceptualisation of ecological processes?

2. Method and sample

The longitudinal study was carried out at a small primary school and later on at a larger secondary school in a town in southern Sweden. I, like many other researchers in science educa-

tion, have found that clinical interviews can give in depth information on pupils' thinking about natural phenomena (Duit, Treagust & Mansfield, 1996).

The students were interviewed about ecological processes individually on eleven different occasions from grade 2 (9 years) to grade 8 (15 years) of the Swedish comprehensive school. In order to challenge the pupils' ideas about conditions for life, I used cultivation of plants in sealed transparent boxes during the interviews. For my interviews about decomposition I had soil, brown leaves and litter on a table in front of the pupils. During my interviews about the flower's role in plant reproduction I showed the pupils different kinds of flowers. Each interview lasted twenty minutes. All the interviews were tape recorded and transcribed verbatim. Ausubel's theory of meaningful learning had important implications for the analysis of the interview data. By following the progressive differentiation through assimilation of concepts to the students' thinking, it was possible to describe their conceptual development (Ausubel, Novak and Hanesian, 1978).

As 19-year-olds, the students studied their last semester at different upper secondary schools with different programs. At the beginning of the semester, I sent a letter to the twenty-eight students and told them about my interest knowing more about the development of their understanding through the years. I also told them that I wanted to hear their comments about my earlier interviews with them. A week later, I called the students and discussed the possibility of meeting again and carrying out an interview on the basis of what they said in my earlier interviews with them. When I contacted them, they were eager to meet me again and listen to my earlier interviews with them. I let each student listen to audiotapes of my interviews with them at 11 and 15 years of age. The students also had a transcript of the interview in front of them. Initially, I asked the students to make comments on the ideas they expressed in the interviews and explain why they said what they did. I also asked them to describe how they thought their ideas had developed, what they thought had been of greatest importance in influencing their ideas and what period of their lives had been most important for the development of their understanding of ecological processes.

All the interviews were audiotaped and transcribed verbatim. I investigated the transcribed data in order to find out what kind of comments the students made when they had listened to my earlier interviews with them and how they described the development of their understanding. By analysing the interviews, I also studied their metacognitive ability in order to see if they looked upon their learning as an integration of new knowledge into their thinking or if they thought their new ideas were added to their knowledge by rote learning.

3. Findings

The students showed great interest in their earlier statements, but a varying ability to interpret what they said. When the students as 19-year-olds listened to the audiotapes of their earlier interviews that laid out for them the history of their thinking, they could in many cases identify key life experiences that shaped their understandings. Most of the students were rather critical of what they had said in the interviews and sometimes expressed astonishment at the poor development of their understanding.

Fifty percent of the students demonstrated a more reflective view on the nature and development of their learning, thus indicating a greater metacognitive ability. Each of these students has a different view of learning, but what they have in common is that they each take their

own learning process as an object to reflect and comment upon. The other half of the class demonstrated a more descriptive view without paying much attention to the importance of their own thinking during the development of their understanding. They did not have a strong sense of themselves as actors in the learning process, and did not take the learning process as an object to be theorised.

3.1 The students views of their understanding

Students with a more reflective view treated the learning itself as an object to be talked about. When they heard what they said in the earlier interviews, they realised that they at that time, and not always understood the concepts they mentioned. Johanna argued that she used words without knowing what the words really meant and therefore missed the general picture. She said: *"Initially, there are small pieces of puzzle that you then put together. And you get a general picture that becomes more and more complete the older you are. At the beginning you only knew a couple of concepts.... some words. You had small pieces of knowledge but could not put them together to one... for example a cycle of matter."* It is typical for the students in this group to describe their conceptual development as putting together something they had heard, read in a book or experienced in another way. The students feel they own the learning, and view learning as a process involving active construction on the part of the learner. It did not just happen.

Sven had also a more reflective view belonged to this group of students. He characterised himself as an observer and a listener, and described his development as a collecting of facts during his childhood by reading books and listening to others. *"I started to read when I was 5 years old. From that age and until I was 12, I collected and absorbed facts uncritically, and that means that understanding came later."* Then Sven argued that he at 13-14 years of age started to more critically analyse the concepts he had heard earlier in order to understand the phenomena. The greater understanding was in these years not a result of more reading or collecting of facts, but a result of reflecting in a more questioning way.

However, other students like Sofia claimed that the development of their understanding did not start by collecting facts but by a new way of thinking. *"Until grade 4 it was my own ideas. I had not learnt everything by myself, but it was my descriptions and compositions from everything. Then I tried to understand how it possibly worked."* She then described how her thinking was enriched as a result of schooling by linking new concepts to her thinking in a way that can be described with an ausubelian term as a progressive differentiation through assimilation of new concepts to the her cognitive structure (Ausubel, Novak and Hanesian, 1978).

When the reflective students were asked to say something about the development of their ideas, they easily described thoughts about their personal development with both cognitive and emotional elements like in the following interview segment with Hanna. Learning has not only to do with thinking. Feeling plays also an important role in the conceptual development. Hanna made the following comment when I asked her about the importance of learning in childhood: *"Of course, when you are a child, you are ready to make mistakes. You don't need any knowledge as reason for what you think and claim. The older you are the more weight you want to give to your argument. All the time, the level of knowledge at school is escalated and directs our thinking. When you are a child you dare to speculate. Fantasies you also have today but don't express loudly because then you can be accused of being ignorant and careless. Children should be researchers because they are willing come up with new ideas."*

Louise described in the earlier interviews the plant's need for oxygen in a human centred way. At 19 years of age she said: *"I think it is because humans need oxygen to survive. And the you think that the plants They are also alive ... sort of also need oxygen."* The reflective students could like Louise to a greater degree describe and value different sources of knowledge that were important for their conceptual development. They more often gave spontaneous comments on their formulations.

Some students found their earlier anthropomorphic formulations a bit strange. Students with a more reflective view were able to make comments on the way they used analogies and anthropomorphic formulations, like Oscar in the following example. As a 19-year-old he became quite astonished when heard his earlier descriptions of the role of the flower in plant reproduction at age 11 and 15. We can also see how he had a more 'scientific' explanation at 15 years of age.

Oscar at 11y

"In order to attract animals that can then suck nectar from inside there so that they can reproduce or perhaps they can boast to the other flowers and make themselves beautiful and so on in the same way as women powder themselves and so on. If you have them in a garden, perhaps you water them very much more cos they are so pretty."

Oscar at 15y

"It's in order to be able to attract the wasps. And then they suck the nectar or something and so the stuff gets stuck, pollination..... No, I don't know what it is called. Perhaps that is what it is called and then they take it with them and so it goes on to the next flower. The flower can't be fertilised from the same stamen there down in the seed, it must sort of change flowers. These stick to the wasp and are carried on and go down into the seed. And a new embryo is formed in there that falls out or when it withers, it stays there."

It is notable that Oscar, along with some other students, did not only use anthropomorphic formulations when talking about pollution. For instance, he also used them when explaining defoliation.

Oscar at 11y

"They don't have the strength remain sitting there. They must jump off."

Oscar at 15y

"Well, it is during winter the tree cannot give nourishment to the leaves and itself, so it drops the leaves. It closes the supply of nourishment to the leaves."

Oscar claimed that the anthropomorphic features in his earlier descriptions about defoliation and the role of the flower could be attributed to the influence of his mother's attempts to explain the phenomena to him. *'I think it's mum that has influenced me. She could say like this when she explained such phenomena.'* He said like several other students that they knew as children that plants do not have feelings or the leaves' muscles. It was a way of explaining why plants had colourful flowers and why the leaves fell down from the trees in autumn. Oscar used the anthropomorphic ideas as analogies rather than as explanations, or as Zohar and Ginossar (1998) expressed it: *"They transform long formulations into shorter ones; enhance pupils' empathy toward scientific topics; and helps pupils to organise information along familiar lines."* As a 19-year-old, Oscar described his reflections in the following way: *"It is your fantasy and what you find out yourself, and what you hear at home. And you are lying*

there and thinking about what you have heard. You are trying to find outor build upon it in some way

Fourteen of the twenty-eight students expressed a more descriptive view of the development of their understanding. They tended to describe their learning as an addition of facts to their earlier knowledge. They talked about catching knowledge from what they experienced, and claimed that you learn by seeing something or hearing somebody say something. For them, learning about the ecological processes was mostly a result of teaching at school. They did not recognise learning as a part of everyday life. There was nothing in their arguments about the student's own thinking as part of her/his conceptual development. They did not have a strong sense of themselves as actors in the learning process. Some of the students talked about knowledge like something that sticks in their memory. Others talked about something that is stored in one's head like Ruth in following example: *"We did it frequently and you had it in the back of your head all the time."*

Students with a more descriptive view of their conceptual development did not to the same extent as the reflective students discuss why they used the anthropomorphic formulations. Anders is an exception. He described the experiences from parties at home that had influenced the way he described the importance for a plant to have a colourful flower when he had listened to the following earlier interviews with him. But for Anders, the anthropomorphic descriptions were more than formulations as Oscar argued.

Anders at 11y

"I think the flowers have cos they have colours to make you think they are nice and want to have them indoors. It gives you something to embroider the table with when you have guests. Then the food on the table and then you embroider the table with some brightly coloured flowers."

Anders at 15y

"Well, actually I've wondered about that too, but I think it's like a human being, they need all this growing around them and the leaves. Life's a bit nicer and not so boring. It is like human beings. We live in our houses. We plant plants and have other things 'cos it makes it nicer. I think that what plays a big part for them to have a flower is that the leaves are not alone. The flower is company for them which makes it nicer for them to grow up. Perhaps it makes them stay on longer 'they're having a nice time."

When Anders had listened to these interviews with him he still had the same view on the role of the flower as he had at 11 and 15 years of age. He said: *"I think I have the same idea to day. A plant has a soul like us. The plant want to have the feeling to look nice."* For him as a 19-year-old, it was more a belief than just formulations from an everyday context. Oscar, on the other hand, was able to discuss the anthropomorphism as a constructed idea.

At the end of the interviews, I asked the students what part of their lives had been of greatest importance for the development of their understanding. Eight of the fourteen reflective students told me that they thought childhood before the age of 11 had been of greatest importance for their conceptual development in comparison with three of the fourteen none reflective students.

Many of the students with a descriptive view had problems seeing differences between the interviews at 11 and 15 years of age. Some of them found their current conception of the

processes to be the same as four years earlier. Perhaps their limited biological knowledge of the processes made it difficult for them to form an opinion on the content of the interview responses.

3.2 Experiences of importance for the conceptual development

At the end of the interviews, I asked the students as 19-year olds to comment on what had been of greatest importance to the development of their understanding. Students with a reflective view on learning could more often trace back personal features in the interviews to everyday experiences they had made together with teachers, neighbours, playmates or family members. Even if the students appreciated what they had learnt at school, they described experiences outside school, often in the early ages, that contributed to their understanding. Hanna described the decomposition of leaves on the ground in the following way that contains a core idea that can be followed in all the other interviews, too.

Hanna at 11y

"I think they mould away. They will dry out ... then an animal is coming, trampling them and they become broken. It will become small, small pieces and then the real soil is pressing them down and they will be a lump and then it is raining and the sun is shining and it becomes soil."

Hanna at 15y

"It must be when it dries up. Then when it rains, it is mixed up with some mud. Then it dries and becomes soil. Or also some animals come and eat it. Their excrement will become soil"

After Hanna had listened to earlier interviews with her, she explained why she described the process in that way. Near the house where she lived with her family were two big birch trees from which lots of leaves fell down to the ground every autumn. At 19 years of age, Hanna said that she remembered how after a rain liked to go out and play by mixing soil and water into mud even if she did not like to be awfully dirty, feelings that supported her ability to reflect over the earlier experiences.

At 19 years of age, Sofia argued that she had developed her understanding of cycles in nature by linking concepts from everyday life to her thinking about the phenomena. In the interviews with her from age 10 to 15, she always described the water cycle in the sealed boxes by integrating the concept of dew into the process as in the following interview segments.

Sofia at 11y

"Well, first you poured in water. Then in the morning, there sort of will be dew on the leaves and the, when it is a little warmer in the box, it rises up towards the floor. And then it is raining down when there is too much."

Sofia at 15y

"You had watered the soil before you planted them and had sealed the box. The plants absorb the water. Then there is dew on the plants that evaporates. It rises. Therefore, it is condensation there. And then it runs down back into the soil."

I asked Sofia to say something about her use of the concept of dew. She referred to childhood experiences: *"It's from childhood. You have walked on grass in morning. The dew has always fascinated me. It is unbelievable beautiful. I thought that water was tremendously important for survival of the plants and tried to put this concerning dew into this context. There is noth-*

ing more beautiful than cobwebs with dew!' Experiences in her childhood had become an important contribution to her understanding and description of the conditions for life in the sealed boxes.

In the following interview transcripts we can assume that there must be an everyday experience of composting that had explanation of the decomposition of leaves on the ground. He referred to composting in all the interviews from 9 to 15 years of age.

Anders 11y

S: *"Well, they have dried. Then they haven't had enough water and then You put many other things there, you can also put eggshells and so on the compost heap. And they stay there and rot in some way. It takes a long time, it takes just about four years to get real and very nice soil."*

I: *Do you have any idea how in fact it works?"*

S: *"The soil underneath that's been there for a long time. And I think it is mixed with that so there will be even more."*

Anders 15y

"It is like composting. You have some soil on the bottom and then it stays there becoming smaller and smaller bits. I think it's the same with the leaves, that they are mixed up and then there'll be more and more of it. I don't think that there'll be soil but I think there will be small, small bits that is mixed up with the soil, then you say that it has become soil." I think there's water and then it rots and then it becomes soil 'cos there is soil."

Anders could immediately when he had heard this on the tape recorder, tell me from where these ideas came: *"We had a neighbour who carried out composting in a special way. I liked to be there together with him. The man even put eggshells and coffee grounds on the compost. I remember the first time I was there. And he asked me to empty a bucket with coffee grounds and some eggshells on the compost heap. I was confused. I think I was 7 years old."* Anders recognised that his learning was influenced by his prior experiences. However, he described the development of his understanding more as addition of facts to a storage than as a construction of understanding: *"It's still several years later. You don't remember what you said and although it is somewhere 'in the back of your head'."*

At the end of the interviews I asked the students what they thought had influenced their conceptual development through the years. All the students claimed that teaching at school had been of great importance. Nineteen students said that talking to parents or other relatives had contributed to the development of their understanding. Ten of these students belonged to the group of students with a more reflective view of their conceptual development. Fourteen students could identify concrete experiences that had been important for the development of their understanding. Only five of these students belonged to the group of students with a descriptive view.

The students often related their way of describing the ecological processes to concrete personal experiences that occurred between the ages of 5 and 10. A majority of the students claimed that early experiences were of great importance for the development of their understanding. Early episodes in childhood seem in many cases to have such an important influence on their future understandings that the students used these as a part of their explanations of natural phenomenon. These explanations could be followed as themes in the interviews.

4. Discussion and conclusions

This research project builds upon data that was gathered by interviewing a group of students on eleven occasions from 9 to 15 years of age. Through the long-term study of students' conceptualisations it was possible to identify personal contexts and continuity as recurrent themes in the students' explanations of ecological processes. Even if the explanations changed through the years towards more or less complete explanations, in several cases it is possible to identify core ideas that can be followed by analysis of the interviews with the same child from 9/10 to 15 years of age. These core ideas can be of structural nature, a way of explaining a phenomenon like Tove's use of a cycle model to explain how the plants could get necessary resources in sealed transparent plastic boxes, or Oscar's use of anthropomorphic formulations to explain defoliation and the role of the flower. It has also been possible to identify individual themes that concern the content of the students' statements. Sofia always used the concept of dew as a part of her explanations. Anders talked year after year about eggshells and composting when he was asked to explain what happened with the brown leaves on the ground. Through tracing their thinking over many years it has been possible to identify personal themes in the development of the students' understanding that would be impossible to identify by probing their conceptions at a single point in time.

The purpose of the present research project was to get information about the origin and importance of these themes by letting the students themselves as 19-year-olds listen to the interviews with them as 11- and 15-year-olds and to comment on the way they described the phenomena.

The students showed great interests in their earlier statements, and a great ability to interpret what they said – ie. why they said what they said, and to identify key life experiences that shaped their understandings. Most of the students were rather critical of what they had said in the earlier interviews and sometimes expressed astonishment over the poor development of their understanding. However, some students demonstrated a more reflective, metacognitive view on the nature and development of their learning. When they heard what they said in the earlier interviews, they realised that they at that time not always understood the concepts they mentioned. One student argued that she used words without knowing what the words really meant and therefore missed the general picture. Some students described how they snapped words from what they heard from others, mostly at school and at home, and how they had formed a general picture by putting together pieces of puzzle. The reflective students also showed a greater ability to use language as a tool to support their efforts to understand the phenomena and express their thoughts.

Other students demonstrated a limited ability to reflect on their learning. They recognised that their learning was influenced by their prior experiences but they described the change in their explanations through the years as a process of addition of information. Some students said that they knew more, simply as a result of being older. Others described a learning process by which new facts were just fastened to their minds. Even if they recognised a change in explanations they gave at age 11 and 15, some students were unable to trace the change in their understanding to any identifiable experiences. They did not know why their understanding had changed, and they often gave the same explanation to the phenomena as they did four years earlier.

Could the reflective students' deeper descriptions of their conceptual development to some extent be a result of concrete experiences in a positive atmosphere? These students often re-

ferred to conversations with parents or other relatives that had been of great importance for the development of their understanding. They said that they could ask their parents to describe and explain different phenomena in nature. Students like Oscar, Sven, Johanna, and Betty appreciated the experiences and discussions with their parents during field trips that had contributed to their understanding. I argue that it was the positive atmosphere in combination with metacognitive ability that made it possible for the reflective students to identify concrete experiences that had contributed to the development of their understandings. Even the students' ability to use a rich and colourful language can contribute to rich descriptions of the processes.

As 19-year olds, several students recognised features in the earlier interviews that they could trace back to experiences they had made together with teachers, neighbours, playmates or family members. Even if the students appreciated what they had learnt at school, they described experiences outside school, often in the early ages, that contributed to their understanding. In some cases the students could recall such experiences in their totality as a part of the students' episodic memory (Helldén and Solomon, in press). There seem to have been powerful experiences in the early ages that made it possible for individual features to exist in spite of all influences while growing up.

Even if there was a substantial conceptual development through the years, there was also a strong element of personal context. The students could as 19-year-olds identify such features after they had listened to the interviews with them when they were 11 and 15 years old. Like in Hanna's case concerning her ideas about decomposition, several students did not replace one understanding with another one. Instead, they widened their ranges of ideas as a result of schooling and experiences outside school (Marton, 1998). The development of the students understanding can be described as a conceptual growth rather than mere conceptual change. Experiences from the present research project has shown

- that there is a great potential to get a deeper insight into the development of students' understanding of scientific phenomena by tracing this over a long period of time, and encouraging them to reflect back on their earlier learning
- that students with a reflective view looked upon learning as an active construction on the part of the learner, and that they take.
- that students with a descriptive view did not view themselves as actors in the learning process, and did not take the learning process as an object to be theorised.
- that the possibilities of listening to previous interviews allowed the students to identify important precursors to their understandings, many of which related to social situations
- that experiences in the early ages seem to be very important for the future conceptual development.
- that students did not mostly replace one understanding with another one but widened their ranges of ideas or increased their repertoires of ideas
- that the development of the students understanding can be described as a conceptual growth rather than mere conceptual change.

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STUDENTS' CONCEPTIONS ABOUT SYSTEM EARTH – SYSTEM THINKING AND MULTI-PERSPECTIVE LEARNING IN THE CARBON CYCLE CONTEXT

Kristin Hildebrandt and Horst Bayrhuber
Leibniz Institute for Science Education (IPN) (Kiel – Germany)
hildebrandt@ipn.uni-kiel.de

Abstract

Earth sciences have undergone significant changes in the past decades towards research that is system theory-oriented and interdisciplinary. Earth scientists increasingly use systemic and multi-perspective approaches in relation to the contents and methods. In contrast, system thinking and multi-perspective learning are rarely emphasised in teaching earth sciences at school. Furthermore, little is known about students' conceptions of the earth as a system and the effect of multi-perspective learning. This study aims at providing practical guidance for teaching complex geo-scientific systems.

In a preliminary study, students' conceptions of the earth as a system were characterised by looking at the global carbon cycle. The carbon cycle represents a complex system which connects biological, chemical, geological and physical processes and serves as an ideal model for illustrating the interactions among the earth's spheres – biosphere, atmosphere, lithosphere and hydrosphere. In a preliminary study, we focused on particular properties of the dynamic of this complex system. For students, non-linearity, irreversibility and cyclicity are difficult to conceive.

The preliminary results of this research are being used as one basis for developing computer-assisted learning materials on the carbon cycle, focusing on a dynamic view of the earth system compared to static concepts which have already been implemented to a great extent.

1. Introduction

Geo-scientific concepts are systemic and multi-perspective. For example, the carbon cycle can be seen as a subsystem of the climate system or of system earth. In addition, the dimensions “climate” and “use of resources” emphasise different aspects of the carbon cycle. System thinking and interdisciplinarity become increasingly necessary on the way to a better understanding of complex geo-scientific concepts. These topics are the basis for sustainable development (Bund-Länder-Kommission, 1999). Hence, teaching earth sciences must be supported by system thinking and multi-perspective learning.

In a preliminary study, which was carried out with the IPN-project “System Earth”, students’ conceptions of the earth as a system were characterised by looking at the global carbon cycle. This research is situated in the fields of constructivism and system thinking. Five secondary school students (two boys and three girls) from 16 to 18 years old were tested separately by using several quantitative and qualitative research instruments. The results of the preliminary study are described. The preliminary results were taken into account in the development of computer-assisted learning materials on the global carbon cycle.

2. Geo-scientific Topic

The study focuses on the global carbon cycle in a systemic context. The carbon cycle system is characterised by the reservoirs and the fluxes of carbon, based on biological, chemical, geological and physical processes. For example, photosynthesis and respiration, important concepts in biological science, are part of these processes. In addition weathering, volcanism (de-gassing), metamorphism of rocks, deep diagenesis, sedimentation, subduction, decomposition, solution of gases, are significant.

The global carbon cycle can be divided into several sub-cycles. For example, we distinguish between a long-term and a short-term carbon cycle. The former is the cycle that operates over millions of years and that involves the slow exchange of carbon between the rocks and the superficial system consisting of the ocean, the air, the organisms and the soil. It differs from the short-term carbon cycle in which carbon is rapidly exchanged within the superficial system (Berner, 1999). We equally distinguish between a terrestrial and an ocean carbon cycle.

3. Theoretical Background

We understand learning as an active process in which concepts already present are developed upon, and this development is to a large extent influenced by the individuals’ pre-knowledge and personal experience (v. Windschitl & Andre, 1998). In the constructivist context, it is also argued that multiple conceptual changes should be given more attention to overcome the current restriction on taking only conceptual changes at a level of science concepts into account. Alternatively, interactions of conceptual changes at the level of science concepts and at meta-levels – conceptions of the nature of science and meta-cognitive views – should be focused on research (Duit, 2000). So we aimed at analysing students’ pre-conceptions regarding the carbon cycle in the earth system context. We investigate students’ pre-conceptions of the content aspects of the carbon cycle as well as students’ ability of system thinking in the carbon cycle context. Pre-conceptions of geo-scientific subjects like continental drift, greenhouse effect and ozone layer depletion, have been already well investigated (Pfundt & Duit, 1994). On the other hand, there are only a few publications available on students’ conceptions of the systemic nature of the earth (v. Ben-Zvi - Assaraf & Orion, 2001; Gudovitch & Orion, 2001;

Kali, Orion & Eylon, 2001). These studies, however, show that students do not recognise the dynamic of the system earth. They often interpret dynamic systems such as evolution or rock, water and carbon cycles by the use of static terms. In order to get a perspective on and an understanding of the complex view of the earth it is necessary to use system theory, which is inseparably connected with modelling. System thinking in the earth system context is fundamental (v. Ossimitz, 2000; Ben-Zvi - Assaraf & Orion, 2001).

System thinking contains the identification of the elements of a system, the relationships between the elements and the properties of a system as a whole. It is characterised by system analysis, i.e. the investigation and the design of systems. The following aspects can specify system analysis:

- separation of the system from the environment,
- identification of the (relevant) elements of the system,
- identification of the (relevant) relationships (effects and fluxes) between the elements and the (relevant) relationships between the system and its environment,
- identification of the characteristic properties of the system: identification of the structural properties (e.g. system parameters, system hierarchies) and identification of the dynamics (e.g. non-linearity, irreversibility, self-organisation, dynamic equilibrium).

These aspects can be further differentiated. For example, the identification of the relationships includes the identification of the network that exists between the elements. In order to be able to analyse the effects listed above the topics “feedback” and “loops” are important. With regard to fluxes the topic “circular flows” needs to be considered. Furthermore, the perception of different dimensions of time is of importance (e.g. long-term and short-term, delays).

Thus, system thinking contains several aspects. Ossimitz (2000) has defined four dimensions of system thinking: thinking in networks, thinking dynamically, and thinking in models, acting in a system-compatible way.

4. Objectives of the preliminary study

In the preliminary study we were especially interested in how the students imagine characteristic properties of the carbon cycle system. Therefore, we focused on the aspects of system analysis – the elements of a system, the relationships between the elements and the properties of the system as a whole. In order to analyse these aspects we considered the permanently changing non-linearity, irreversibility and cyclicity. In this connection we assumed that students have difficulties in linking scientific findings to their own experiences. Mandl et. al., (1993) found evidence of a comparable fragmentation of knowledge in connection with learning physics. The preliminary study included the following two objectives:

- to identify students’ pre-conceptions of the carbon cycle,
- to identify the aspects of system thinking which are used in the carbon cycle context.

5. Research Questions

For the preliminary study, the following research questions were asked:

- Which scientific concepts do students have of the global carbon cycle?
- Which aspects of system thinking do students use in connection with the global carbon cycle?

These two questions are inseparably connected with each other and affect each other.

6. Research Design and Methodology

Five secondary school students (two boys and three girls) from 16 to 18 years old were individually tested and interviewed in the preliminary study. The students attended the same school. They were selected by their teacher, who was asked to choose students of above average, average and below average scientific ability. At the time of testing and interviewing the selected students studied biology, chemistry, physics and geography. The biological, chemical, physical and geographical basic concepts which are necessary to understand the carbon cycle was already part of the lessons.

The students' prerequisite knowledge from biology, chemistry, physics and geography which is necessary to understand the carbon cycle was tested and analysed as well as their pre-conceptions of the carbon cycle system. The data collection of the preliminary study was based on several quantitative and qualitative research instruments:

- *Drawing and Estimation:* First the students were requested to draw the carbon transfer through the earth's spheres – lithosphere, atmosphere, hydrosphere and biosphere. Thereby the students had the possibility to read definitions of the four earth's spheres. In addition the students were asked to estimate the distribution of carbon among the earth subsystems – air, ocean, fossil fuels, rocks, organisms and miscellaneous – in percentage of the total carbon in the system earth. For drawing and estimation 10 minutes were available;
- *Interview:* A half-structured interview of 45 minutes was carried out in order to investigate the pre-instructional conceptions of the structure and dynamics of the global carbon cycle. Some questions were related to the students' drawing. After the interview the students were asked whether they would like to modify their drawing;
- *Questionnaire:* Subsequent to the interview the students had to fill out a questionnaire, which included biological, chemical, geological and physical topics, necessary to understand the global carbon cycle. The questionnaire included multiple choice questions and open questions. The questionnaire required 20 minutes.

7. Data analysis

The data from the preliminary study comprised drawings, recorded interviews on audiotape and written responses.

Every interview was transliterated from the audiotapes by two persons. To analyse this information the inductive method was used. The information was gradually examined. It was read again and again. The different kinds of alternate conceptions were compiled, adjusted and modified. Thereby, we accounted for the drawings. Content categories as well as system thinking categories were developed.

The written responses of the questionnaire were verified.

8. Findings

Generally, the results on the basis of content categories show that the students have problems with getting the *relevant elements* of the carbon cycle system. The students declare animals and plants as the important elements. Especially water respectively hydrosphere and rocks respectively lithosphere plays no role in the carbon cycle system. In this connection the students estimation of the distribution of carbon among the earth subsystems (air, ocean, organisms, rocks, fossil fuels and miscellaneous) is interesting. The students assume carbon in wa-

ter and rocks but not in the right chemical bond and not in the right condition of aggregation. Four of the tested students imagine carbon in rocks as CO_2 in the air interstices of rocks. Furthermore, the students do not perceive the ocean carbon as parts of the carbonate-system ($\text{CO}_{2(\text{aq})}$, $\text{HCO}_3^-_{(\text{aq})}$, $\text{CO}_3^{2-}_{(\text{aq})}$). They imagine carbon in water as carbohydrates in water organisms or gaseous CO_2 in the form of bubbles in the water.

In addition, these findings show with regard to the system thinking categories that the students do not estimate the *right size of the elements* of the carbon cycle system (v. Fig 1). For example, they overestimate the atmosphere and the biosphere as a carbon reservoir compared to the lithosphere and the ocean. As a result of the estimation of the distribution of carbon the students overestimate the fossil fuels. The students tested assume the greatest volume of carbon in the fossil fuels. The students underestimate the rocks. It is important to note that the students' perceptions are very far from the scientific fact that the rocks contain more than 99.9% of the total carbon in the earth system. In addition, the students underestimated the ocean which represents the second largest carbon reservoir.

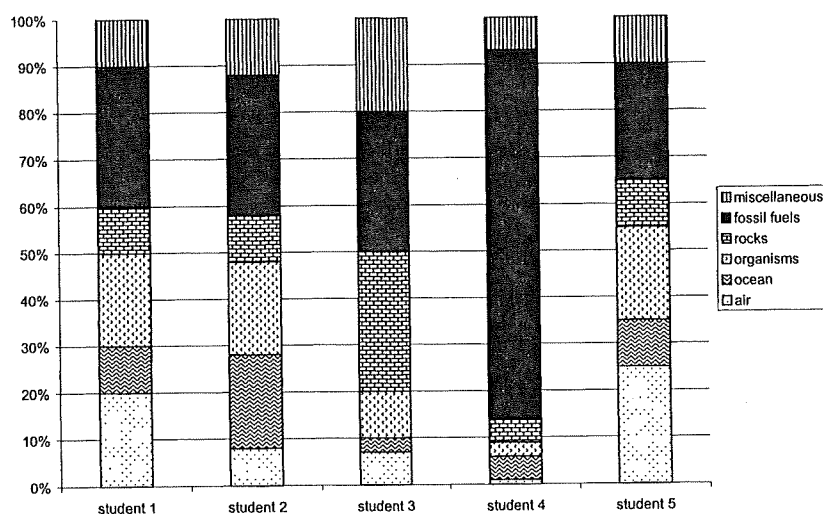


Figure 1. Estimation of the distribution of carbon among the earth subsystems air, ocean, organisms, rocks, fossil fuels and miscellaneous in percentage of the total carbon on earth.

Furthermore, the students have problems with the *relevant relationships* between the elements. In relation to the *fluxes* of carbon the results show that the students have difficulties in seeing the transfer of carbon as a *circular flow*. Some of them describe the fluxes of carbon as a linear flow between the lithosphere and the atmosphere. In this connection the lithosphere is considered an inexhaustible source and the atmosphere an unlimited sink of carbon. In some cases the students describe a closed loop but they reduce it to the relation between the processes photosynthesis and respiration. In this case they focus on an interaction between only two elements of the carbon cycle system, the animals and plants.

Moreover, *processes* which characterise the fluxes of carbon on earth are not used correctly in the carbon cycle context. The tested students were able to describe the gross equation of the processes photosynthesis and respiration. However, they were not able to use these processes in the carbon cycle context. They talked about a carbon transfer from lithosphere to biosphere when "plants eat soil". Decomposition was considered as a carbon transfer from the biosphere

to the lithosphere. In addition, students were able to describe the chemical equilibrium of the carbonate-system. But they did not use this concept in the carbon cycle context. They described weathering as a process which characterises fluxes of carbon into the atmosphere. However, weathering of carbonates and silicates is connected with fluxes of carbon from the atmosphere or the lithosphere to the hydrosphere – in the form of bicarbonate ions ($\text{HCO}_3^-_{(\text{aq})}$).

Moreover, the students do not consider the carbon cycle as being a permanently changing system. The students tested have problems realising *dynamic properties*, such as non-linearity and irreversibility which have determined the transformation of the carbon cycle system in course of earth's history. They explain the development of the carbon cycle system in terms of linear processes. The students deduce a continuous increase of the concentration of CO_2 in the atmosphere since genesis of the earth from the current increase. The students were asked which concentration of carbon was realised in the atmosphere before organisms evolved on earth. One student answered:

"... lower (than today), because ... we burn up quite a bit ... nowadays humans burn up a lot of things ... crude oil and gas ... it is pumped a lot into the atmosphere ... I think, if there are no humans which burn up things, it (the concentration of carbon in the atmosphere) must be lower ... I do not know, whether it was a grandiose difference (between then and nowadays) ... but in any case, I think it is continuously and slowly increased ..."

However, this change is only observable on a historical time scale. Maybe students do not distinguish between individual experiences of the earth as a practically stable system during their lifetime and scientific findings on the history of the earth.

In addition, the students have problems with thinking in *different time scales*. They do not distinguish between long-term processes and short-term processes.

Findings on the basis of system thinking categories show that students have difficulties to perceive the systemic view as a process of modelling. For the students the concept "circular flow" is connected with a carbon atom, that ranges on a circular way through the earth subsystems. If an atom changes between air and water due to diffusion, the students do not perceive a relation between this process and the carbon cycle system. Cross flows are not connected with circular flows.

The questions on prerequisite knowledge were answered surprisingly well by the students. The questionnaire tested knowledge about basic facts as well as problem solving expertise. The students made relatively few mistakes. The basic scientific concepts which are fundamental to understand the carbon cycle are well represented, e.g. gross equation of the photosynthesis or the chemical balance concept. Nevertheless, the five students did not use these concepts in the carbon cycle system context. The preceding instructions did not lead to a decontextualisation.

9. Conclusions

In conclusion, the preliminary study has shown that the students' pre-conceptions of the carbon cycle system are very far from the geo-scientific conceptions. The basic scientific concepts which are fundamental to understand the carbon cycle are well represented. However, the students did not use these concepts in the systemic context of the carbon cycle. The students had difficulties with knowledge transfer. How can the characteristics of earth sciences - system theory and interdisciplinary – solve this problem? On the one hand, system-thinking skills serve for modelling the complexity which is given by the multifarious dimensions of a geo-scientific concept. System thinking skills are used for structuring geo-scientific concepts (Hagel, 1985). On the other hand, a multi-perspective view of a complex scientific content

enhances system thinking. Klieme & Maichle (1994) describe the taking of different perspectives as improving system thinking, as being part of system thinking. Hence, teaching geo-scientific concepts must be supported by system thinking and multi-perspective learning. In contrast, these topics are rarely emphasised in teaching earth sciences at school.

10. Practical guidelines

The learning process, from the pre-instructional concepts to the scientific concepts, must be supported by the learning environment in which it is embedded. The Cognitive Flexibility Theory is an instructional approach to advance knowledge acquisition. It offers fundamental aspects for the design of a constructivistic learning environment (Gerstenmaier & Mandl, 1995). The Cognitive Flexibility Theory emphasises the real-world complexity and ill-structuredness of knowledge domains in, e.g. geo-scientific topics. The theory concentrates on the learning process of advanced learners. For the theory multiple perspectives are significant. The aim of instruction is the induction of multiple knowledge representations to flexible use of knowledge in different contexts. To construct multiple and flexible representations by the learner *one* concept will be taught from different perspectives, at different times, in rearranged contexts and for different purposes (see Spiro et al., 1987; Spiro et al., 1992). These instructions should support the application of knowledge. Complex contents are not oversimplified by the use of reductionist rules or general principles. They are taught in their complexity. The different perspectives present the multiple facets of a concept. Learners represent not only one prototype but also several aspects of a concept. This is necessary for learning heterogeneous concepts. Geo-scientific concepts are multidimensional. Thus, multi-perspective learning is essential in earth sciences education. Non-linear hypertext systems have the power to convey ill-structured aspects of knowledge domains and to promote features of cognitive flexibility in ways that traditional learning environments like textbooks and lectures cannot (Spiro, 1992). The development of system thinking can lead to several types of cognitive representations. Ossimitz (2000) describes several ways of building such representations:

- verbal description
- causal loop diagram
- stock-and-flow diagram
- equation

Particularly graphical illustrations, like causal loop diagrams and stock-and-flow diagrams, are important. These diagrams can serve as mental tools for structuring system-oriented contents, and can thus foster conceptual understanding in science as well as other content areas (Ossimitz, 2002, Stern, Aprea & Ebner, in press). According to Stern et al. drawing diagrams may not only help to integrate complex information, it can also help to reveal the structure of a problem, thus providing a better knowledge base upon which inferences can be drawn. Besides supporting the emergence of conceptual knowledge, they can also offer efficient approaches to solving formal problems, and they may also foster analogical transfer of knowledge across different content areas.

11. Prospects

In addition, a learning experiment about the carbon cycle system was designed. Based on system theory and cognitive flexibility theory computer-assisted learning materials were devel-

oped. Therefore, their structure is a non-linear hypertext containing different content perspectives (e.g. "climate" and "use of resources") of the carbon cycle in a systemic context.

We will investigate the influence of instructions in system thinking and multi-perspective learning on the learning process. Therefore, the learners will be instructed in the self-construction of systemic illustrations (causal loop diagrams, stock-and-flow diagrams), and they will be instructed in changing the perspective of the geo-scientific topic.

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STUDENTS OF HEALTH SCIENCES' EVALUATION OF MEDIA REPORTS OF HEALTH RESEARCH: A NORWEGIAN STUDY.

Sverre Pettersen and Jeanette Solberg
Faculty of Technical and Vocational Teacher Education
Akershus University College (1356 Bekkestua – Norway)
sverre.pettersen@hiak.no

Abstract

Media reports of health science research are a pervasive and important source of new knowledge. Evaluating conclusions found in those reports are an important form of *scientific literacy*. In this paper the types of requests for information made by Norwegian college students studying in four different Health Science programs were examined as they evaluated scientific news briefs. Given the prevalence of news reports about science and the importance of decisions based on scientific research, skill at analyzing these reports critically should be a valued outcome of education in the Health Sciences. This research will help us characterize how knowledge acquired within formal educational settings prepares students to deal with scientific information presented in informal contexts. However, most students generated very few requests for information, accompanied by their high rating of the conclusions of each news brief. The results suggest a need for stronger emphasis on teaching about the 'nature of science' (NOS) in the Health Sciences in Norway.

1. Introduction

There has been an increasing interest in understanding the skills and knowledge students need to critically evaluate articles about science in the popular science press, in newspapers, and in news magazines (Mallow, 1991; Korpan et al. 1994; Korpan et al., 1997; Zimmerman et al., 1998). Evaluation of news reports about scientific research can influence personal or professional decisions and participation in public policy debates about pressing social issues (Collins & Bodmer, 1986; Jacobs, 1982). Reports of scientific research are often brief, sometimes preliminary, and necessarily incomplete. Treatment studies are common in a variety of scientific disciplines and are often reported in the media (Zimmerman et al., 1997; Korpan et al., 1997).

In the late 80's and early 90's, education in the Health Sciences (HS) in Norway was organized into a nationwide college level education system, committing educators to pay special attention to the presentation of *scientific knowledge* in their courses. Consequently, new subjects like *The Philosophy of Science and Research Methods* were implemented into the HS national core curricula. During 1997-2000, all HS adopted new national core curricula. In nursing education, the *biological sciences* received more emphasis in the curriculum. In the curricula of other vocational areas of HS, such as physiotherapy, radiography and social educator education, only minor changes of the science content were made. However, the most pronounced change of these new curricula was that all vocational areas of HS should now contain *The Philosophy of Science and Research Methods* as a *common* subject (6 ECTS-credit points). In the course of the study, HS-students must:

- acquire scientific insight and scientific methods in order to read research reports and utilize research findings in their work.
- learn how to explain their actions to patients or clients, and to co-workers and employers.
- learn how to carry out project work and document their work.

Important topics are:

- the consequences of different directions in the philosophy of science in the area of health and social work
- health and social work as practical work, with an emphasis on concepts like theory, empiricism and practical training
- constructive criticism of academic research, theory and practical work, and textual criticism
- general requirements for defining problem areas
- learning various methods for collecting and handling data, and various types of report making
- research ethics for health and social work, with an emphasis on informed consent (KUF, 2000)

Most of these goals were also present in former editions of the various intended curricula of HS, and they also reflect goals of *scientific literacy* (Driver et al., 1996). Scientific literacy may be manifested in a variety of skills, including identifying problems for investigation, formulating hypothesis, designing and conduction research, and evaluating evidence and conclusions (Alberta Education, 1995; Roberts, 1995). With this study, I have investigated to what extent HS-students (in their final 3rd year) of the following vocational categories: Nursing, Physiotherapy, Radiography and Social Educator, have the capability of making a

scientific assessment of published *health claims*. The following *hierarchical taxonomy* for classifying HS-student questions and knowledge about scientific research was applied:

Table 1. The Hierarchical Taxonomy for classifying questions and knowledge about scientific research (Korpan et al. 1994).

Topic Code Categories	Description
<i>Social Context</i>	Information about the prestige and bias related to <i>who</i> did the research or funded it and <i>where</i> it was conducted or published
<i>Theory/Agent</i>	Information about <i>why</i> the reported effects might have occurred, including questions about the properties of the putative causal agent and/or possible underlying mechanisms
<i>Method</i>	Information about how the research was conducted, including such topics as research design and procedures
<i>Data/Statistics</i>	Information about precisely <i>what</i> was observed in the reported study or about statistical tests
<i>Related Research</i>	Information about whether the findings have been replicated or fit other results
<i>Relevance</i>	Information about the importance or applicability of the findings

Students' requests can be telling reflections of what HS-educators have taught them or failed to teach them about "the nature of science" (NOS). Curriculum goals of the joint subject *The Philosophy of Science and Research Methods* in HS are highly equivalent to teaching goals of NOS (Hogan, 2000). In broadest terms, the meaning of the concept *nature of science* (NOS) is those ideas someone has *about* science, rather than scientific knowledge:

- how the body of public knowledge called science has been established and is added to.
- what our grounds are for considering it reliable knowledge.
- how the agreement which characterizes much of science is maintained.

The latter involves an understanding of the social organization and practices of science (social context), whereby knowledge claims are transmitted into public knowledge, and of the influence of science or the wider culture - and vice versa. Issues surrounding the application of scientific knowledge in practical situations are an important focus, as the lack of consensus about these invites a re-evaluation of claims about the status of particular kinds of knowledge. A related issue is about the purpose of scientific work (in seeking explanation) and the boundaries of its areas of interest. Another, quite distinct argument that an understanding of the NOS is useful underpins the so-called "process approach" to science. This identifies the NOS with a method of inquiry, through claims, for example, that the essential characteristic of education in science is that it induces students to the method of science. In this view, science is portrayed as a powerful, and quite general, method of inquiry that can be learnt and then used in a wide range of other contexts, both scientific and non-scientific (Driver et al., 1996).

Graduates of HS are very likely to become involved in occupations in which they are exposed to reports of scientific research, lay health claims, pseudoscience and alternative medicine epistemology (Sampson, 1995). The HS-students performance in a scientific assessment test of published health claims probably provides one indication of the success, or failure, of the teaching of *The Philosophy of Science and Research Methods* in HS in preparing graduates to evaluate new scientific and health claiming information critically.

My research question was:

- Do the year three students of the four Health Sciences; Nursing, Physiotherapy, Social Educator, and Radiography (HS-students) have the capability of making a (satisfactory) scientific assessment of published health claims?

At the college level, *science* - and especially the *biological sciences*, is the “common denominator” in all vocational areas of HS in Norway. The *biological sciences* consist of science subjects such as physiology, microbiology and pathology. The importance of the *biological sciences* in HS is probably indisputable, especially in nursing, physiotherapy and radiography. However, claims of *social science* increasingly displacing science in international health education have been put forward by several investigators, for instance by Trnobranski (1996) who has called attention to the risk of *omitting* the teaching of the epistemology and methodology of science, which still has a large influence on new knowledge evolvement in the HS. Of a total of 180 credits in a HS college bachelor degree, the *biological sciences* in Nursing education seem to have 45 credits, in Physiotherapy 72 credits, in Social Educator 21 credits, and in Radiography education 45 credits (based on my own curricula analyzes of KUF, 2000). The curriculum of the Norwegian Social Educator education highly resembles the curriculum of Nursing education, but pays special attention to the caring and nursing requirements of mentally retarded persons integrated in society.

2. Research design and Method.

2.1- The development of the “News Brief Assessment Test”.

Four fictitious health-claims containing news briefs were created. Although these four news briefs are fictitious, they all reflect a typical content and format standard of a real health claiming news brief found in each of two major newspapers in Norway during 1999-2000. A total of 88 news briefs were collected and analysed, regarding their content of scientific topic codes and structure. As in the Canadian studies of Korpan et al. (1994), and Korpan et al., (1997), Social Context and Method were most frequently described, while Relevance, Data/Statistics, Theory/Agent and Related Research, were, in decreasing order, less frequently present. The standard structure of a Norwegian real news brief was slightly different from the Canadian standard (Korpan et al. 1997, Solberg, 2002). Therefore, the Norwegian fictitious news briefs ended up having the following format: (a) an initial conclusion that the research finding is important; (b) researchers report this finding; (c) a general concern or issue is described; (d) an independent group hails this research finding. Two newspaper journalists approved that these following fictitious news briefs were fairly similar to a real news briefs' content and structure.

Table 2. The Four Fictitious News Briefs.**DRUG AGAINST SMOKING**

Nicotinend is an important drug, which makes you quit smoking.

American scientists have reported that the use of a new drug called Nicotinend, has stopped the urge for cigarettes among health professionals. Lately, the numbers of smokers in this group have largely increased. The Council of Tobacco Health Problems has hailed this important research finding.

HIGH VOLTAGE POWER LINES CAUSE LEUKAEMIA

Living close to high voltage power lines (HVPL) is an important cause of child leukaemia.

Norwegian scientists have recently reported that children living close to HVPL have higher risk of developing leukaemia than others living far away from such lines. In sub-urban areas, where HVPL have been put up, the number of child leukaemia incidents, are shown to increase. The Leukaemia Children Parents' Organization has hailed this important research finding.

THERAPEUTIC TOUCH RELIEVES PAIN

Using Therapeutic Touch is an important treatment of migraine.

British scientists have reported that people suffering from migraine receiving the Therapeutic Touch treatment experienced a noticeable pain relief. Intensive and durational headache are problematic for these people. The Migraine Association has hailed this important research finding.

PHYSICAL TRAINING CUTS BACK ON MEDICATION

To reduce the amount of drugs used by people suffering from manic depression, physical training is important.

Swedish scientists have reported that regular physical training could reduce manic depression people's need for medication. Lately, the extensive drug consume in this group of people, has been of great concern to the national mental health authorities. The Mental Illnesses Research Support Association has hailed this important research finding.

Deliberately, these four fictitious news briefs do not contain any of the scientific topic codes mentioned in Table 1. Intentionally, the health related concepts and content applied in these briefs requires scientific knowledge, which all four HS educations should be quite familiar with.

The two questions following each of these four fictitious news briefs were:

- How likely do you think that the conclusion (in **bold letters**) is true?
- Suppose that the **conclusion** (in **bold letters**) is very important to you and that you must determine whether it is true. What additional pieces of *information*, if any, would you like to have about the researchers' report to decide whether this **conclusion** is correct? Please list each point you make separately.

In the first question, Likert scaled alternative answers were available (1= not very likely; 5 = very likely). Seven numbered places for requests were provided for each news brief in the second question, with additional space available if needed. The coder's task was to reach each request and assign the scientific topic code that most clearly represented the student's request for information. Three coders independently scored the data for the pilot and this present study. The reliability of their judgement across the topics was 97 %.

2.1.1- The development of the student questionnaire.

The "News Brief Assessment Test" initiated the HS-student questionnaire. Transcriptions and analysis of open-ended interview answers from student samples (N = 13) and samples of *The Philosophy of Science and Research Methods* teachers (N = 6) of the four HS, founded the basis of the development of the rest of the student questionnaire. Two PhD students of science

education performed peer review providing some content and lay-out adjustments. 6 master students of Nutrition, Health and Environmental Sciences, and six of their Philosophy of Science teachers volunteered upon invitation to participate in a pilot study of this 254 items questionnaire. Analysis of the pilot studies resulted in a few linguistic changes of this survey instrument. In addition to questions about the HS-students age, gender and pre-college background, the questionnaire also contained several Likert-scaled attitude questions and statements, which were mainly meant for other research purposes.

2.2- The questionnaire handout procedure and response rate.

During the spring of 2001, all Norwegian colleges of HS were invited to participate in this study. On permission from the positive responding HS-colleges, a paper copy of the HS-student questionnaire was sent by post to each student's home address. The completed form should be returned to sender similarly (a postage paid envelop was included in the dispatch). Information of the research project aims and questionnaire guidelines were included in the questionnaire dispatch. All returned questionnaires were treated anonymously.

Table 3. The fraction of HS-colleges who voluntary participated in this research study, and the corresponding response rate of the HS-student questionnaire.

HS-students:	HS Colleges in Norway	Eligible Student Population (P)	Participating HS colleges (Pa)	Handout Question- naires (H)	Returned Question- naires (R)	Response rate (H/R) %	R/P %
Nursing	31	3117	16	1266	317	25	10
Physiotherapy	4	296	3	244	63	26	21
Social Educator	8	592	5	306	59	20	10
Radiography	3	128	2	105	34	33	27

Because of the relatively low response to the letter of invitation to participate in this study, all students of the positive responding HS-colleges (Pa) were included as samples. Five college deans of nursing education and one of physiotherapy education answered that they did not want the college students to participate in this study, mainly because of organization staff shortages. One college of radiography education was recently established, and had not any third year students to offer. The rest of the college deans did not answer to the letter of invitation (after two applications). Table 3 shows that the response rate of the student questionnaire was rather low; only 20-33 % were collected after two applications. The postal communication of the HS-student questionnaire, and a minor subject interest (and skills?) among the students, can possibly explain the low response rate. However, questionnaires from all the non-probabilistic students samples (H) were returned (R). Only highly motivated (and skilled?) HS-students have probably participated in this study. Therefore, extensive use of sample statistics and result generalizations, have been avoided.

87 men and 386 women responded to in the HS-student questionnaire.

For statistical analysis, SPSS 11.0 for Windows was applied. The level of significance (p -value) was set to 0,01 in this study.

3. Results.

Table 4. The percentage distribution of HS-students' immersion in six science subjects during their high-school period.

Responding students	----- High-School Science Courses -----					
	1 st Year BIOLOGY %	2 nd Year BIOLOGY %	1 st Year PHYSICS %	2 nd Year PHYSICS %	1 st Year CHEMISTRY %	2 nd Year CHEMISTRY %
Nursing (N = 317)	20	20	9	4	13	8
Physiotherapy (N = 63)	37	41	35	22	43	30
Social Educator (N = 59)	3	10	2	2	2	2
Radiography (N = 34)	24	24	18	12	18	12

In Table 4, the 2nd year courses are more advanced than the corresponding 1st year courses. Although immersion in science is not a compulsory entrance requirement for HS education in Norway, the Physiotherapy and Radiography students are the most science-immersed group of these HS-students. As a result of a selective Physiotherapy student intake (a restricted number of places), only the applicants with the best high-school marks are accepted (personal communication with a dean of Physiotherapy education). In my study, this seems to be students with a high-school immersion in science. Some college students of Radiography are university science study "drop-outs" (12 %). In Nursing and Social Educator education, students *without* high-school subjects' related qualification for college and university studies, have been given entrance to HS education after evaluation of their previous health work practice (10 % and 10 %, respectively).

Table 5. The HS-students answers to the question: "How likely do you think that the conclusion to each of the four news briefs is true?"

Responding students	----- NEWS BRIEFS -----							
	<i>Quit smoking</i>				<i>High Voltage Power Lines</i>			
	% not undecided likely			Mean ± S.D.	% not undecided likely			Mean ± S.D.
Nursing (N =317)	22	35	43	(3,21 ± 0,93)	11	32	67	(3,58 ± 0,83)
Physiotherapy (N = 63)	19	53	28	(3,10 ± 0,78)	14	44	42	(3,25 ± 0,74)
Social Educator (N =59)	29	31	40	(3,05 ± 0,96)	14	22	64	(3,56 ± 0,79)
Radiography (N = 34)	6	42	52	(3,48 ± 0,67)	15	35	50	(3,47 ± 0,90)

Responding students	<i>Therapeutic Touch</i>				<i>Physical Training</i>			
	% not undecided likely			<u>Mean ± S.D.</u>	% not undecided likely			<u>Mean ± S.D.</u>
	likely	likely	likely		likely	likely	likely	
Nursing (N =317)	4	16	80	(4,00 ± 0,77)	2	9	89	(4,18 ± 0,67)
Physiotherapy (N = 63)	5	20	75	(3,85 ± 0,79)	0	0	100*	(4,43 ± 0,50)
Social Educator (N =59)	14	29	67	(3,53 ± 0,98)	3	5	92	(4,29 ± 0,72)
Radiography (N = 34)	24	26	50	(3,29 ± 0,87)	0	15	85	(3,97 ± 0,52)

In Table 5, 1+2 and 4+5 Likert-valued answers were recoded into two “dichotomised” variables; “not likely” and “likely” (this explains the 100 % “likely” answers in the table box marked by *, and the corresponding mean of 4,43). The distribution of answers show that the HS-students thought it was “likely” that the conclusion to each of the four news briefs was true. A One-way ANOVA-test revealed that there were significant differences between the four HS-student group answers to the news briefs about *Therapeutic Touch* and *Physical Training* ($p < 0,01$). All four HS-student groups were most sceptical to the conclusion of the *Quit smoking*-news brief, whilst least sceptical to the conclusion of the news brief of *Physical Training*.

Table 6. The percentage of HS-students (N = 473) requesting between 0-6 scientific topic code categories to each of the four fictitious news briefs.

-----FICTITIOUS NEWS BRIEFS-----

The Number of Scientific Topic Code Category Requests	<i>Quit smoking</i>	<i>High Voltage Power Lines</i>	<i>Therapeutic Touch</i>	<i>Physical Training</i>
	(%)	(%)	(%)	(%)
0	33	34	43	47
1	28	33	29	29
2	23	21	19	17
3	13	10	7	6,6
4	3	1,8	2	0,4
5	0	0,2	0	0
6	0	0	0	0

33-47 % of the HS-students did *not* request *any* information in the four news briefs (Table 6). Just 0,4-3 % of the students requested four scientific topic codes. On average, Physiotherapy and Radiography students requested more scientific topic codes to the four news briefs than the Nursing and Social Educator students (not significant). Only 45-56 % of the HS-students

who answered “not likely” to the question in Table 5 concerning the four news briefs’ conclusions, requested scientific information in these news briefs. However, 36-42 % of the “likely”-answering students in Table 5 did also requested scientific information. Few students requested more than two scientific topic codes in each of the four news briefs (Table 6). HS-students, who have immersed themselves in science during their high-school period (Table 4), HS-students, who had a university or college background (N = 130), and HS-students, who had completed the Norwegian university compulsory course of *The History and Philosophy of Science* (N = 107), requested more scientific topic codes than HS-students who have not (not significant). The most frequent requested scientific topic codes are shown in Table 7 below:

Table 7. The percentage of HS-students (N = 473) requesting each of the six scientific topic code categories to each of the four fictitious news briefs.

-----FICTITIOUS NEWS BRIEFS-----					
The Topic Categories	Scientific Code	<i>Quit smoking</i> (%)	<i>HVPL</i> (%)	<i>Therapeutic Touch</i> (%)	<i>Physical Training</i> (%)
Social Context	7	7	7	5	4
Theory/Agent	33	33	30	29	22
Method	28	28	22	26	26
Data/Statistics	29	29	37	18	19
Related Research	6	6	7	5	4
Relevance	2	2	2	1	1
Other (not 'scientific')	22*	22*	6	9	7

As in the Canadian study of Korpan et al., 1997, where university students of psychology were used as samples, Table 7 shows that the Norwegian HS-students most frequently requested information about *Theory/Agent*, *Method*, and *Data/Statistics*. Questions about *Social Context*, *Related Research* and *Relevance*, were less frequently requested. 22 % of the HS-students requested information about *side effects* (*) of the drug, which was mentioned in the *Quit Smoking* -news brief. The side effects are very often emphasised in media reports of medical treatments, and sometimes even more explicitly described than the direct effect of the medicine itself (Moynihan et al., 2000).

Table 8. “To what extent did you apply *scientific journal articles* when you learned how to “*read research reports*?”

Responding students	In <i>The Philosophy of Science</i>				In <i>Research Methods</i>				
	seldom	% neither/ nor		often	Mean ± S.D.	seldom	% neither/ nor		often
Nursing (N =317)	49	20	31	(2,70 ± 1,15)	45	23	36	(2,76 ± 1,13)	
Physiotherapy (N = 63)	33	23	44	(3,15 ± 1,21)	29	22	49	(3,25 ± 1,11)	
Social Educator (N = 59)	43	29	28	(2,76 ± 1,27)	42	25	33	(2,79 ± 1,19)	
Radiography (N = 34)	74	15	11	(2,07 ± 0,96)	77	13	10	(2,00 ± 0,93)	

In Table 8, 1+2 and 4+5 Likert-valued answers were recoded into two “dichotomised” variables; “seldom” and “often”. A One-way ANOVA-test revealed that the responding Physiotherapy students had significantly higher means than the other three educational categories ($p < 0,01$). Students of these three HS-educations seem to have applied scientific journal articles quite “seldom” in order to learn how to read scientific reports (43-74 % in *The Philosophy of Science*, and 42 –77 % in *Research Methods*).

In seven analysed Norwegian textbooks of *The Philosophy of Science and Research Methods* the framework of a scientific enquiry is described. However, *qualitative* research methods are far more emphasised in these books than *quantitative* research methods, accordingly (Solberg, 2002). The teachers might well have applied journal articles of qualitative research in their teaching, whilst the students probably have requested more examples of quantitative research based articles (Table 8).

Table 9. “To what extent did you apply *scientific journal articles* when you learned about “*textual criticism*”?”

Responding students	In <i>The Philosophy of Science</i>				In <i>Research Methods</i>				
	seldom	% neither/ nor		often	Mean ± S.D.	seldom	% neither/ nor		often
Nursing (N =317)	48	22	30	(2,39 ± 1,17)	56	18	26	(2,46 ± 1,12)	
Physiotherapy (N = 63)	33	29	38	(2,96 ± 1,20)	29	27	44	(3,13 ± 1,13)	
Social Educator (N = 59)	57	20	23	(2,45 ± 1,14)	56	18	26	(2,56 ± 1,25)	
Radiography (N = 34)	79	10	11	(1,93 ± 0,96)	73	12	15	(2,00 ± 1,17)	

The “dichotomised” recoding of the five variable Likert scaled answer values was also performed in Table 9. A One-way ANOVA-test showed that the responding Physiotherapy

students had significantly higher means than the other three educational categories ($p < 0,01$). In order to learn about “textual criticism”, students of these three HS-educations seem to have applied scientific journal articles quite “seldom” (48-79 % in *The Philosophy of Science*, and 56-73 % in *Research Methods*).

Table 10. “To what extent did you apply *media reports* (newspaper or weekly magazine articles) when you learned about “textual criticism”?”

Responding students	In <i>The Philosophy of Science</i>			Mean \pm S.D.	In <i>Research Methods</i>			Mean \pm S.D.
	% seldom neither/ often				% seldom neither/ often			
		nor				nor		
Nursing (N =317)	80	10	10	(1,82 \pm 1,03)	79	10	11	(1,81 \pm 1,02)
Physiotherapy (N = 63)	76	13	11	(1,98 \pm 1,05)	72	11	17	(2,13 \pm 1,15)
Social Educator (N = 59)	80	13	7	(1,70 \pm 1,02)	79	13	8	(1,70 \pm 0,97)
Radiography (N = 34)	89	7	4	(1,43 \pm 0,76)	91	6	3	(1,41 \pm 0,76)

As in Table 9, the “dichotomised” recoding of the five variable Likert scaled answer values was also performed in Table 10. A One-way ANOVA test showed that the responding Physiotherapy students had significantly higher means than the Radiography students ($p < 0,01$), but most HS-students answered that various media reports were (very) “seldom” applied as material when learning about “textual criticism” (76 - 89 % in *The Philosophy of Science*, and 72-91 % in *Research Methods*). However, reading media reports of scientific research is a common means of acquiring information *about* science, and evaluating conclusions found in those reports is an important form of *science literacy* (Norris & Phillips, 1994). Evaluation of news reports about scientific research can probably also influence personal and professional decisions (for instance product safety and medical treatment) and participation in public debates about pressing health issues (for instance gene technology). Therefore, the HS-students’ capability to perform a critical assessment of scientific news brief is important.

Table 11. “ It’s necessary for me to learn about *the content criteria of scientific texts*.”

Responding students	Answer Distribution			Mean \pm S.D.
	% disagree undecided agree			
Nursing (N =317)	10	28	62	(3,62 \pm 0,86)
Physiotherapy (N = 63)	10	24	66	(3,66 \pm 0,85)
Social Educator (N = 59)	9	20	71	(3,80 \pm 0,90)
Radiography (N = 34)	9	24	67	(3,67 \pm 0,78)

As in Table 10, the “dichotomised” recoding of the five variable Likert scaled answer values (“strongly disagree”= 1; “strongly agree”= 5) was also performed in Table 11. The need for teaching the content criteria of scientific texts is explicitly expressed by the HS-students. Although, the criteria are synonymous with the six scientific topic codes of Korpan et al. (1994) in this study, these or any other similar criteria are *not* described in *any* of the six analysed HS-textbooks of the joint subject *The Philosophy of Science and Research Methods* (Solberg, 2002).

4. Discussion.

Health-related information is widely available to the public. One forum for that information, the scientific news briefs, can provide a valuable service by educating the general public about important health-related issues. However, these columns can potentially harm readers if the advice or information provided is incomplete, inappropriate or misleading. This is a concern because health advice columns attempt to deal with complex issues in a brief format, they are read by a large heterogeneous audience, and they have often status of being *science-in-the-making* rather than *ready-made-science* (Millar, 1997). Evaluating conclusions found in those reports is an import form of science literacy. The HS-students’ capability of making a scientific assessment of published health claims is probably also very important knowledge and skills needed in their future work practice. The teaching goals of the HS joint subject *The Philosophy of Science and Research Methods*, underpins this need. As an attempt to explore HS-students science literacy and their knowledge and skills acquired by these teaching goals, I examined the requests for information made by HS-students as they evaluated conclusions in four fictitious, but plausible scientific news briefs.

The low response rate of the HS-student questionnaire calls for reservations regarding the generalisation of the results to the national populations of HS-students. However, taken into consideration that the respondents are probably the most subject motivated HS-students of the participating samples, the mode of just one scientific topic code request across all four news briefs, and that one third of the students made no requests, the results suspect that the teaching of critical assessment of published health claims have probably not been emphasised in the four HS-educations studied, especially when publications invoke a *science* based methodology. The students probably do *not* know *what* to ask for, aside from the three scientific topic code categories, Theory/Agent, Method, and Data/Statistics, which were most often requested, but only by one third of the HS-students. Few HS-students requested information about Social Context and Related Research. These findings may reflect a lack of sensitivity to the fact that scientific research takes place within a social community that can influence the selection of research questions, the interpretation of results, and the acceptance of research findings and theory.

Why people have a tendency to uncritically hail the conclusions of *most* newspaper science research reports is probably subject to further research. Although the four fictitious news brief topics were plausible, the framework of this research was deliberately very insufficiently described. Alarming, the majority of the HS-students thought that the conclusion to each of the four news briefs was “true”. In science publications, conclusions are closely linked to detailed descriptions of (at least) method and theory. The presentation of news brief conclusions with such limited Research Methods information attached, one could expect that HS-students’ showed more professional vigilance on these matters.

In several fields of HS work practise, *pseudoscientific* information material is available (Sampson, 1995). However, all the interviewed HS-students (N = 13) expressed that they had not received text examples of this concept during the teaching of *The Philosophy of Science, Research Methods*, or the *biological sciences*. In two other separate questionnaires, answers from teachers of these subjects could largely confirm these students' claim (the author's unpublished results). In future work practise, the HS-students' ability to reveal pseudoscientific health claims is probably an important skill for maintenance of HS-professionalism.

HS-students, who have immersed themselves in high-school science (especially the responding Physiotherapy students) requested more topic code categories to all news briefs than student with no such immersion (not significant). Interestingly, evaluation of scientific publications is not an item of the Norwegian high-school science curriculum (KUF, 1999). However, my results suggest the introduction of teaching such knowledge and skills to Norwegian high-school students following the compulsory science course in order to improve their science literacy.

To achieve HS-student critical thinking and assessment skills for future vocational professionalism, HS-teachers, especially of the joint subject *The Philosophy of Science and Research Methods*, should probably explicitly apply newspaper and weekly magazine articles of scientific research as teaching material. By combining these materials with scientific *journal* articles, and through the use of the hierarchical taxonomy and procedures developed by Korpan et al. (1994) to categorize questions about scientific research, four complementary goals of *science* in the HS, can be achieved: a) HS-students will be able to recognize any of the (six) scientific topic code categories necessarily described in reports of science research; b) non-scientific or pseudoscientific health claims in the mass media can be revealed and critically discussed; c) HS-students will attain epistemological knowledge of science, and d) HS-students will learn essential aspects of the NOS. HS-students' achievement of knowledge *about* science implicates that their teachers of *The Philosophy of Science and Research Methods* are in good command of these issues.

Based on my research results, specific teaching material with emphasis on critical assessment of published health claims, should be developed, tested and assessed.

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ENVIRONMENTAL EDUCATION

OUTDOOR ECOLOGY EDUCATION AND ITS INTERACTION WITH ASPECTS OF ENVIRONMENTAL PERCEPTION

Franz X. Bogner, Didactics of Biology, Institute of Natural Sciences, University of Education Ludwigsburg (Ludwigsburg, Germany)
Bogner_Franz@ph-ludwigsburg.de

Abstract

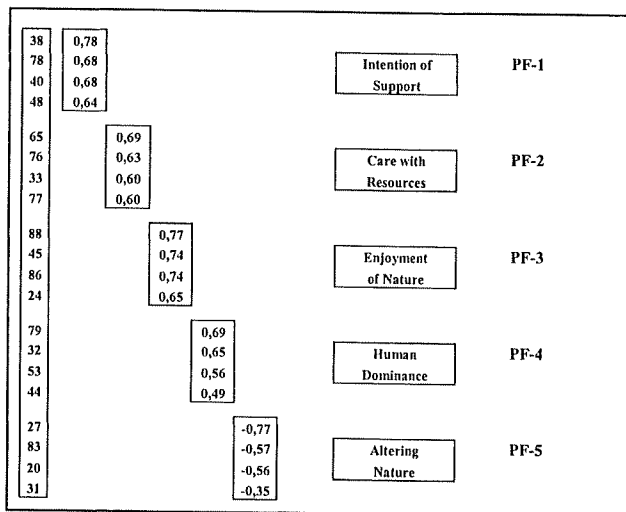
Four empirical survey studies find support for the hypothesis that participation in residential education programmes enhances facets of pupils' environmental perception. The field programmes in question covered ecological aspects of a complex ecosystem (study-1, study-4), conservational elements focussing on an endangered bird species (study-2) and environmental protection as well as conservational problems (study-3). Using a two stage sampling design in a pre-post-treatment evaluation (post-test delayed for a one-month period after participation) participating pupils (N=333 [study-1]; N=226 [study-2]; N=151 [study-3]; N=258 [study-4]) responded twice to the same perception questionnaire (whose primary and secondary factorial structure previously was developed with a N=4500 European sample; see Bogner & Wiseman, 1999; 2002). The pre-post-test survey showed significant differences in at least two of the five primary factors but divergent ones within the three specific studies. In the fourth study an expanded questionnaire with eight primary factors was first pilot-tested and then introduced in an intervention survey. When a change in preservational and/or utilitarian preferences was surveyed, all shifts signalled an increase of sensitivities. Pre-post-tested control groups unveiled none effect.

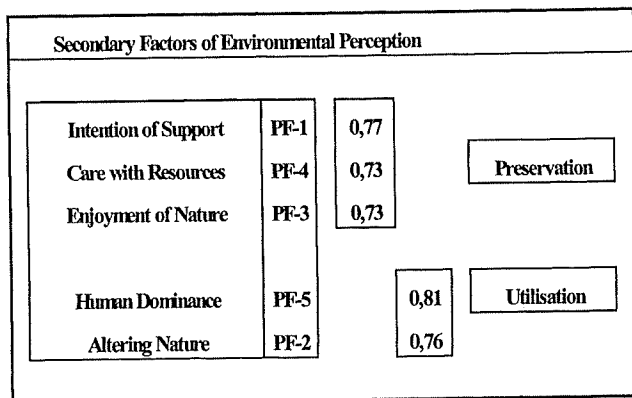
1. Introduction

Field courses and outdoor ecological education programmes nowadays are standard practice in the experience of many pupils and often are assumed to be synonymous with fostering environmental literacy and supporting a willingness to take environmental action. This is either due to a teaching tradition in teaching ecology favouring outdoor experiences or due to the common belief that current environmental problems increasingly require educational outdoor settings to engage adolescent concern for the environment (e.g. Dunlap & Hefernan, 1975; Falk *et al.*, 1978; Lucas, 1980; Hungerford & Volk, 1990; Ryan, 1991; Armstrong & Impara, 1992; Leeming *et al.* 1995).

Measuring the environmental perceptions of adolescents requires one to draw on several research fields. A well-known problem of empirical measurement lies in its measurability and its standardisation (Sia *et al.*, 1985; Hines *et al.*, 1987; Schahn & Holzer, 1990; Newhouse, 1991; Leeming *et al.*, 1993). Adolescent attitudes and values towards nature and environment are rarely a focus of psychometric approaches. For instance, Leeming *et al.* (1993, 1995) extracted in their meta-analysis no single instrument for which validity and reliability were entirely proven; the authors expressed the desperate need for better evaluation techniques. In general, due to the absence of rigorous psychometric techniques, measurement instruments remain invalid and fail to provide any reliable basis for evaluation.

Table 1. Primary and secondary factor pattern of the environmental perception scale (retaken from Bogner & Wiseman, 1999) (loading scores below 0,3 are not shown).





Consequently, a factorised item battery was developed by Bogner & Wilhelm (1996) and subsequently revised through its application to various pupil populations in Western Europe (Bogner, 1998; Bogner, 2000; Bogner & Wiseman, 1996, 1997, 1998; Bogner *et al.* 2000). Finally, by means of factor analyses and structural equation modelling, a scale valid for the entire European sample was identified (Bogner & Wiseman, 1999, 2002) (see Table 1). This scale quantifies sections of ecological attitudes (scored with a Likert-scale from 1 to 5) measured by first-order factors and presented by a theory encapsulating ecological attitude-sets in two orthogonal higher-order factors: Utilisation (U) and Preservation (P). The secondary factor of U consists of two primary factors (composed of 4 items each): Human Dominance, Altering Nature while P contains three primary factors (also composed of 4 items each): Care with Resources, Intent of Support, Enjoyment of Nature.

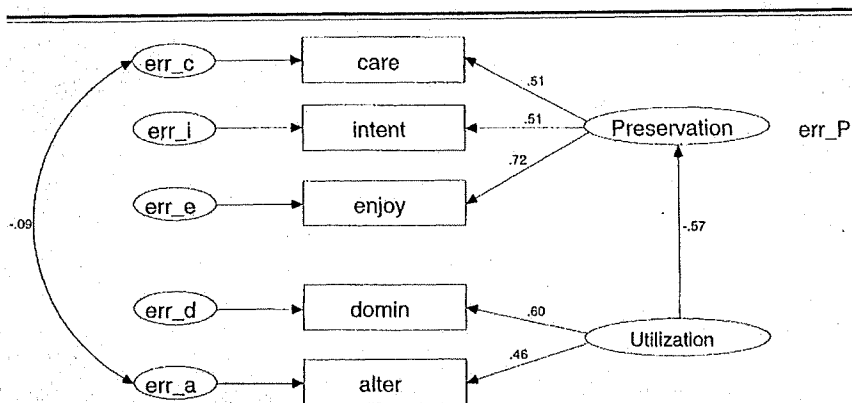


Figure 2
Our final model and the standardized estimates of the various coefficients, including correlations between specific (error) terms. $\chi^2 = 2.80$, $df = 3$, $p = .42$.

Figure 1. Linear structural model of the environmental perception scale which factor analysed structure is shown in Table 1 (retaken from Bogner & Wiseman 1999).

Two cross validation studies shed additional light on our measurement approach. The first one included personality variables in terms of risk-taking. Six primary factors were taken into account: Positive Risking, Ambivalence, Thrill in Gambling, Ineffective Control, Effective Control and Anger reaction (Bogner *et al.*, 2000). The analysis of the correlation matrix between the "Risk-taking" domain and the one of Environmental Perception revealed two antagonistic profiles: The high scorer on "Preservation" is the controlled and cautious gambler while the "Utiliser" profile reflects a contrary image, not enjoying unpredictable risks, reacting with Anger when risks fail or failing to control the own risk-taking behaviour (Bogner *et al.*, 2000). The second study in this context also integrated personality variables, the Eysenck's personality factors of "Psychoticism" (P), "Extraversion" (E), "Neuroticism" (N) as well as a social desirability response set "Fake good" (L) (Wiseman & Bogner 2002). "Neuroticism" was related to "Preservation", "Psychoticism" to "Utilisation" both providing eminently sensible correlations with external variables and confirming the two-dimensional representation of ecological values. This Model of Ecological Values (MEV), therefore, was formulated as "*Ecological Values are determined by one's position on two orthogonal dimensions, a biocentric dimension that reflects conservation and protection of the environment (Preservation) ; and an anthropocentric dimension that reflects the utilisation of natural resources (Utilisation)*" (p.5; Wiseman & Bogner, 2002).

2. Research design and method

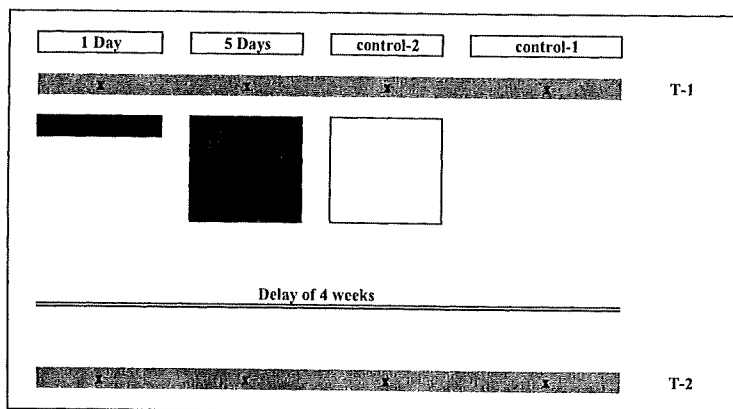


Figure 2. Design of the intervention study of Bogner (1998) (as well as of the two subsequent ones in terms of treatment and control-arrangement).

The design of all four intervention studies involved an experimental and a control group. All surveyed programmes consisted of a variety of conceptually oriented outdoor activities guided by the principle of original encounter and focussing on ecology, biodiversity and geology. A basic principle of the educational programmes comprises affective elements and hands-on activities as well but favours in a central manner cognitive fundamentals (for details see Bogner 1998, 1999, 2002).

All statistical comparisons between the pre- and the post-test factor scores were based on the counts of individuals instead of cohort ones. Comparison calculations for all subdivisions were provided using Wilcoxon's matched-pair signed ranks tests.

3. Results and Discussion

The factor scores derived from the pre-test and post-test questionnaire of the experimental group yielded shifts in two (study-2 and -3) and four (study-1) of the five primary factors ($p < 0.001$). The factors involved were primary factors of the utilitarian and the preservational primary factor set as well. However, remarkable differences within the three studies prevail. Firstly, the study-1 within a German National park (N=333; Bogner, 1998) focussed on a face-to-face experience of nature detailing the satisfying result that long-term variables such as 'Care with Resources' were affected; a one-day alternative with similar settings did not reach the tested variables (Bogner, 1998). Secondly, the study-2 within Swiss schools focussed on a conservational programme featuring an endangered migratory bird (N=226; Bogner, 1999). Participation in the programme yielded a shift in two preservational primary factors but none in the utilitarian ones. Thirdly, the study-3 (N=151; Bogner, 2002), a extra-curricular educational unit with a cognitive outdoors point of convergence, focussed on a regional environmental protection problems including structured and participatory learning activities. Participation in this programme resulted in shifts in the utilitarian sector only rather than affecting the preservational one.

Table 3. Comparison of empirical survey results of three previously published intervention studies based on the same factorised item questionnaire

	Care	Intent	Enjoy	Domin	Alter
Bogner (1998a)	*	*	*		*
Bogner (1999)		*	*		
Bogner (2002)				*	*

Due to identical designs and empirical identical instruments, but different educational programmes, a comparison of the outcome of all three studies is feasible (Bogner, 1998, 1999, 2002). All programmes favoured outdoor settings and lasted for at least four days. It is an interesting finding that all three experimental treatments were able to increase some of the surveyed primary factors, at least, and it can be stated that educational programmes can shift adolescent preservational and utilitarian preferences. However, three empirical survey studies might not yet provide a sufficient empirical basis to allow a final answer to the research question as to which kind of details an outdoor programme has to include in order for the programme to provide a specific desired shift in adolescent attitudes.

In general, correlation scores counted up to 0,66. Additionally, the more a pupil liked school, the greater was his/her agreement with preservational primary factors 'Care with Resources' (0,25), 'Intent of Support for Conservation' (0,29) and 'Enjoyment of Nature' (0,24) as well as was his/her disagreement with 'Human Dominance' (-0,24). Furthermore, the programme rating score showed a significant correlation to 'Enjoyment of Nature' (0,36); thus, the better a pupil rated the programme, the more he/she enjoyed nature.

Table 4. Secondary factor structure of eight primary factors subjected to a factor analysis revealing the (positive) preservational and the (negative) utilitarian domain.

	Utilisation	Preservation
Man Over Nature	0.82	
Altering Nature	0.75	
Human Dominance	0.57	
Balance of Nature	-0,44	
Intent of Support		0,77
Enjoyment of Nature		0,62
Limits to Growth		0,58
Care with Resources		0,46

In the fourth study, two further aspects were acknowledged: Firstly, the “New Environmental Paradigm” (NEP) additionally was integrated (Dunlap & Van Liere, 1978), providing a set of eight primary factors which consistently loaded within the described dichotomous pattern of the two secondary factor domains, the positive one (preservation) and the negative one (utilisation). Secondly, the education programme was adjusted in order to meet explicitly the need for developing children’s awareness of human impact on the environment.

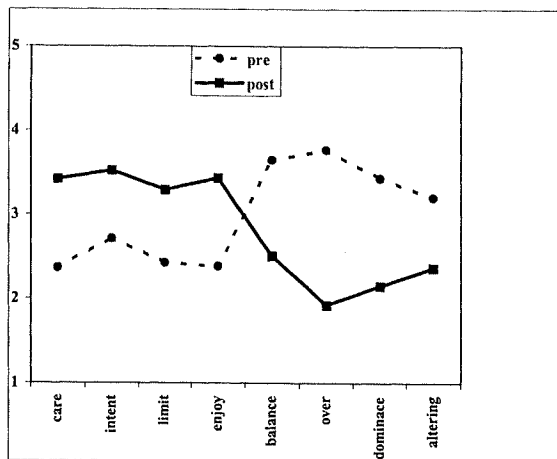


Figure 3. Comparison of pre-test and post-test scores of the eight primary factors of environmental perception.

The eight factor pattern of adolescent environmental perception was consistently shown to be shifted by participation in a week-long residential ecology field course: Scores in the preservational domain were increased when pre-test and post-test scores were compared, in the utilitarian domain scores were decreased. Therefore, the pattern of change fits into the set of previous survey studies of week-long residential educational programmes.

Due to our pre-testing of all pupils involved in intervention surveys we know about their positioning within the dichotomous preservational / utilitarian configuration. Therefore, all pupils were clustered according the Festinger's dissonance model (see Wiseman & Bogner, 2002) into one of four quadrants according to their endorsement of both domains (P [preservation], U [utilisation]). Scores of the two domains P and U were computed in two stages: first, the primary factor (attitudes) scores were calculated as mean scores of the corresponding item selection; second, the secondary factor (value) scores as the ones of the primary factor scores. High scorer in the secondary factor utilisation (U) endorse an utilitarian belief system, high scorer in preservation (P) do so with an preservational belief system.

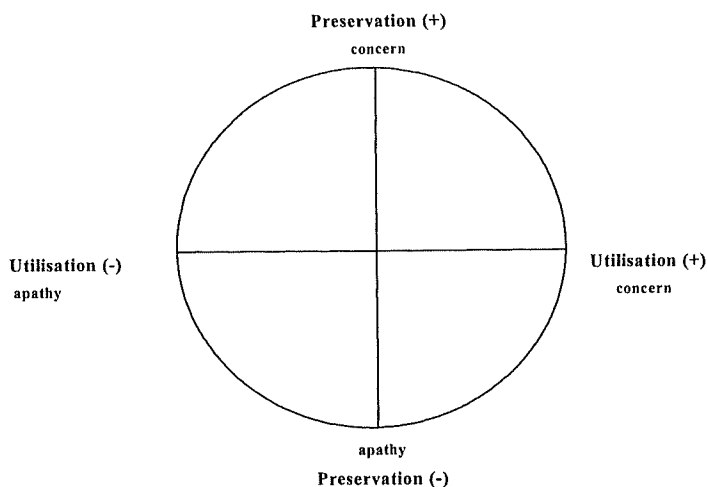


Figure 4. Two-dimensional Model of Ecological Values (MEV) of Wiseman & Bogner (2003): *Ecological Values are determined by one's position on two orthogonal dimensions, a biocentric dimension that reflects conservation and protection of the environment (Preservation) ; and an anthropocentric dimension that reflects the utilisation of natural resources (Utilisation).*

A specific portion of the participants, for instance, were found to be in the quadrant P- and U+ showing the most desired candidates for an educational intervention being shifted towards more sensitivity to preservation and less agreement to utilisation. A comparison of both graphs below shows a dramatic shift within the scores of both domains portraying an improvement of attitudes and values towards the environment. The size of effect is highly significant. Just to mention the contrary quadrant (P+ U-), which showed no significant interference with the educational programme.

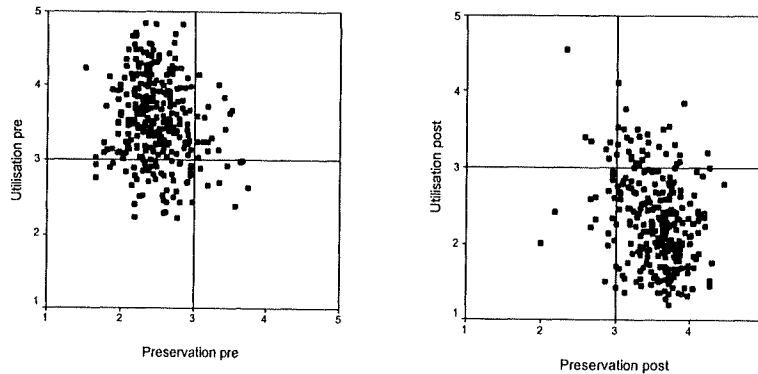


Figure 5. Shifts of a selected subsample, in their pretest favouring high scores in utilisation (U) and low ones in preservation (P) to their post-intervention position (low scores in utilisation and high scores in preservation).

To summarize the empirical analyses, sufficient support is provided for the hypothesis that pupils undergoing structured learning activities in outdoor settings are influenced in the direction of particular environmental perception. It appeared that the experience of a residential programme resulted in significant shifts in some aspects of adolescent perception. In the case of all four surveyed programmes, utilitarian and preservational understanding and attitudes were influenced, *i.e.*, the whereabouts of human impact on the environment, the interaction between humans and environments and the extent of human effects on nature were conceived and understood in a more sensitive manner. 'Green' environments were better recognised as being something also generally influenced by human beings. Altogether, it is a very encouraging result that an education programme should not only influence attitudes but also increase the pupils' sensibility towards nature and to the need for conservation.

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SHARING THE AUTHORITY TO EVALUATE ENVIRONMENTAL ATTITUDES: A CASE STUDY IN PRIMARY SCHOOL

Ramón López Rodríguez and María Pilar Jiménez Aleixandre
Universidade de Santiago de Compostela (Santiago de Compostela – Spain)
ramolo@lugo.usc.es, ddmaleix@usc.es

Abstract

This paper reports data, which form part of a three-year longitudinal study about development of environmental competencies in Primary School. A group of 22 students was followed from 4th Grade through 6th (9 to 12 years of age), combining classroom discourse analysis with written questionnaires, with the objective of documenting their progression in the development of competencies. The focus are the strategies used by the two teachers in the 4th and 6th grades for what is interpreted as sharing the authority to evaluate, and the competency exhibited by the pupils in connection with evaluation.

The methodology involved audio- and video-taping classroom conversations, keeping field notes and collecting pupils' productions and written responses. The data are interpreted in terms of knowledge production and use, and goals pursued. The results show how pupils are able to evaluate sophisticated questions and behaviours, how they reflect on their own work and identify the limits or flaws in it and how they justify their claims; and how the teachers' strategies such as sharing the authority to evaluate, empowered students to attain these performances, to reflect about their own learning and about the coherence of their behaviour. Implications for science and environmental education are discussed.

1 Knowledge production and evaluation: rationale and objectives of the study

One of the goals of Biology education, and in general of Science education is to provide students with the opportunity of being part of a community of learners (Brown, 1992), of a community involved in the production of knowledge, thus preparing them to participate in scientific practice. This practice is understood, not only as activities carried out in research laboratories, but in a variety of situations, locations and communities where science is created and used (McGinn & Roth, 1999). The classes in the school where this study was conducted could be considered communities of learners, for the school has, as a prominent, explicit feature, a commitment to pupils' taking responsibility for the planning of learning tasks as well as of behaviour rules. This compromise made possible the exploration of features of a knowledge-production community, of a learning context where students are knowledge producers, not just knowledge consumers (Jiménez & Pereiro, 2002). These features are difficult to document in conventional classrooms where the production of knowledge, and particularly the *authority to evaluate*, seem to be solely in the hands of the teacher, the one who decides whether the objectives of the instruction have been fulfilled or not. Another issue that needs to be considered when studying evaluation is that it should include the assessment of the objectives of a lesson or sequence, not just the concepts or models learned by the pupils. These objectives could include, as in the case here, tasks performed by the students related to attitudes, values and behaviour.

A recent review (Rickinson, 2001) about the nature and quality of the evidence generated in empirical studies about learning in environmental education suggests gaps that need to be filled, such as the learning *processes*. But the study of learning processes is, in our opinion, better carried out through classroom studies undertaken over a certain period, at least a complete teaching sequence and, if possible, comprising several years. Because the focus was on processes, this was designed as a longitudinal study from 4th to 6th grade in Primary School. To assess the development and progress of students in the complex field of environmental education Smyth's (1995) proposal of four stages has been used: environmental awareness, literacy, responsibility and competence. We have modified Smyth's proposal, rearranging the stages in three, merging the firsts two, defining them, and developing criteria for assigning the performances of the students into each stage, criteria which will not be discussed here in detail, being the subject of another paper (Jiménez and López, 2002). For the higher stage, environmental competence, these criteria include the *use of justifications and criteria* to evaluate different options and goals.

The focus of the paper are both the strategies used by the two teachers in the 4th and 6th grades for what is interpreted as sharing the authority to evaluate, and the competency exhibited by the pupils in connection with evaluation. The research questions are:

- Do pupils show competency to reflect on their own learning and performances, to evaluate their behaviour and the goals of the teaching sequence?
- Which type of justifications and criteria do pupils use in their evaluations?
- Which teachers' strategies are related to these performances?

2 Methods, participants and data sources

The participants are a group of 22 students, 15 boys, 7 girls and their teachers, studied during selected periods through grades 4, 5 and 6 (ages 9 to 12 years). There were 25 students in 4th grade and 23 in 6th grade, three left the school and one entered, so 22 remained through the whole study. The teachers, called here Ms. Ares and Mr. Vazquez were conducting teaching sequences with a focus on the environment. The methodology involved recording classroom conversations, both in whole class and small group, videotaping selected sessions, keeping

field notes as a participant observer (first author) and collecting pupils' productions, for the discourse analysis, and written responses to questionnaires. Both teachers were interviewed. In this paper the analysis focus on data from transcriptions and field notes, which are interpreted in terms of knowledge production and use, of competency for evaluation. The analysis of the competency and criteria for evaluation of the students takes into account these dimensions:

- The capacity of reflection on their own productions and behaviour
- The capacity to identify flaws, mistakes or limits in them.
- The justifications used to support the evaluation and the criteria revealed by them.

3 Results: competency and criteria for evaluation

Data from the two sequences related to environment are discussed: in the 4th grade, during 8 days, the pupils themselves designed and conducted a field study (Jiménez and López, 2001); in the 6th grade they proceeded through a unit about “the water in our lives”. The focus are the last sessions in each unit, when an open discussion about the fulfilment of the goals of the unit took place. The students are identified by pseudonyms respecting their gender.

3.1 Was the field code useful? Evaluation in the 4th grade

The analysis focus on the 8th and last session of the teaching sequence, when the teacher, Ms. Ares, asked them to discuss the interest and relevance of the field code (called “the rules”) designed by the pupils themselves. All the 9 and 10 year olds pupils (25) attended the session that lasted 50 minutes. Figure 1 (at the end of the paper) summarizes the episodes of the session. We consider one episode a fragment of dialogue that revolves substantially around one issue.

After the teacher presented the task Ignacio, turn 6, and Zoilo, turn 8, gave opposite opinions, supported by others, with the teacher only signalling turns as students raised their hands. From turn 27 the discussion turns on the actual observation of the rules, until the teacher, turn 44, restates the question: to assess the relevance of the rules, not to discuss who broke them. The last two episodes focus on how the code construction could be improved and a decision is taken by voting. The behaviour code with the 8 rules is reproduced in Jiménez and López (2001). Transcriptions are reproduced to illustrate the analysis.

Line	Actor	4 th grade, session 8, Episode 1
1	Teacher	(...) First I would like us to talk about the criteria that we set to be paid attention in the pond, about the rules that we constructed in order to be good observers, to be respectful in the pond... ok?
3	Teacher	Let's see, we are going to talk about this issue: Would it have mattered if we had not made them [<i>the rules</i>]? Was it important to have them? I would like us to give our opinion about this... ok?
6	Ignacio	I think that they were important because otherwise we would not know how to behave; we would arrive there and... God knows. At least for me they were very useful.
8	Zoilo	For me it was almost a waste of time, because each one arriving there is not going to throw himself into the pond and begin to kill frogs, see? This thing of being careful, well, you can assume that is clear... For me it was almost useless; many rules were not used. For instance, the one about not putting together carnivorous with others, was not used and neither was the one about being careful with the animals that you don't know...

- 13 Mario For me Zoilo is right, because there were many things that we didn't have to do in the pond... and the others everybody knows already.
- 24 Paula I believe that most of them were useful, because we used and observed them... boy, we didn't use them all because not everything that we wrote happened there, but they were very useful because we knew what to do.

The presentation of the teacher (line 3) focuses on the importance of having the code and, from the beginning, Ignacio and Zoilo set two opposite evaluations, useful and waste of time, supported by other students with arguments discussed below for the whole session, but centred mainly on the question about part of the rules not being used in the pond.

- Line Actor 4th grade, session 8, episode 2**
- 27 Zoilo Look, teacher, wait, we are not going to spoil the pond. Even if we hadn't written rules, it doesn't mean that we are going everyday to spoil the pond and kill the animals (...)
- 28 Néstor Of course not, but if we have some rules that we set ourselves, it is better, because we will know better what to do (...)
- 29 Zoilo (...) it doesn't matter, because we had the rule about caring for the animals and not catching them and we broke it.
- 30 Néstor No, we didn't break it.
- 31 Zoilo We broke it because Germán caught frogs and then dropped them somewhere else.
- 32 Néstor Well, and I caught frogs too, to look at them, but then I put them back.
- 33 Zoilo Yes, but many people caught them and then threw them away... and would you like that someone threw you away... this is not respecting the animals.
- 34 Cosme But they didn't throw them. If we took them it was to see well the colour and the spots on its skin, but not to throw them as you say.
- 37 Cosme (...) we took the frogs and tadpoles to look at them and see their colour and parts, but this doesn't mean that the rules were useless(...), because we didn't hurt them and put them back in their place, because we knew that otherwise it would be bad for the frogs and for the pond... So, for sure if we didn't set these rules, we wouldn't do it the same... For instance, before we had planned to collect frog's eggs and after setting the rules we didn't.

Episode 2 is mainly an argument between Zoilo and Néstor about breaking the rules, particularly # 4 ("We must not catch animals and if we take one to observe it, then we should put it back where it was"). Other pupils support Néstor's position, and Cosme (37) offers an instance of change of behaviour. It has to be noted that Zoilo was the only student who, in the pond, pretended to take some frogs that he had caught with him (Jiménez and López, 2001), and now he is using his own transgression as justification for his position.

- Line Actor 4th grade, session 8, episode 3**
- 44 Teacher Well, see, listen one moment... What was the question that I asked at the beginning? What did we plan to discuss? Was it if someone broke the rules? Or was it about the importance of the rules...? (...)
- 45 Zoilo But Cosme and others broke them.
- 46 Teacher Let's see, Zoilo. Let's focus on this. My question was not: Who broke the rules? My question was: Were they useful for something? (...) Was it of some use the work that all of us took during two days in order to elaborate the rules, or was it useless?

- 49 Lino Yes, it was useful, because if we did not set rules, for instance go slowly and silently, perhaps someone would walk fast and talk.
- 51 Hugo (...) Because if these rules wouldn't have been made by us, many times they would not have been observed... because we wouldn't know what to do.
- 55 Cosme And what Zoilo said about who has brains knows what to do, it is not so, because another time, when we made the observation here, in the school garden, he says that we knew and look! [*ironically*]...
- 60 Valerio I believe that... we learned a lot of things... we learned not just about how to behave, but how to collect data much better.
- 70 Zoilo (...) the rules that we have in the school, they can be used all the time, everywhere. If you spit in the pond it is like you spit on a human being, if you kill a frog for no reason it is like stabbing someone in the back with a knife... If you kill living beings or behave badly towards them, you are breaking some rules.
- 76 Lino But if there were no rules, most of us perhaps would kill something in the pond, without meaning to, a frog or something
- 96 Zoilo Look, then it would be better to take all the eleven or ten rules that we set and write only one that made for all: to deal with the animals well, with care, and that is all.
- 99 Teacher (...) If we write only this rule, look what could happen: for you [Zoilo] for instance, to deal with the animals well means not to take them, but for Cosme or Saúl, like they said, it is to take them, to observe something, and then put them back in the same conditions...

Episode 3 begins with the teacher restating the question on the meaning of the rules, and then develops in a discussion with Zoilo opposing almost all the rest of the class, changing his arguments, first that the field code is not needed, because there are already school rules (also negotiated with the students), with an interesting comparison among living and human beings, and later to the reduction of the eight rules –which he augments to ten or eleven– to one.

- Line Actor 4th grade, session 8, episodes 4, 5**
- 114 Teacher Let's see, perhaps we made some mistakes when setting the rules. Which mistake could we have made? (...)
- 115 Abel That we didn't want to observe them (*the rules*).
- 116 Teacher Not all, for instance, we didn't catch animals. But perhaps this rule about not mixing carnivorous in the same jar we didn't use it...
- 116 Abel Because we didn't catch them.
- 117 Teacher Then: What could be the mistake?
- 118 Fina I believe that writing the rules before knowing what we were going to do in the pond.
- 119 Cosme Yes, that first we set the rules and then the work to do in the pond and perhaps set rules for things that then we didn't... or the reverse
- 123 Teacher Anyway, even if we did make that mistake, I am asking again: was it useful to have the rules or not? With independence of observing them or not (...) Do we believe that they were necessary?

Episode 4 begins with the teacher asking the students to reflect at the mistakes in the construction of the code and prompting them to identify flaws rather than doing so herself. Fina and Cosme point out the construction right at the beginning of the sequence and the

teacher accepts it. Episode 5 is a wrapping up, formulating again the question about the usefulness of the code and voting about it with the result of a majority of 22 who consider it useful, and three who consider that it was not, and with the proposal of preparing a poster for sharing the experience with the rest of the school.

Analysing these episodes in terms of the dimensions, it seems that the 4th grade students exhibit a capacity of reflection about the field code: they are engaged in true dialogue, arguing with each other, sometimes, as seen in episode 2, without intervention of the teacher for a considerable length. They support their evaluations of the code with justifications and instances of their own behaviour in the field trip. Their capacity of identification of mistakes is shown in episode 4 when Fina and Cosme point out the order in the teaching sequence without indication on the part of the teacher of what kind of mistakes they might have made.

The students offered a variety of justifications in support of their positive or negative evaluations, that we interpret as indicators of explicit or implicit criteria about what a good field code should be or about what was important to do in the field trip. It is worth noting that the two students who evaluated the code as useless (particularly Zoilo) also offered coherent arguments for their position. The justifications and our interpretation of the criteria that they reveal are summarized in table 1 with some instances of students who offered them.

Table 1. Justifications in support of the positive or negative evaluation of the code.

Justifications in support of the evaluation (actor, line)	Criteria
<i>Positive</i> – to know what to do/ how to behave (Ignacio 6, Paula 24, Lino 49) – avoiding doing harm inadvertently (Néstor 28, Lino 76)	Need to have clear norms
<i>Negative</i> – people already know what to do (Zoilo 8, 27, Mario 13) – general school rules are enough (Zoilo 70)	No need for particular norms
<i>Negative</i> – rules not used, unnecessary (Zoilo 8, Mario 13)	Rule only needed if is going to be used
<i>Positive</i> – rules made by ourselves (Néstor 28, Hugo 51)	Responsibility in their own hands
<i>Positive</i> – catching/ returning frogs with a purpose (Néstor 32, Cosme 34)	Difference among catching / studying
<i>Positive</i> – change of behaviour promoted by code (Cosme 37, 55) – promoted better data collection (Valerio 60)	Evidence for code being useful
<i>Negative</i> – rules broken (Zoilo 29)	Evidence for uselessness

As seen in the table there is a connection between several of the positive and negative justifications: need or no need for norms in one case, and the use of evidence to support the positive or negative evaluation. It can be said that all during the session the dialogues of the students show that they have the capacity of identifying good points as well as mistakes in the code and to justify their evaluations. It is worth noting that they are not asked to assess their own learning of concepts or skills, but a code related to attitudes and behaviour that constitutes a more complex and subtle issue.

3.2 Did our behaviour change? Evaluation in the 6th grade:

The analysis focuses on the 9th and last session, devoted to revision and evaluation of the teaching sequence "The water in our lives" which included debates about the personal use of water, the situation of river Miño, that goes across the city, and two visits to the water treatment and purifying plants of the city. During session 8 and the first part of session 9, not discussed here, the students elaborated posters that were to be shared with the rest of the school. The group is the same, two years later, with only one new student; 21 of the 23 students were present. It must be kept in mind that Galicia has a humid climate, similar to Britain, and that in Lugo the average annual rainfall is 1.100 mm³ per square meter. Figure 2 (at the end of the paper) summarizes the episodes of the second part of the session, lasting 50 minutes.

The teacher, Mr. Vázquez, presents the task, the evaluation of the sequence, and the students begin to discuss the posters' format, until he, turn 13, asks them to focus on the purpose and content, which they do. The third episode begins with a second reformulation of the question by the teacher: do the posters serve the purpose of raising environmental awareness? After a debate, he takes another angle (turn 43) challenging them with a different question: Who changed his or her behaviour about water? The fifth episode focuses on the possibility of the posters bringing about a change of behaviour, and the sixth on how long the changes would last. Transcriptions are reproduced to illustrate the analysis.

Line	Actor	6 th grade, session 9, episode 1
1	Teacher	I would like us to revise and criticize the work, everything that we did during these days (...) to begin we could revise and criticize the posters (...)
5	Urbano	That poster, the thing about how we soil the water has stop signs, but the part about how to avoid it is bent, it cannot be read.
6	Lino	I think that the one about the purifying plant is good, but it has too much text.
6	Hugo	I think that they could be more colourful, to draw attention.

The students react to the general question posed by the teacher talking just about the formal aspects of the posters: text, colour, presentation, and the teacher restates the question.

Line	Actor	6 th grade, session 9, episodes 2, 3
13	teacher	Look, you are criticizing the colours, the set-up, the wording, if it is not clean... I think that (...) we have to focus on the content (...) What was the purpose of these works? Was it fulfilled or not?
16	Cosme	I think that [<i>the purpose</i>] was to show people the process that the water follows in our city (...) perhaps we say: the water is dirty because the purifying plant is not good (...)
19	teacher	Then: Why is [<i>water</i>] in a bad state?
20	Cosme	First because we pollute it. It is our fault.
22	Mario	[<i>the purpose is</i>] That people realize it, that they think twice before throwing waste or whatever into the water...
26	Fina	Sure, for instance if you don't see how [<i>dirty</i>] the water is when it enters the purifying plant, then people don't realize what they are doing.
28	Dora	It is important for people to know that water is not easy to get, that there is not as much as we think (...)
29	Abel	(...) people think that sewage is bad water, and because it is sewage they can throw there waste and things (...)

- 32 teacher And, is it possible to achieve this? Imagine that you are someone who didn't live this experience, and you go and see these posters: Would they help you to be aware of the problem?
- 37 Dora I think that the posters could be of some use, I don't know... but the best form for understanding this problem, of being aware, is of course going to the purifying plant.
- 40 Mario Yes, I agree (...) If I just saw the posters it would be difficult to change my behaviour (...) But after doing this work and seeing what happens to the water, to the purifying plant, all what arrived there, I changed... because I saw it. Now before dropping something into the water or if I take a shower instead of a bath, I realize that.

In episode 2, after the teacher's reformulation, the students offer similar summaries of the purposes of the posters: to promote awareness in other people, acknowledging (Cosme, 16, 20) their responsibility of the state of the water and the status of water as a resource (Dora, 28). Episode 3 begins with the teacher asking a precise question: Do the posters achieve their purpose? Dora (37) and Mario (40) express some doubts about it, with the argument that people need to see things for themselves, and Mario offers himself as an instance of change, providing an opportunity for the teacher to ask his next question.

- Line Actor 6th grade, session 9, episode 4**
- 43 teacher Look, let's see: Who, sincerely, who (...) Who really changed something in her or his habits? Who changed something in her or his behaviour in these things? Would you raise your hand?
[13 out of the 21 students raise their hands]
- 48 teacher Let's discuss this for a while... for instance: What was your change?
- 49 Kalia I mostly in using less amount of water, for instance now I always take a shower, and not throwing things into the toilet or the sink.
- 57 Rosa That my mother and me, before, we threw things into the toilet, but now we know that it is much better throwing them in the waste.
- 58 teacher [interrupting her] But, do you actually do it?
- 59 Rosa No, we don't [throw stuff in the toilet], and also taking showers or baths, that now I always take a shower.
- 61 Ovidio Well, I use less water, when I brush my teeth and that, I turn off the tap, and in the cistern that has a button to stop water running and also in the toilet, I don't throw things and besides I convinced my sister not to do it... before we used to throw many things in the toilet that now go to the waste.
- 65 Mario I only changed in not throwing stuff into the toilet. Before I threw many things, for instance I ate a biscuit and the wrapping paper went always into the toilet and now no, never.
- 75 Xosé (...) For instance I do not throw cotton sticks in the toilet, and before I always did it, and I don't leave water running, and before I didn't worry about it.
- 77 Fina That now I never throw bags or papers in the street, nor into the toilet, because before I did it because I didn't know, I said: bah, this doesn't matter and I threw it away.

Episode 4 begins with the teacher, after Mario has claimed to change, asking the students whether each one did. The question is not a usual one, but the classroom and school climate, the confidence and trust between teacher and students, allows them to express their views

freely. Of the 21 pupils, 13 raise their hands and 8 do not. Then the teacher asks, one by one, and the 13 students who raised their hands explain the nature of her or his personal change. As the use of water is in the domestic context, out of the school, it is not possible to confirm these behaviours, as it was with the fulfilment of the field code (being that the field visit was videotaped and observed). But there is indirect evidence which make them believable, as the details offered by the students: taking showers, not dropping papers or waste in the street (it was discussed in another session that it would end up in the sewage), or not throwing wrappings or cotton sticks into the toilet. The fact that eight students acknowledged not having changed shows also that they are not afraid of recognising it.

Line	Actor	6 th grade, session 9, episodes 5, 6
82	teacher	Good, very good. And after talking about us, I am wondering: Do you think that someone else after observing these posters could in some ways change her or his habits like many of you did?
85	Fina	I don't think so.
86	teacher	You don't think so. And: Why not?
87	Fina	Because someone reading this... I believe that many people would think: this is silly. Or perhaps they would say, well I already know it, and not do anything, not change anything (...)
89	Tina	I think that yes, that they are going to keep something. And I believe that what they are going to keep is that about water being a resource that it is scarce, and above all how we pollute the water.
92	teacher	[to Tina] And do you think that they are going to change their habits?
93	Urbano	[taking the floor] It is not the same to live it as to read it, you know. It is not the same to see it in a paper as to go to the purifying plant like we did...
94	Cosme	I agree. It impresses a lot to see all the dirt there in the purifying plant. If you see it, it impresses you and you see what cannot be done anymore...
97	teacher	And now I am wondering, this change in your behaviour, at least of some of you who recognise that you changed it: How long is it going to last? (...) As long as you remember this work, or do you think that it could really be a serious change?
98	Hugo	I think that the first option.
100	Kalia	I believe that I would change forever, because for instance before I brushed my teeth and left the tap running, but I didn't know what happened, and now I don't, but not because I have to remember it: it comes out like that.
107	Dora	I think that yes [it is going to last], because even if we forget these things, I think that we take different habits, and habits are not forgotten... then, the same as before I used not to turn off the tap, now as a habit I always turn it off.
108	Mario	Man, as long as we remember it, it would be better...
110	teacher	(...) Something else that worries me. Look here, the ones who didn't change (...) could someone explain why not?
111	Yagos	Because of being more convenient.
119	Yagos	For not taking the trouble... for instance when I am in the shower I leave a lot of water running... but I am still doing it. [some students murmur]
121	teacher	Listen: we have to respect all opinions. And Yagos has been very sincere. He is giving a sincere and brave explanation. Perhaps others think the same but do not dare to say it (...)

In episode 5 the teacher takes again the issue about the effect of the posters on other people, with a more precise question: would others change their habits? All of the pupils who expressed views agreed that the change of habits was not probable. The justification supporting this view could be summarized in Urbano's sentence "It is not the same to live it as to read it". Then the teacher introduces the question of how long the changes would last, which is seen in a different way by the three girls who talked about this (they would last) and by the boys (as long as we remember it). Finally the teacher asks the students who didn't change to explain why and, when Yagos does so, defends him for his sincerity.

Analysing the episodes in terms of the dimensions explored, it can be said that the 6th grade students are capable of reflecting on their productions, the posters, and assessing the limits of its effects on others, as seen in episodes 3 and 5, acknowledging that the awareness experienced by them couldn't easily be transferred. They are also able to assess the influence of their actions on the environment, recognising their own responsibility in the state of the water, as seen in episodes 2 and 4, when they acknowledge the way they behaved before the sequence, the mistakes in their use of water. Their capacity of identification of limits is shown for instance in their explanations, in episode 5, about why they do not think that other people are going to change their habits as a consequence of the posters.

These reflections of the students are supported in a variety of justifications. As the issues discussed in the 6th grade are several things –not just one, the evaluation of the code, as in the 4th grade– the range is wider. The justifications for each issue discussed and our interpretation of the criteria revealed by them about how to produce a change in environmental behaviour or about what constitutes such change are summarized in table 2.

Table 2. Justifications offered by the pupils of 6th grade in support of their evaluations.

Justifications in support of the evaluation (actor, line)	Criteria
<i>Effects of the posters on others (limited effect)</i> – difference live it / read it (Urbano 93,) <ul style="list-style-type: none"> – need to visit purifying plant (Dora 37, Mario 40) – it impresses to see the dirt (Cosme 94) 	<i>how to produce a behaviour change</i> importance of experience
<i>Instances of behaviour change (about water use)</i> – taking showers / turning off tap (Kalia 49, Rosa 59, Cosme 73) – not throwing waste into toilet (Ovidio 61, Mario 65, Xosé 75)	<i>To care for water is</i> - to save it - not to pollute it
<i>Durability of change</i> – habits are not forgotten (Dora 107) – it comes out like that (Kalia 100)	<i>What makes a change last</i> New habits

During the session the students exhibit the capacity of assessing the difference among the goals or intentions of their work (the posters) and its actual effect on other people. For them, the change experienced by themselves had its origin in the experiences in the unit, particularly the visit to the purifying plant. A more sophisticated issue is the durability of change: although the students disagreed about it, it should be noted the identification of habits as a warrant of long term effect (Dora and Kalia): when you don't have to think about it but "it comes out".

4 Teachers' strategies: sharing the authority to evaluate

The students were able to evaluate their own work, as seen in the previous section, but this competence needs, for its development, a particular learning environment. The third research question explores the teaching strategies that are effective in promoting students' participation in the evaluation.

The students in both grades showed a considerable degree of autonomy, not only in the last sessions of the units discussed here, but also in proposing issues to be studied, discussing them and planning the methodology to do it. But this doesn't mean that the teachers, Ms. Ares in 4th grade or Mr. Vázquez in the 6th, were just observers, or that the pupils performed all these activities unguided. On the contrary, all the sessions were carefully designed. In the interviews Ms. Ares claimed that she planned each session or group of sessions using as a starting point the pupils' interests and previous knowledge, and Mr. Vázquez that his purpose was to integrate the environmental education as part of the regular sessions. From the transcriptions and field notes, we identified a number of strategies which seem connected with the pupils' performances. Some are related to true dialogue, as 1) exploring pupils' ideas and attitudes, 2) praising pupils' proposals, 3) reformulating and synthesizing pupils' proposals, 4) participating as a pair in the dialogue, and 5) sharing the authority to evaluate. From these only the last two, in our opinion connected to evaluation, will be discussed here.

Participating in the dialogue as pairs

This doesn't mean that Ms. Ares is not guiding the process of elaboration of the code, the proposals to be studied or the evaluation, or that Mr. Vázquez is not planning the activities, but that their leadership is achieved through subtle methods, more through the ability to synthesize proposals and to find solutions to conflicts, than by an appeal to authority. The evidence for this participation as equals is found more in the tones and countenance than in particular lines, but some examples are, in 4th grade the discussion about the proposals in session 2, reproduced in Jiménez & López (2001), where the teacher is just repeating or rewording the pupils' proposals or asking them their opinion, or lines like these:

<i>Grade, teacher, statements</i>	<i>session, line</i>
<i>4th Grade, Ms. Ares</i>	
"Are there other reasons?"	1, 150
"Do you like it?" "Is it O.K.?" [about proposals]	2, 109, 187
"What do you think about it?" [about proposals]	2, 120, 204
"You have to say what do you want to study in the pond"	3, 31
"Do we agree about this?"	5, 19
"Yes, I agree. Our mistake was perhaps that we wrote the rules first"	8, 121
<i>6th Grade, Mr. Vázquez</i>	
"Only a few people think this or do more people do?"	1, 77
"What do you think? Is all this investment worth it?"	7, 88
"What do you think about it?"	8, 15
"Do you agree?"	8, 17

These questions have in common that they are non-directive, so they can elicit the students' opinions. In general they don't provide cues for the answer or imply that some answers could be better than others. When we say that they promote true dialogue it is because most of them cannot be answered by a simple «yes» or «no», they require an elaboration, for instance "are there other reasons?", and promote the participation of pupils, in fact in most sessions all the pupils, or all but two or three, participated in the debates.

Sharing the authority to evaluate

It could be seen as a particular case of shared participation, but we think that it has a particular significance, since in conventional classrooms it is only the teacher who exercises this authority. This shared assessment is documented not only in the last sessions discussed, but also in different occasions along both sequences, for instance in the transcriptions from 4th grade reproduced in Jiménez & López (2001), as in session 1, line 129 and onwards, when Saul tells about a toad that he caught which died (the teacher just raises the question “what do you want the toad for?”) and then Rosa advances a proposal of planning before catching animals; the teacher doesn’t evaluate it –although later it will be apparent that she disagrees with the idea of keeping animals in captivity– but suspends the judgment until the issue is discussed and a decision adopted by the majority of pupils as their own. The proposals for the field code are not written down until agreed by all. Also other instances are:

<i>Grade, teacher, statements</i>	<i>session, line</i>
<i>4th Grade, Ms. Ares</i>	
“Does somebody want to add something?”	2, 39
“Very good, very good... it is a good point”	2,163
“You can write it, if the majority agrees”	2, 222
“I would like us to give our opinion about this [the code]”	8, 3
“Perhaps we made some mistakes [about the rules]”	8, 114
<i>6th Grade, Mr. Vázquez</i>	
Zoilo “Do tell us what do you think it is lacking”	8, 33
“No, I am not saying anything. You did the work, you saw all the process and now the thing is how you see it”	8, 34
“What do we seek with this work?”	9, 21
“Do you think that someone else (...) could change her or his habits?”	9, 82

The exchange between Zoilo and Mr. Vázquez in session 8 is an example of explicitly sharing the evaluation with the students: they should say what is relevant, what summarizes the important issues in the sequence and should be included in the posters. Of course, the teachers take the floor and are ready to restate the questions discussed, as seen above, for instance in the 6th grade, when the students discuss only the format aspects in the posters. In general both teachers created a classroom climate of trust and confidence, in which the pupils feel safe to propose any idea because they know that nobody is going to scold them or tell them that they are “wrong”; they help the pupils experience that they have a role in the activities going on in the classroom, that they are participants, knowledge producers and not just spectators.

5 Discussion and educational implications: sharing the evaluation

The results show how pupils are able to evaluate sophisticated questions and behaviours towards the environment, how they evaluate the goals and which justifications (warrants) they use for their claims; and, on the other hand, how the teachers’ strategies such as sharing the authority to evaluate, empowered students to attain these performances, to reflect about their own learning and about the coherence of their behaviour.

In the 4th grade the pupils assess the usefulness of the field code. They are even able to identify some flaws, for example the construction of the behaviour code before deciding the contents to be studied. It has to be noted that the order in the sequence, beginning by the values and attitudes and devoting the longest time to them, was a conscious decision of the teacher, as she explained in the interview. However, she didn’t discuss this critique of the students, she didn’t justify her decision with arguments like the importance of bringing values and attitudes to front. The objective, in session 8, seems to be the development of the

competencies of reflection and evaluation, that the students feel that they are able to point out flaws, and to this she subordinates other things. We think that finding flaws in their own work, as the 4th Grade students did, is much more difficult for young students (and probably for older) than praising, and this feature leads us to consider this evaluation more rigorous than other classroom self-assessment where only good things are mentioned and that became an exercise of self-praise.

Another issue worth noting is that the students, as Néstor (line 28 “If we had not made these rules”) or Hugo (line 51), assume the rules as their own. Hugo claims, “if these rules would not have been made by us, many times they would not have been observed”. This points to the difference between rules imposed and rules agreed upon, the second being the ones that can be appropriated by the students.

The results of the progress along the three years are more easily documented in the responses to the questionnaires, discussed in another paper (Jiménez & López 2002). What can be seen here is how in the 6th grade the students are able to critically assess the influence of their actions on the environment, how they perceive the limits of their actions and the difficulties of transference of environmental awareness.

It must be noted that this school, where a great deal of responsibility about their own learning is laid in the hands of the pupils, cannot be considered representative of Spanish schools. Most teachers would provide the evaluations, the proposals and the answers rather than spend several sessions eliciting them from the students. But the results suggest that time and effort are rewarded in terms of the competencies developed.

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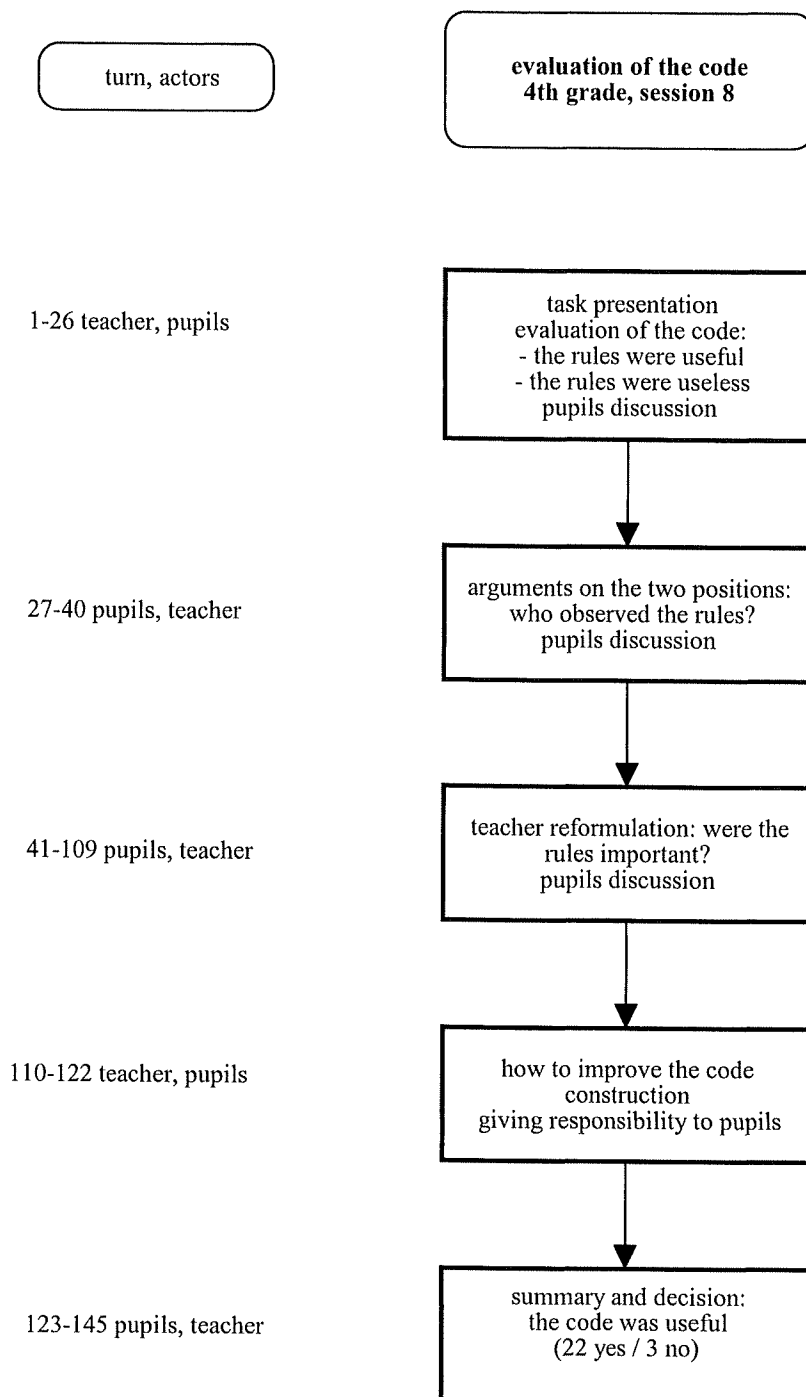


Figure 1. Summary of episodes in session 8, 4° Grade

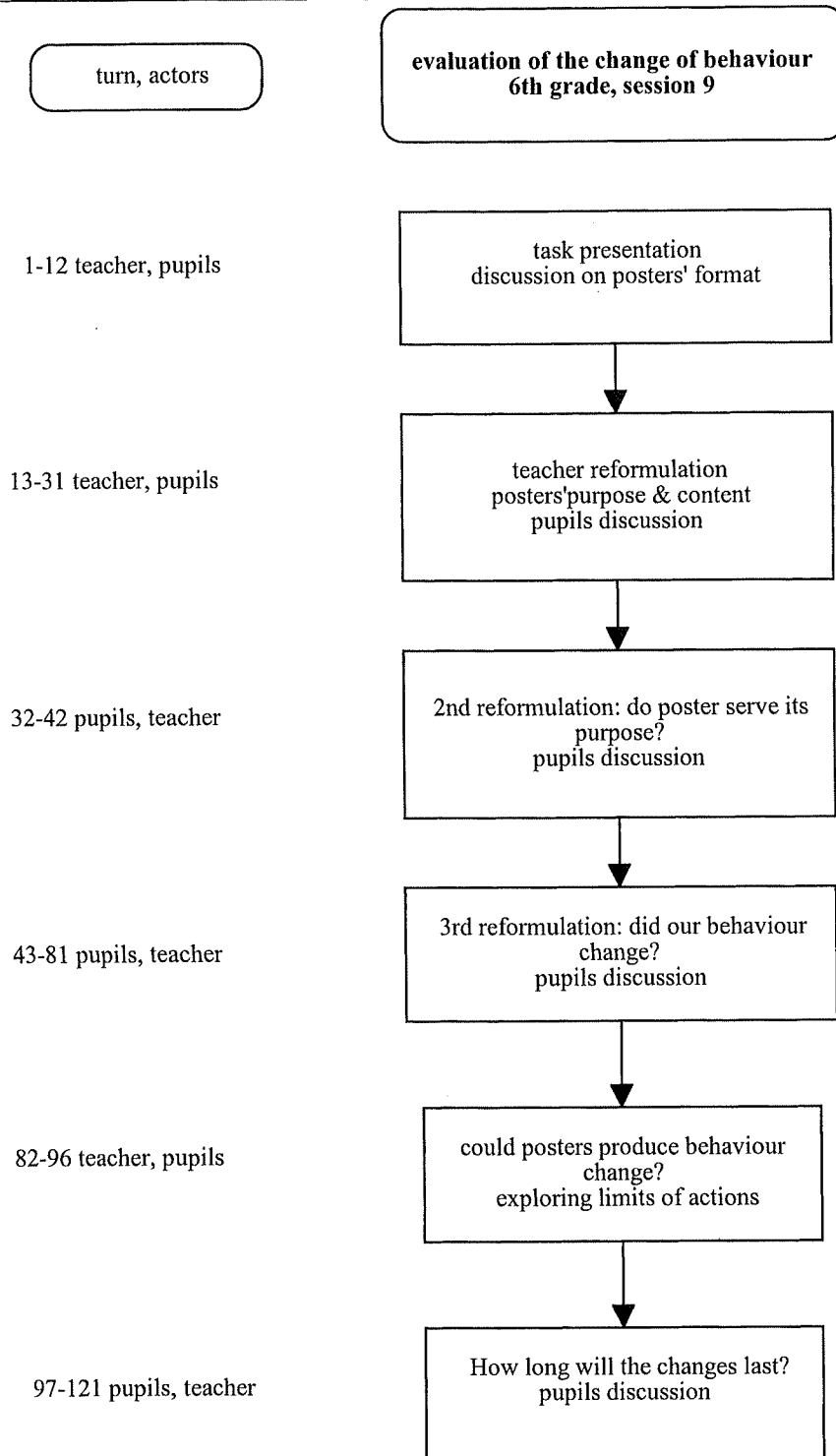


Figure 2. Summary of episodes in session 9, 6^o Grade

**DEVELOPING STUDENTS' MENTAL MODELS OF ENVIRONMENTAL
PROBLEMS BY DECISION-MAKING ROLE-PLAY IN SYNCHRONOUS
NETWORK-BASED ENVIRONMENT**

Kai Pata, Tago Sarapuu
Science Didactics Department, University of Tartu
kpata@ut.ee, tago@ut.ee

Abstract

The present research focused on clarifying the mechanisms of developing individual and shared mental models during the collaborative decision-making process in synchronous network-based environment. The role-plays of 14 groups of secondary school students with 3 different environmental scenarios were conducted by using the Collaborative Virtual Workplace software CVW 4.0. The activity of participants was supported by text-embedded-, tutor-, and peer-scaffolding. In order to analyse the competency of individual and collaborative decisions an appropriate evaluation model was developed. It embraced the solution-paths for both avoiding causes and preventing consequences linked to the problem. Different aspects of science, legislation, economy and ethics were also taken into account. It appeared that the mental model of individuals changed during the role- and expert-discussions depending on the particular role and task of each student. The competency of team-decisions could be described by the certain patterns of mental models. The comparison of students' individual answers in pre- and post-test demonstrated a significant advancement of their ability to solve analogous problems. It can be concluded that by using collaborative role-plays on environmental issues the students' individual mental models can be effectively developed.

1. Introduction

At school the traditional decision-making techniques on environmental issues are often built on the assumption of predefined set of alternatives and criteria from which the students can select the ideal solution that is correct from the viewpoint of science. In real life, on the other hand, we have to deal with ambiguous ill-defined problem situations demanding more complex knowledge and skills than is obtained in the classroom. In order to make sound decisions, deeper understanding of the nature of environmental problem situations and the way, how these can be solved in society are needed.

In this article we attempt to describe the process of developing students' environmental decision-making skills with role-plays in synchronous network-based environment. We analyse the changes taking place in the students' understanding about the nature of environmental problems at individual and collaborative level while participating in the activity. The effectiveness of the role-play method for teaching the decision-making skills on environmental issues will also be evaluated.

1.1. Mental models of environmental problems

One of the tasks of the environmental education ought to be developing adequate understanding of environmental problem situations and the ways of solving these.

As to their nature, environmental problems are complex dilemma situations in society. The initial cause of the problem is usually economic, technical or behavioural activity of different actors. The behaviours that result in short-term advantages for some individuals or certain social groups often cause long-term negative effects for the society as a whole (Liebrand & Messick, 1996; Lichbach, 1996). The pollution of the environment, the degradation of ecosystems or the negative influence on human health will be inducing the pressure on industry, society and legislative organs. The potential solutions proposed for social dilemmas by Lichbach (1996) are i) the market solution that is based on modifying the "cost/benefit" equation so that the benefit exceeds the cost, ii) community solutions that require altruistic rather than egoistic behaviour from people, iii) contract solutions that are based on the concept of rules and punishment, and iv) hierarchy solutions that reside on the concept of hierarchical organisations enforcing co-operation. For sound environmental judgements the economic, ethical and legislative aspects must be combined with ecological considerations (Zandbergen & Petersen, 1995). It is clear that different groups of actors involved in the environmental dilemma situation will be emphasising the importance of these aspects differently in their decisions. Co-operation of all the actors for the common good is needed for solving the dilemmas (Liebrand & Messick, 1996).

In order to control the environmental system, a decision-maker must have a mental model of it. Mental models are internal representations that humans develop of themselves and the objects they interact in the world (Norman, 1993). Johnson-Laird (1983) proposes mental models as the basic structures of cognition in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life. Having incomplete mental models of the environmental problem situations will cause the decision-making actors to make choices that do not always consider the common good. Differences in mental models can also bring forth communication gaps between the counterparts of the dilemma and will complicate the process of finding solutions (Abel et al., 1998).

By Derry (1996) the mental model represents situational understandings that are context dependent and do not exist outside the situation being modelled. She describes the construction of mental model as mapping the active memory objects onto components of the real world phenomenon, then reorganizing and connecting these objects so that they together form a model of the whole situation. This notion gives a good explanation why it is necessary

to teach environmental decision-making in a real to life context. The mental models of environmental dilemmas are not only the static collections of objects, states of affairs, sequences of events, but they also comprise the knowledge about actions, grounding and negotiation processes between the actors involved in the decision-making process. Gentner & Gentner (1983) have referred to mental models as mental simulations of the real situation of the problem. They are of dynamic nature, changing as a result of running the model (Banks & Millward, 2000). Once developed the dynamic mental models can be used as a basis for further reasoning and problem solving. Barker & Schraik (1999) have found that experts with rich and powerful set of mental models relating to the given task domain will be able to show much greater creativity and diversity with respect to problem solving than those with weak knowledge structures.

1.2. The role of shared mental models

While solving the problems individually, the decision-makers' mental models of environmental problems often remain insufficient. The inherent cognitive limitations of short-term memory (Miller, 1956; Tulving, 1970) make it difficult to consider the different aspects of the complex problem situation at a time. People are also forced to rely on simpler and restricted models due to the presence of time pressure in dynamic systems (Diehl & Serman, 1995). In order to reduce the cognitive load on working memory, the minimal amount of possible information is used when constructing mental models and the resulting model is based on a limited number of relations causing the individual decision-makers to fail to consider all the alternatives.

In order to develop more complete mental models the learners' individual mental capacities should be enlarged. One of the research interests of the current study was if the students are able to construct more adequate individual mental models after being involved in collaborative environmental decision-making process that simulates the real life situations.

It could be presumed that if the individuals have difficulties in making environmental decisions on their own, their process of making judgements could be enhanced in collaborative teams where the learners can obtain better understanding about the complex nature of the process. Supposedly, in teams the learners will be able to consider more aspects of the problem due to the processes of social learning (Bandura, 1977), cognitive apprenticeship (Brown et al., 1989), and due to the increased shared mental capacities of the team (Espinosa & Carley, 2001). During the discussions with people who have different mental models of the problem the team members will always elaborate a common knowledge place (Sauvagnac & Falzon, 1996). Within this knowledge space it is possible to keep at the working memory of the team more information from different aspects than the individuals could be able to run alone. The synergies achieved from pooling complementary knowledge from various members can potentially create team knowledge structures that are greater than the sum of the individual knowledge of its members (Espinosa et al, 2001). This common knowledge, developed by team members while performing the task, is called the team mental model (Klimosvki & Mohammed, 1994). Kraut et al. (1999) have named it the shared mental model. The shared model of the team is an average correlation among team-members about how much each person knows (Kraut et al., 1999). While working together the teams' shared mental model is constantly changing. The result of this discussion is the teams' decision that represents its members' shared mental model of solving the environmental problem.

The members of the team can have identical mental representations, a distributed configuration of representations (no overlap) or configuration of overlapping representations (Klimovski & Mohammed, 1994). Cannon-Bowers et al. (1993) describe the hypothetical process of how shared mental models operate as following: individuals run their mental models independently of each other and when these are the same, the performance is

optimum. The overlap of individuals' mental models can lead to greater shared expectations and explanations within a team and in turn improve the communication and lead to superior team performance (Rouse et al., 1992). It is also predicted that it is possible that certain distribution patterns of the shared knowledge might be more efficient for task solving than the others (Espinosa & Carley, 2001). If the shared mental model is distributed in disorganised fashion then supposedly it is not possible to form the final solution as an outcome of running the model. In the groups of actors with big communality and common frame of reference the grounding processes could be progressing more easily enhancing thereby the formation of the overlapped shared mental models. The shared mental model in negotiation-groups, on the opposite, could be of more distributed manner due to the actors' different individual mental models. For this reason, the role of the formation of organised or disorganised shared mental models in teams on the effectiveness of team decisions was studied in this research.

1.3. Teaching the decision-making of environmental problems

It was supposed that the basis for teaching the environmental decision-making process has to be the model of solving dilemmas in real life. In the multilateral model elaborated by Chasek (1997) upon comparative analysis of real environmental problem cases the final judgements are made after several stages and turning points. The six stages of the process include drawing attention to a particular environmental problem in society; developing the common body of knowledge by scientists and experts before negotiations; stating the initial positions from where the negotiations between different actors begin; exploring the various alternative drafts and building the consensus and finally, after the agreement has been adopted, implementing the solution.

A promising framework for simulating this process was sought to be the team role-play using a modified version of jigsaw (Aronson, 1978). Using the idea of jigsaw in the collaborative judgement making with dilemma problems, the first phase of the process should comprise the creation of alternative viewpoints by different teams of actors (role-groups) involved in the process. In order to create the full problem situation, negotiations in expert groups must follow. In each expert group different role-group members should be represented. The final competent decision for managing the dilemma can be reached through negotiations.

In order to create the realistic atmosphere of solving the dilemmas the synchronous network-based chat room might be used. Network-based environments enable collaboration and favour the co-construction of knowledge. Via chat room it is possible to support learners with necessary role-descriptions and materials about the environmental dilemma situation. Also, adequate verbal support of the tutor is easily available.

The following research questions were formulated:

1. How do the students' individual and shared mental models of environmental problems change in the different phases of the collaborative decision-making process?
2. Does the formation of shared mental model influence the teams' final judgements?
3. Do the students' individual mental models about the nature of the environmental problems change as a result of participating in collaborative role-play in synchronous environment?

2. Research design and method

The study was based on the analysis of environmental role-plays with different scenarios (What should be done with neglected dogs? Should the highways be salted in winter? How must the garbage problem in countryside be solved?), that were aimed to develop students'

decision-making skills on environmental issues. After conducting the role-play the students had to solve the environmental problem with a similar structure individually.

2.1. Subjects

The participants of the role-plays were 14-17-year-old students from 16 Estonian secondary schools. 14 role-plays were carried out. Out of these 14 role-plays five on the topic about Stray Dogs were thoroughly studied. In these 5 role-plays 62 students, 30 girls and 32 boys took part. In each game ten to twelve students were participating. The number of students in role-groups ranged from two to five persons, in expert groups the number of students was from four to seven. The students participated in the role-plays in the computer-labs of their own schools in science lessons. All the role-plays were scaffolded in the synchronous environment by the online tutor who was located separate from the students. The science teachers provided the technical assistance to the students in computer labs. Within the same week the students had to solve another environmental problem individually. 53 students returned the essay.

2.2. The learning environment

The role-plays were carried out in java-based synchronous learning environment *Collaborative Virtual Workplace 4.0*. (CVW) (<http://cvw.mitre.org>). The CVW environment had several technical properties that favoured its use for making environmental decisions during the role-play. It offered a graphical interface with different virtual rooms and floors that could be used for working in separate teams and also the virtual building floor plan that enhanced to develop the imagination of real floors and rooms. It was possible to rename rooms according to the role-groups and, therefore, to create authentic atmosphere for discussion. For each role-play the rooms were named according to the roles of a certain play (Dog-owners Club, Stray Dogs' Asylum, etc.). The user-names for participants were chosen according to their future roles in the game (citizen1, animal-protector2, etc.). The learners were provided with adequate instructional scaffolding by establishing appropriate links to the web pages in the rooms of role-groups. In each room the documents of *Problem introduction*, *Role description* and *Additional material* were deposited. The rooms were also equipped with recorders to save the content of the discussions. All the participants of the role-play had movable folders for individual documents (*Carries*). Students were instructed to use these for saving their individual- and role-decision documents (*Notes*) while moving from one virtual room to another. It was also possible to drag the decision-documents from the individual document-folders into the room of the role- or expert-group for sharing these. The users could scroll back and forth the log-file of the chat in order to review the discourse of the discussion in teams.

2.3. Description of the role-play

The aim of the environmental role-play activity was to oppose the role-groups representing different environmental knowledge, attitudes and values, and to initiate a discussion for generating ideas, evaluating alternatives and making competent environmental decisions. For this the decision-making process was divided into making individual decisions, collaborative role-decisions and collaborative expert decisions (Figure 1).

At the beginning of the role-play the students were divided into four role-groups by getting different user-names to enter the game. The users with similar role-name met in their role rooms of CVW. According to the learning protocol the tutor introduced the students with their first task. In each room there was a link to a brief survey of the problem (*Problem introduction*). Each student had to generate a note of his or her initial decision. This was completed on the basis of an initial mental model. Bohm (1990) has found that the

apprehension of initial mental models before group discussion is of great importance. These individual decision documents could be used later for evaluating alternative decisions generated by other members of the team. The note could be also used as a rehearsal material during the decision-making process when short-term memory was overloaded.

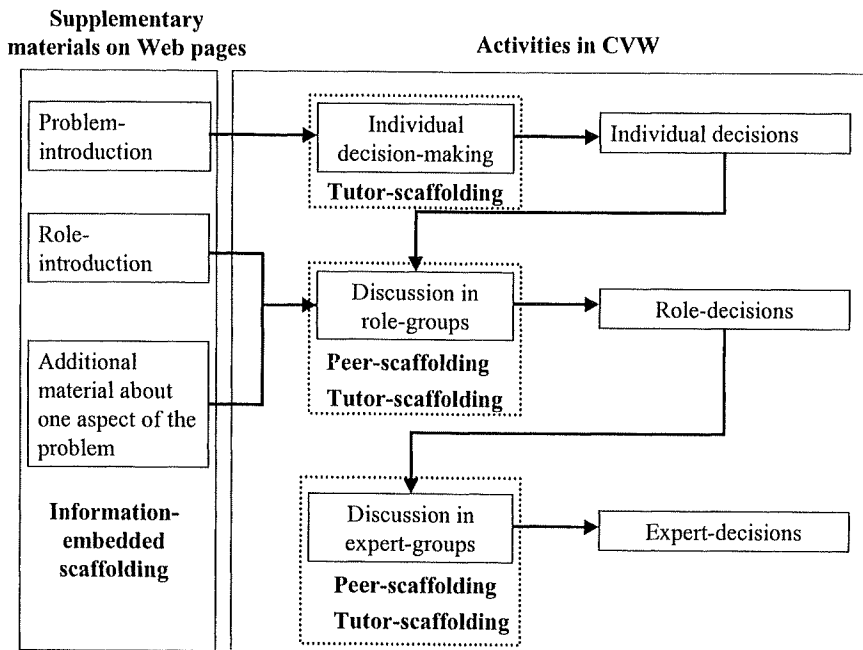


Figure 1. The model of the role-play

After the individual phase of the activity each member of the role group got acquainted with its team's role (*Role description*). To direct the decision-making processes of groups towards competent judgements, the teams must have different roles that would complement each other in final expert-decisions. We predicted that the roles should be divided according to the economic, ethical, juridical or scientific aspects of the problem (Zandbergen & Petersen, 1995) and accordingly supported by these aspects with relevant information. After choosing the leader of their role-group, the students had to work together in their virtual room using supplementary web-material (*Additional material*) about their certain aspect of the problem. For each group a limited amount of additional information was offered in this web material because only some aspects of the problem were important from the specific viewpoint of each role. During group discussion the learners of the same role had a possibility to create the shared understanding of the problem and formulate their joint decision how to solve it from their role's viewpoint. A decision-document was created by each role-group and these were stored in their role rooms and also copied into the personal folders of participants. The students could use the decision documents during the formation of final decisions in expert groups.

Subsequently, the members of different role-groups moved to the expert-rooms to discuss their preliminary judgements as experts in order to find controversial issues in their previous decisions. In each expert-group the members from all role-groups had to be present. Using the

documents generated in the role-rooms they discussed and evaluated the role decisions and made an expert-decision. The final documents with decisions were stored in the expert rooms. The whole activity was scaffolded online by a tutor. The tutor's main task was to follow the learning protocol giving process, functional and content scaffolding. The tutor was not supposed to intervene into the real process of making decisions and could only initiate discussions and evaluation of judgements by summing up or opposing different ideas generated by students.

2.4. Methods and procedures

The log files from chat rooms and the note-documents generated by individuals and groups formed the corpora of analysis for the study. The notes of decision-documents and the students' statements during the discussion were used as the representations of participants' mental models in the different phases of the decision-making process. We investigated the following variables in the study:

- The content structure of individual mental models;
- The distribution structure of the shared mental models in teams;
- The quality of the individual and team decisions.

All the characteristics from log-files and decision documents were categorised by one researcher. In order to test the validity of categorisation one role-play was randomly selected and categorised by another researcher.

2.4.1. The phases of the role-play

In order to analyse the content structure and the distribution structure of the individuals' and teams' shared mental models, the decision-making process of each individual was divided into the five phases in respect with the different stages of role-play:

Phase I

The initial mental models were characterised by the individual decision document;

Phase II

The dynamic changes in each student's mental model during the role-discussion were extracted from the log-files of the discussion. The structure of the shared mental model of the role-group was derived from the comparison of the individual mental models during the role-discussion.

Phase III

The shared mental model of the role-group was derived from the role-decision document (supposedly each team-member had to have a similar individual mental model if the team had reached the common ground);

Phase IV

The dynamic changes in each student's mental model during the expert discussion were extracted from the log-file of the discussion (in this phase the students were supposed to protect their team's decisions). The structure of shared mental model of the expert-group was characterised by the comparison of the individuals' mental models in the discussion.

Phase V

The shared mental model of the expert-group was described by the expert-decision document (it was predicted that the individuals had more or less similar mental model to the expert-group model by this time due to the discussions).

2.4.2. The content structure the individual mental models

The content structure of the individuals' mental models about the environmental problem was analysed according to the evaluation model of usage of different (scientific, economic, juridical or ethical) aspects in these. The content of decision-notes and extracted individual mental models during the role- and expert discussion Phases II and IV was categorised according to the usage of aspects. In each mental model one to four different aspects were

possible to be registered. Thereby, the development of each student's individual mental model could be followed in five phases. In addition, the same categorisation method was used to evaluate each student's mental model about solving the similar environmental problem after the role-play.

2.4.3. *The distribution structure of the shared mental models*

The distribution structure of the shared mental models in role- and expert teams was analysed during the discussion Phases II and IV using the scale proposed by Banks and Millward (2000):

- 1 – Shared mental model was not formed (no common ideas, no discussion);
- 2 – Disorganised shared mental model was formed (team-members had separate ideas without any overlap of individual decisions);
- 3 – Organised shared mental model was formed (team-members had several common ideas with partial overlap of individual decisions).

The type of the shared mental model that formed in the groups where students had participated during the discussion was used as one characteristic describing individual decision-makers.

2.4.4. *The quality of the decisions*

The quality of the individual and the final team decisions in the Phases I, III and V was also assessed using the evaluation-model of environmental decisions (Figure 2).

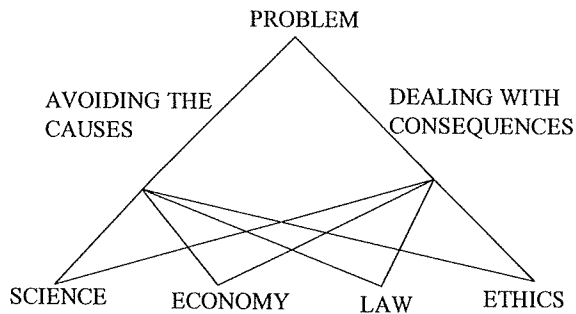


Figure 2. Evaluation model of environmental decisions

This comprised both the solution-paths directed to avoid the causes of the problem and the ways dealing with the consequences of it. Also, the aspects of science, law, economy and ethics were taken into account in the model. This formed the basis for the evaluation scale of environmental decisions:

- 1 – No decision documents were made or important aspects of the particular role were not considered in the decision document;
- 2 – Important aspects of the particular role were considered in the decision document but only from the viewpoint of preventing the causes or eliminating the consequences of the problem;
- 3 – All the important aspects were considered in the decision document, both from the viewpoint of preventing the causes of the problem and eliminating the consequences of the problem.

2.5. Analysis

In order to describe the changes taking place in individual and teams' mental models during the role-play the content structure of both models was studied in five sequential phases.

For investigating the changes in understanding the nature of environmental problems as a result of the role-play in CVW, students were given a similar individual decision-making task after the role-play. The involvement of different aspects of information in making decisions was studied in comparison with the number of aspects in the students' essays with those in their individual decisions of role-play in the Phase I. Therefore, the cross-tabulation and the Chi-square analysis was carried out.

The Spearman correlation analysis was conducted for finding out how the distribution and content structure of shared mental models in teams influenced teams' final judgements.

3. Findings

We investigated separately the changes taking place in the content structure of the individuals' and teams' mental models during the different phases of the collaborative decision-making process and the quality of individuals' and teams' decisions during the role-play. The influence of the formation of shared mental models on the quality of team decisions was clarified. The content structure of students' mental models was also evaluated after the role-play while solving similar environmental problems.

3.1. The content structure of individuals' and teams' mental models in the role-play

It appeared that although the problem introduction consisted of balanced information about all the problem aspects, the students tended to emphasise only one or two different aspects in their initial mental models in the Phase I (Figure 3).

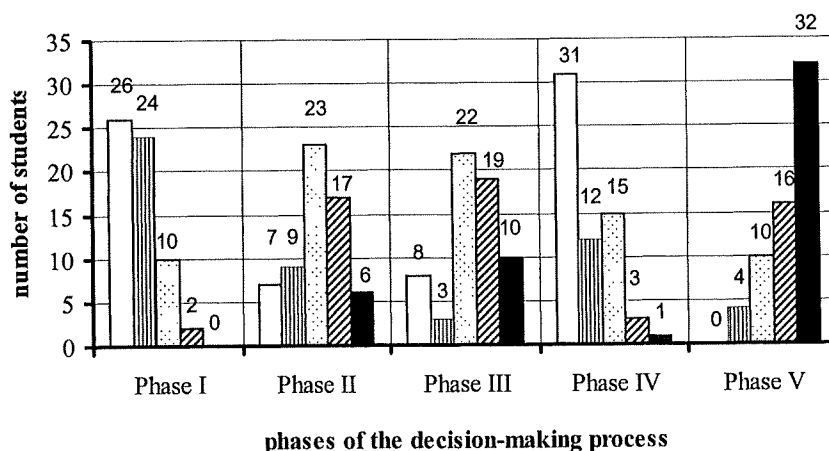


Figure 3. The number of different aspects considered by individuals (n = 62) in different phases of the decision-making process in CVW. (□ - 0 aspects; ▨ - 1 aspect; ▩ - 2 aspects; ▤ - 3 aspects; ■ - 4 aspects)

This demonstrated that in the process of making individual decisions not all the relevant information is used by students in their individual mental models. It might be caused by the lack of students' environmental decision-making skills, their limited memory space and incomplete mental model on this issue. The same tendency was also found with two other environmental issue topics.

During the discussions students enlarged their initial mental models with new aspects by using both additional information and the opinions of their peers. As it was expected, the number of different aspects that the students were considering in their decisions increased during the role-discussion of the Phase II. The students mainly took into account 2-3 aspects in their statements. This shift was probably caused by the collaborative decision-making process and not by the additional material that mainly consisted of the information about one area of the problem for each role-group. It appeared that the first individual mental model supported the learners in the collaborative decision-making process serving as a gauge for evaluating other alternatives and making further decisions. If this gauge was too rigid students were not capable of making competent decisions and their initial mental model remained unchanged during the whole decision-making process influencing the final decisions.

In role-decision documents in the Phase III, that expressed the structure of role groups' final shared mental models, 2-3 aspects were considered. The number of aspects that were involved was very similar to the summed content structure of individual students' mental models during the role-discussion of the Phase II. It supported the idea that the role-decision documents reflect the teams' shared mental models.

The number of aspects involved by one individual during the expert-discussion of the Phase IV was lower than in the role-discussion (Phase II) – mainly 1-2 aspects were considered. This can also be explained with the scenario of the role-play – each student was a representative of its own role and had to defend the role-document.

In expert-decisions in the final Phase V the students mainly considered 3-4 aspects in team decisions. The conclusion can be drawn that the collaborative decision-making process during the role-play enabled the individuals to enlarge their mental models and the teams to form more complete shared mental models. Therefore, the students were able to make competent environmental decisions during the joint decision-making process in CVW.

Participants in the role-discussions appeared to be more active than in the expert ones. In role-discussions the variety of aspects used by individuals in their judgements exceeded both the aspects that they had used in their individual decisions and that were considered in role-decisions. The changes that took place in the team's shared environmental mental models during the role- and expert-discussions were influenced by participants' roles and tasks. In role-decisions the aspects were overbalanced towards the aspect that the team represented. In expert-decisions the competency of decisions was revealed by balanced consideration of all the aspects.

3.2. The quality of individual and team decisions in the role-play

The structure of individual, role- and expert decisions was also evaluated using the more detailed model that took into account the strategy paths of avoiding the causes and dealing with the consequences of the problem (Figure 2). It appeared that in their initial decisions in Phase I students were seldom thinking both about the actions that could help to avoid the causes of the problem and about those that were directed to get rid of unwanted results of the environmental dilemmas (7 students). 16 students in Phase I used in their individual mental model only the path of avoiding the problem occurrence, the path of dealing with consequences appeared to be used less in individual decisions (10 students). A number of participants did not formulate their initial decisions in written notes and, therefore, it was not possible to analyse their individual mental models. Due to the result of team discussion the

content structure of shared mental models became more balanced, 14 from 20 role-decisions (70 %) were already considering both strategy paths, and the number of aspects that the team found the most relevant in their role's context was 2-4. From expert decisions eight from eleven were considering both strategy paths and 3-4 aspects, two were directed only to dealing with consequences from the viewpoint of 2 aspects and in one decision only one aspect concerning the problem avoidance was used. These data also show the gradual process of the development from individual to team's mental models. At team level the groups will be moving towards forming more balanced shared mental models of the environmental dilemmas assessed according to the proposed evaluation model for environmental decisions. In competent models both solution paths should be used from different aspects.

3.3. The influence of the formation of shared mental models on the final team decisions

One of the research interests was to investigate how the formation of shared mental models in teams is connected with the teams' final judgements. For this the Spearman correlation analysis was conducted between the variables of content aspects used in decisions and the distribution structure of shared mental models in role- and expert-teams. In the discussions, where organised shared mental models had been formed, more aspects (2-3) were taken into account during the role-discussion ($r = 0,57$; $p < 0,01$). Furthermore, the groups, who had formed the organised shared mental model during the expert discussion, had used more often 3-4 aspects in their role discussion ($r = 0,45$; $p < 0,01$). The formation of the organised type of shared mental model depended on the participants – when it had been formed during the role-discussion where the students participated, it had also been formed during the expert discussions of the same participants ($r = 0,68$; $p < 0,01$).

3.4. Changes in students' mental models after the role-play

It was also studied if the activity of role-play in the technically demanding synchronous environment will enhance students' decision-making skills on environmental issues. The individual decisions from the first role-play were compared with the students' individual decisions after the role-play on solving another environmental problem (Figure 4).

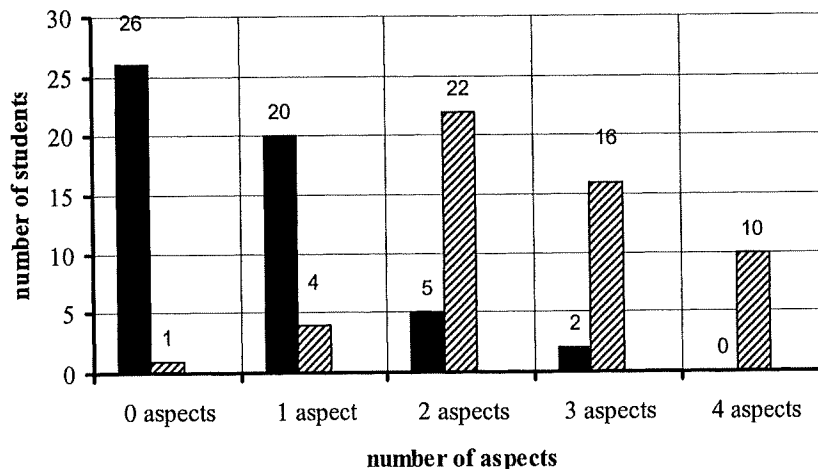


Figure 4. The number of aspects considered by the students ($n = 53$) in their individual decisions before the game in CVW (■) and in their essays after the game (▨) on the basis of five role-plays.

It appeared that the number of different aspects (scientific, ethical, economic and juridical) that the students had involved in making judgements in the second problem exceeded significantly ($\chi^2 = 28$; $p < 0,01$) the number of aspects that the participants had used in their individual decisions before the role-play. Initially the students had mostly used 1-2 aspects in making individual decisions. After the role-play the majority of them considered 2-4 different aspects in their essays. Therefore, it can be concluded that the students had obtained the awareness of the complexity of the environmental decision-making process as a result of the role-play in CVW.

4. Conclusions

This study raised both theoretical questions and practical tasks connected with developing students' environmental decision-making skills. Derry (1996) theorizes that mental models represent context dependent situational understandings and do not exist outside the situation being modelled. This leads to the assumption that students' mental models of solving the environmental dilemmas can be developed mainly through simulating the process. In the current study, the role-play in synchronous CVW environment was based on the model of multilateral environmental negotiations elaborated by Chasek (1997). It was found that the process of making judgements in a role-play supported the development of individual and shared mental models during the phases of the activity. The evaluation model for environmental dilemma problems measured the development of mental models at two-dimensional scale – as a result of teamwork the usage of different aspects of information (scientific, economic, juridical and ethical) increased from 1-2 aspects in case of individual decisions, to 2-3 aspects in case of role-decisions and 3-4 aspects as to expert judgements. If individuals mainly used one solution path for dilemmas (either avoiding the problem or dealing with consequences) in their mental models, then in the shared mental models of role-groups and especially in those of expert-groups both solution paths were used from different angles. The analysis of essays on solving the second environmental issue proved that students could effectively transfer the mental model of solving the dilemmas to the other analogical situation. This lets us to affirm that the role-play helped to enlarge students' mental models of solving environmental issues.

From the theoretical viewpoint the decision-making process during the role-play was investigated in order to get an insight look of what influences the formation of shared mental models in groups while solving dilemmas. It appeared that the role-group and expert-group discussions differed from each other as to the activeness of discussions. It was easier to find the common ground in role-groups and this enhanced the sharing of individual mental models in team. The variety of aspects discussed in role-groups was therefore bigger than in expert-groups who had to choose between the opposite alternatives of role-group decisions in order to make final judgements. One of the important presumptions of the role-play activity was that individuals would obtain their team's shared mental models if the team had sufficient communication between its members. The analysis showed that the ownership of the final mental models of role-groups during the expert discussion phase depended on the formation of the organised shared mental models in the role-groups from where the students originated.

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REALISATION OF ENVIRONMENTAL EDUCATION CONCEPTS IN TEACHER TRAINING

Kirsten Schlüter

Leibniz Institute for Science Education (IPN, Kiel - Germany)
schlueter@ipn.uni-kiel.de

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Abstract

In former German concepts of environmental education, the primary goal was to impart ecologically compatible modes of behaviour. However, analyses of empirical studies have revealed that a strong correlation between the transmission of environmental knowledge and the change of attitudes as well as a change in behaviour can not be verified. Therefore, the objectives of today's concepts of environmental education have been changed. Emphasis is to a greater extent placed on students' understanding of the complexity of environmental problems and the diversity of interests and values in our society.

An unsettled question is whether teacher trainers have already integrated these socio-ecological aspects in their lessons. This issue was investigated in an inquiry which was carried out on a representative sample of teacher trainers involved in environmental education in German-speaking Switzerland. The majority of lecturers hold lessons which correspond to different criteria of the socio-ecological approach. Current problems are discussed in classes, students are actively engaged in organising the lessons, and values are a part of the content. However, the goal which is most important to the teacher trainers does not correspond with the socio-ecological idea. Teacher trainers still set higher value on changing students' behaviour than on promoting students' understanding.

1. Introduction

Environmental education has changed in the course of recent decades. Its original *aim* was to promote knowledge and abilities which are regarded as a prerequisite for a form of *behaviour*, which takes ecological laws into consideration and is, therefore, environmentally compatible (Eulefeld et al. 1981, Klautke & Köhler 1991). However, analyses of empirical studies have revealed that a strong correlation between the transmission of environmental knowledge and the change of attitudes as well as a change in behaviour can not be verified (Hines, Hungerford & Tomera 1986, Kuckartz 1995, Lehmann 1999). Even if a meta-analysis has shown that classroom interventions can improve proenvironmental behaviour (Zelenzky 1999), the objectives of today's concepts of environmental education have been changed. The emphasis today is on the students developing an appropriate *understanding* of reality, especially of human-nature relations. This understanding includes the conditions which influence human action, the purposes of action as well as the effects on nature and society (Kyburz-Graber et al. 1997). Moreover, environmental education aims at imparting social, economic, political and technical competencies which allow the students active participation in the creation of our society's future in the sense of sustainable development (de Haan & Harenberg 1999). Even though the aims of environmental education have changed, the *didactical components* of the different concepts of environmental education are very similar.

A comprehensive *Concept on Ecology and Environmental Education* was devised by Günther Eulefeld's group at the IPN in the 1970ies (Eulefeld et al. 1981). The concept framework consisted of three components: educational tasks of the school; guidelines for instruction and an interpretation of the curriculum which was based on these. The didactical components of the concept comprise essentially three fields:

1. The inclusion of concrete subsystems which are linked with human use, which are moulded by opposing interests, which can be experienced by the students, and which pose questions relating to environmental protection (*situational orientation*).
2. The explanation of a subsystem by means of statements from different scientific areas as well as non-scientific ones. This demand for interdisciplinarity assumes the demand, however, for *action orientation*, since only concrete fields of activity are capable of illustrating the complexity of reality and, as a result, go beyond the disciplinarity.
3. The selection of ecological viewpoints which structure the processing of contents of a subsystem: a) the interlinking of the examined subsystem with other systems, (b) its *problem orientation* (compromise between holding up the function of the subsystem, its greatest possible use and the least possible negative effects when considering the different interests and values in our society), (c) its history (analysis of the evolution of the problem) and (d) its process orientation (knowledge of the dynamics of the system).

Essential elements of the *Concept on Ecology and Environmental Education* (Eulefeld et al. 1981) are also present in the *Concept of Socio-Ecological Environmental Education* by Kyburz-Graber et al. (1997). This is to be seen in the choice of didactical components which also refer to situational, problem and action orientation. In addition the *Concept of Socio-Ecological Environmental Education* attaches great importance to *value orientation* and students' *participation* in arranging the lessons.

1. Social situations in which people act and thereby intervene directly or indirectly with nature are the starting point of instruction. These so-called action systems can be represented by e.g. a household, a firm, a shopping centre or a school. The relation to everyday life gives the students the opportunity to explore the system independently and if necessary to alter it through their own actions (*situational orientation*).

2. An experience-related problem perception can be achieved by applying the Issues Analysis Technique by Ramsey et al. (1989). When determining aims, interests and moral concepts of different groups of persons who are involved in an action system or influence it externally, the students reveal the core problems themselves (*problem orientation, value orientation / societal analytical orientation*).
3. In order for the students to learn to plan and realise a project themselves as well as take over responsibility for its success, they should be involved in the planning of contents, methods and realisation of the instruction. The *Project Method* turned out to be most suitable for this (*action orientation / participation*).

It is evident that the didactical components *situational, problem, value and action orientation* are important elements because they are also present - with slight modifications - in other current didactical concepts on education for sustainable development, e.g. in the *Orientation Framework by The Federal-State Commission of Educational Planning and Promotion of Research* (BLK, 1998) and in the *Basis Concept by de Haan & Harenberg* (1999). The latter contains three instruction principles: the promotion of interdisciplinary knowledge, of participative learning as well as innovative school structures. Thus, interdisciplinary knowledge refers to everyday life, self-reflection and ethical viewpoints as well as problem solving competency.

The question now has to be posed is to what extent the mentioned didactical components as well as the changed aims of environmental education have been incorporated into school practise. In an analysis of pilot projects in German schools de Haan et al. (1997) criticised that in regard to contents subjects which are oriented toward the protection of nature, the sciences and technology still dominate. The promotion of an environmental consciousness and the training of environment friendly behaviour continues to dominate as an aim. In the sector of teaching and learning methods there are numerous innovations including - among other things - field studies, case studies and projects in environmental lessons (de Haan et al. 1997). Rode et al. (2001) ascertain that the proportion of in-service teachers which adhere to essential didactical criteria (*situational, problem and action orientation, the use of paper and experimental materials*) in their environmentally-related instruction is about 40%, whereas in the 1980ies it was only 15%. However, what is the situation like now in teacher training?

2. Issues

The following survey concerns an analysis of environmental education by teacher trainers in German-speaking Switzerland as well as about the trainers' assessment regarding the priorities of environmental education in schools. The detailed survey issues are:

Is environmental instruction in teacher training ...

1. *...situational oriented?*
2. *...problem oriented?*
3. *...value oriented and/or societal analytical oriented?*
4. *...action oriented and/or participative?*
5. *Is the promotion of understanding the primary aim of environmental instruction in schools for teacher trainers?*

3. Methods

3.1- Range of samples

In teacher training institutions in German-speaking Switzerland a letter was circulated with the request that the teacher trainers who work in the sector environmental education take part in the planned survey. From a total of 56 rectors, 46 confirmed their participation and handed in the addresses of a total of 236 teacher trainers. These lecturers then received a questionnaire on environmental education. Replies amounted to 126 which was about 50%. 120 questionnaires were included in the evaluation. Six questionnaires were invalid because the teacher trainers could not be classified with regard to a special school type or subject area.

3.2- Survey

A questionnaire was used for surveying purposes (Kyburz-Graber et al. 2001). Two sections are relevant here for answering the posed research questions:

- a) A description of the lecturers' specific environmental instruction.
- b) The aims which the lecturers regard as significant for environmental instruction.

Both sections contained closed questions whereby the response scale was divided into five (a) or four (b) categories. For the characterisation of environmental instruction (a) a special form of closed questions exists. Two contrary teaching approaches can be placed in a time ratio to each other. The teacher trainers state whether they use the one type of teaching approach much more frequently, more frequently or just as frequently as the other teaching approach. Based on the results it can be ascertained if the instruction is oriented towards the didactical components of environmental education concepts, or if this is not the case. If a teacher trainer is personally active for more than 60% of the time of teaching then the instruction is categorised as mainly not in agreement with a didactical component of environmental education. If, however, the students are active for more than 40% of teaching time then this is in regard to participation in agreement with current environmental education concepts.

3.3- Statistical analysis

In an initial step, a descriptive evaluation of the data took place. Subsequently, the items were summarised as factors by means of the reliability and factor analysis. The Cronbach Alpha value was cited as a parameter for the correlation between the individual items of a factor. In order to determine an interdependence between the different variables' single factor analyses of variance were to be carried out in a next step of the analysis. Since, however, certain response categories of several factors were seldom chosen by the interviewees, the response scale was dichotomised. Following this, cross tabs were calculated.

4. Results and Discussion

4.1- Sample Profile

A profile of the interviewed teacher trainers is to be found in Table 1. It should be emphasised that the majority of the lecturers acquire their environmental experiences as grown ups and not as adolescents. Gathering these experiences happens more when people are working in professional life and less during their period of vocational training. Additionally, the family is an important element.

Table 1. Profiles of lecturers

Criteria	lecturers [%] ¹
1) Gender	
• Women	23
• Men	78
2) Age	
• 20 - 30	2
• 31 - 40	12
• 41 - 50	36
• > 50	51
3) Taught Subjects²	
• mainly science	58
• almost no science	35
• no recognisable order	7
4) Training of teachers for ...³	
• primary level	53
• lower secondary level	25
• advanced secondary level	22
5) Place of employment	
• teacher training college	35
• teacher training college and school	65
6.1) Amount of teaching in schools⁴	
• > 20%	14
• 20-40%	14
• 40-60%	30
• 60-80%	19
• 80%	22
6.2) Amount of environmental instruction in comparison to total instruction	
• 0% ⁵	8
• > 20%	38
• 20-40%	32
• 40-60%	13
• 60-80%	2
• > 80%	4
• no data	3

Criteria	lecturers [%] ¹
7) Distribution of lessons in environmental instruction⁶	
• individual and double lessons	83
• excursions	51
• block courses	43
• project weeks	38
• project days	19
8) Co-operation	
• interdisciplinary	56
• subject intern	24
• none	18
9) Initiative for co-operation from	
• lecturers	63
• institution	19
• lecturers and institution	15
10) Co-operation partners	
• biology	74
• chemistry	53
• physics	42
• geography	41
• people and environment	31
• history	22
• home economics	22
• sewing /handicraft	21
• religion	16
• sport	10
11.1) Acquisition of environmental experience	
• in adolescence	38
• as adults	86
11.2) Acquisition of environmental experience as adults	
• during vocational training	20
• in professional life	50
• in the family	45
• in social clubs	31
• in one's circle of friends	28
• none	14

¹ = The percentage data refer to n = 120 lecturers.

² = Many lecturers teach more than one subject, above all in teacher training for primary level.

³ = It is necessary for the evaluation to classify the interviewees to a school level. However, a third of the lecturers trained the ongoing teachers for more than one school level. In these cases the level of classification was based on the earlier training of the lecturers: a complete subject course of studies (for the advanced secondary level teachers), part of a subject course of studies (for lower secondary level teachers) or without any subject course of studies (for primary level teachers).

⁴ = the data refer only to the lecturers who also teach at a school: n= 78.

⁵ = It can be assumed that these teachers are involved in topics relevant to the environment outside of their regular teaching commitments, because they were named as contact people by the school heads.

⁶ = Several responses possible.

4.2- Characterisation of Environmental Instruction

Question 1: Is environmental education in the teacher training phase distinguished by situational orientation?

For the majority of teacher trainers this question can be affirmed: 62% of the lecturers ($n=120$) give lessons which contain numerous concrete-practical elements, whereby 28% give lessons which mainly consist of general-theoretical tasks. For 10% of the lecturers, no classification could be applied since their information relating to individual items was either incomplete or they were not involved in environmental education.

The factor "situational oriented subject direction" ($\text{Alpha} = 0.72$) is composed of four items. The descriptive results on the individual items are listed in Table 2. The percent data refer to those 111 teacher trainers who carry out environmental education. Since the items were not constantly answered by all lecturers, summing up the percentages for the two contrary teaching approaches does not result in a value of 100.

The single factor analysis of variance showed the following results:

A weak but significant correlation exists between the school level and the general-theoretical direction of the instruction ($p = 0.017$). The more advanced the school level is for which the teacher trainers train their students, the more theoretical their instruction is and the more it refers to general problems instead of concrete everyday situations in the direct vicinity. For less advanced school levels, a more graphic form of instruction is in the foreground, whereby the higher levels are more in contact with a generalisation of knowledge.

Teacher trainers with *adult experience in the environmental sector* offer environmental instruction which is oriented more towards concrete-practical aims in comparison to teachers without the respective adult experience ($p=0.003$). It is conceivable that the latter lack the ideas and motivational impetus for a praxis-oriented environmental instruction which is why they prefer to refer to theoretical knowledge.

Table 2. *Situational orientation of instruction*

Instruction aspects	Lecturers [%] ¹	
	less situational orientation ²	more situational orientation ³
In environmental instruction we deal with topics ... <ul style="list-style-type: none"> • of national and international interest. • settled in the direct vicinity of the students 	33	62
In environmental instruction we deal with topics ... <ul style="list-style-type: none"> • which have to do with general environmental pollution. • which have to do with concrete everyday situations. 	22	73
Environmental instruction takes place ... <ul style="list-style-type: none"> • in the rooms of the teacher trainer college. • outside or externally (e.g. outdoor work, excursions). 	68	29
In my environmental classes, the ongoing teachers work ... <ul style="list-style-type: none"> • theoretically. • practically. 	39	58

¹ = The percentage numbers refer to those lecturers who carry out environmental instruction: $n = 111$.

² = The percentage numbers of lecturers who organise their instruction in more than 60% of the time in a general-theoretical manner.

³ = The percentage numbers of lecturers who organise their instruction in more than 40% of the time in a concrete-practical manner.

Question 2: Is environmental instruction in the teacher training phase distinguished by problem orientation?

This question can also be answered positively: 51% of the teacher trainers ($n=120$) carry out a more problem oriented form of instruction, and 39% are mostly subject oriented.

The factor "problem-oriented subject direction" ($\text{Alpha} = 0.64$) has three items. The descriptive results of the individual items are to be found in Table 3.

The single factor analysis of variance showed the following results:

Teacher trainers who consider *imparting knowledge* an important aim of environmental education organise their instruction in a more problem-oriented manner ($p = 0.010$). For them, current topics are part of the knowledge which teachers in training should consciously consider in organising their own environmental instruction. It could also be the case - according to the opinion of these lecturers - that problems can only be appropriately understood and assessed when a sufficient basis of knowledge exists.

Teacher trainers, who consider *activism* (realisation of practical work) an important aim of environmental education, also put increased value on problem orientation in their environmentally related courses ($p = 0.033$). It can be assumed that these lecturers see a possibility in practical activities to curb current problems. In this manner, an environmentally-beneficial form of behaviour is practised in class.

Table 3. problem orientation of instruction

Instruction aspects	Lecturers [%] ¹	
	less problem orientation ²	more problem orientation ³
In environmental instruction I choose ...		
• traditional topics which are dealt with in many course books.	27	
• new, controversial topics – e.g. from the newspapers.		66
As a teacher, I make sure that environmental instruction is ...		
• made to fit in with my subject area.	39	
• interdisciplinary.		58
The topics which are to be dealt with in environmental instruction		
• are determined by me as the teacher.	62	
• are chosen by the on-going teachers.		34

¹ = The percentage numbers refer to those lecturers who carry out environmental instruction: $n = 111$.

² = The percentage numbers of lecturers who organise their instruction in more than 60% of the time in a knowledge oriented manner.

³ = The percentage numbers of lecturers who organise their instruction in more than 40% of the time in a problem oriented manner.

Question 3: Is environmental instruction in the teacher training phase distinguished by value orientation and/or by a societal analytical orientation?

This question was affirmed by numerous lecturers.

It is not possible to form a unified factor from individual items by means of reliability and factor analysis. Therefore, only descriptive results are listed concerning the individual items in the following.

Table 4. *value orientation of instruction*

Instruction aspects	Lecturers [%] ¹	
	limited value orientation ²	broader value orientation ³
During instruction time when on-going teachers work practically <ul style="list-style-type: none"> they carry out natural scientific investigations. they make enquiries and conduct interviews. 	33	54
In environmental instruction the on-going teachers analyse ... <ul style="list-style-type: none"> their own environmental behaviour. the environmental behaviour of different pressure groups. 	26	60
In environmental instruction we analyse ... <ul style="list-style-type: none"> the different environmental impacts which exist. how environment. impact is assessed by different societal groups. 	42	42
If we deal with the reasons of environmental problems, we discuss <ul style="list-style-type: none"> the advantages and disadvantages of technical applications. the values and attitudes in our society. 	17	77
If we deal with the reasons of environmental problems, we discuss <ul style="list-style-type: none"> the individuals' standard of comfort. the wrong economical impulses in the society. 	16	77

¹ = The percentage numbers refer to those lecturers who carry out environmental instruction: $n = 111$.

² = The percentage numbers of lecturers who organise their instruction in more than 60% of the time in a knowledge oriented or societal critical oriented manner.

³ = The percentage numbers of lecturers who organise their instruction in more than 40% of the time in a value oriented or societal analytical oriented manner.

A variance analysis was not carried out because the formation of a unified factor was not possible from the items.

Question 4: Is environmental education in the teacher training phase distinguished by action orientation and/or by participation?

This can be affirmed for more than half of the teacher trainers ($n = 120$). In the case of 54% of the lecturers, the independent activities of the students take up a significant part of instruction. 35% of the lecturers mostly organise their course in a more teacher-centred manner.

The factor "activity-oriented subject direction" (Alpha = 0.73) is composed of three items. The descriptive results of the individual items are listed in Table 5.

The single factor analysis of variance showed the following results:

The age of the teacher trainers influences the extent to which the activities are adopted by the lecturers or the students during the lessons ($p = 0.038$). Of the teacher trainers who are older than 50, 48% are mainly active in class themselves. A possible explanation for this is that the lecturers mainly learned teacher-centred methods during their training and practised this later as teachers. From this point of view, it could have been difficult for them to replace their accustomed teaching style with new teaching methods allowing the students to work independently. In the case of the teacher trainers under 50 years of age, "only" 29% of them organise their instruction in a mainly teacher-centred manner.

Teacher trainers who see the aim of environmental education in *promoting understanding*, are more frequently active in lessons concerning environmental education than teacher trainers who do not regard promoting understanding as the central aim ($p = 0.014$). A possibility of interpretation here could be that the first group feel themselves more responsible to explicate the complexity of the discussed environmental problems to the students and not to expect the students to be able to produce a comprehensive picture independently in the time available to them.

Table 5. *action orientation of instruction*

Instruction aspects	Lecturers [%] ¹	
	less action orientation ²	more action orientation ³
Activity phases in instruction <ul style="list-style-type: none"> • I as a teacher am active. • The on-going teachers are active. 	20	76
Knowledge about the environment ... <ul style="list-style-type: none"> • I impart as a teacher. • the on-going teachers work out independently. 	30	67
For theoretical projects ... <ul style="list-style-type: none"> • I organise the study material as a teacher. • the on-going teachers look for suitable material themselves. 	71	25

¹ = The percentage numbers refer to those lecturers who carry out environmental instruction: $n = 111$.

² = The percentage numbers of lecturers who organise their instruction in more than 60% of the time in a teacher-centred manner.

³ = The percentage numbers of lecturers who organise their instruction in more than 40% of the time in a student-centred / action-oriented manner.

Question 5: Is the promotion of understanding for teacher trainers the primary aim of environmental instruction in school?

This question has to be negated: the promotion of understanding is indeed an important aim for many teacher trainers, however, it does not have utmost priority in environmental instruction. From the interviewed teacher trainers, 98% consider behavioural change, 81% the promotion of understanding, 74% imparting knowledge and 57% activism an important aim of environmental instruction.

By means of the reliability and factor analysis, the items could be summarised in four factors. In Table 6, these four factors which are the aims of environmental education are described more precisely.

It is noticeable that behavioural change is an important aim in environmental education for almost all teacher trainers. For 63% of them, this is a very important aim (the promotion of understanding is in comparison only considered by 20% as an very important aim). This attitude is understandable when considering that 90% of the teacher trainers feel individual direct measures to protect the environment are effective (Kyburz-Graber et al. 2001). This kind of measure can be carried out by everyone and it will result in a direct contribution to environmental protection, such as paying attention to environmentally friendly products when shopping. If, however, the students are to contribute to environmental protection by their behaviour, then they have to practise such behaviour. This appears to be, in the opinion of the teacher trainers, the most important task of environmental education in school. A dependency of this attitude on age, gender, school level or subject does not exist.

The single factor analysis of variance showed the following results:

Imparting knowledge is a more important aim in environmental education for science-oriented teacher trainers than for teachers of other *subject areas* ($p = 0.029$). Knowledge is, therefore, for science lecturers the basis on which the possibilities for explanations and solutions of environmental problems are to be found.

Table 6.: Percentage number of lecturers who consider the mentioned aims as important in the school sector.

Priorities in Environmental Education	Lecturers [%] ¹
1) Behavioural change (Alpha = 0.76)	
• I would like to create an awareness for environmentally correct behaviour among the students.	97
• Environmental protection should begin in the classroom.	95
• The students should recognise that they themselves can be active with simple environmentally friendly behaviour.	93
• Using energy and water economically should be normal for the students.	92
• I would like to show the students that environmental protection has to start in everyday life.	91
2) Promotion of understanding (Alpha = 0.81)	
• The students should be aware that their attitudes have been formed by certain values.	90
• I would like to reveal certain target conflicts in the field of environmental problems with the students.	76
• The students should recognise that the real problem has to do with different concepts regarding the use of nature.	75
• The students should recognise that different demands on nature lead to environmental problems.	73
• The students should experience that environmental concerns evoke resistance in the public.	58
3) Imparting knowledge (Alpha = 0.59)	
• The students should get to know indigenous animals and plants.	67
• I would like to demonstrate how the landscape has changed in the course of time.	63
• Environmental education should take place as often as possible in nature.	63
• The students should understand that nature functions in cycles. ²	94
4) Activism (Alpha = 0.79)	
• Instead of just talking about the manner, I would prefer to do something for nature with the students.	68
• I would like to make visible changes in the school building.	50
• I would like to help with the maintenance projects in nature together with the students.	50
• I would like to carry out a campaign together with the students.	47

¹ = The percentage data refer to $n=120$ lecturers.

² = This item could not be included in the factor imparting knowledge because of the results of the reliability and factor analysis.

A weak but significant correlation also exists between the preference of *knowledge imparting* in environmental education and the acquisition of *environmental experience during adulthood* ($p = 0.025$). The fact that 50% of the lecturers acquire their environmental experience in the course of their working life may offer an explanation for the linking with knowledge acquisition and/or with knowledge transmission. A further explanation would be that lecturers with *adult experience* are more conscience of the fact that environmental problems can only be correctly accessed when a sufficient basis of knowledge exists.

A significant correlation exists between the aim of instruction *activism* and the *school level* for which the lecturers educate their teacher students ($p = 0.007$). Here practical activities at primary level and lower secondary level have more impact than in upper secondary level. The increasing theoretical direction in the advanced school level corresponds to the advanced age of the students and their more developed abilities of abstraction.

The aim of instruction *activism* is held as being more important by lecturers with *environmental experience in the adult phase* than by those without corresponding adult experience ($p=0.002$). A possible interpretation for this correlation is that the lecturers during acquisition of their environmental experiences have become more acquainted with the possibilities of how to become practically involved in environmental protection and, therefore, find it easier to hand this experience down to the students.

Activism is increasingly seen by those lecturers as an important aim of instruction who consider *individual indirect instruction measures* as effective ($p = 0.002$). Political activities is what is mainly understood as individual indirect measures. The correlation can be explained in the following manner: if the teacher trainers consider it important that adolescents become involved later in political activities then they have to foster the students' initiative and motivate them to become actively involved in such causes.

5. Summary and Conclusion

The survey on teacher trainers relating to the kind of their environmental instruction showed that the majority of them teach in a manner which:

- addresses concrete-practical topics,
- is problem oriented,
- makes the discussion of value issues possible,
- promotes the students' own initiative.

Altogether, instruction seems to correspond to significant didactical criteria of environmental education concepts. However, it has to be emphasised that this result is based solely on teachers' responses. Direct classroom observations could have led to a different result.

In view of the aims of environmental education, traditional ideas tend to dominate more among the lecturers because the change in behaviour remains, in contrast to the promotion of understanding, the most important educational aim. This result raises doubts of what environmental instruction in teacher education really has a social-ecological direction. If a fostering of understanding is to be attained in instruction then it is not sufficient to realise individual sections of an environmental concept; on the contrary, the concept in its entirety has to be applied. This, however is only possible when the general conditions are suitable. A part of this is that the lecturers identify themselves with the aims of current environmental education concepts and permit the students social access to the topics. How can this access be

realised most effectively? One possibility would be to realise the suggestion put forward by Kyburz-Graber et al. (2001) and to hand over the main responsibility for interdisciplinary environmental instruction to social science lecturers.

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ALBE Virginie
Ecole Nationale de Formation Agronomique
BP 87
31326 Castanet Tolosan
France
Virginie.albe@educagri.fr

ANDERSON Trevor
University of Natal
School of Molecular & Cellular BioSciences
Private Bag X01
Scottsville 3209, Pietermaritzburg
South Africa
Anderson@nu.ac.za

BANDIERA Milena
Universita "Romatre"
Dip. di Biologia
Viale Marconi 446
00146 Roma
Italy
Bandiera@uniroma3.it

BAYRHUBER Horst
IPN an der Universität Kiel
Olshausenstr. 62
24098 Kiel
Germany
Bayrhuber@ipn.uni-kiel.de

BERGENDAHL Christina
Umea Universitet
Department of Chemistry
90187 Umea
Sweden
Christina.bergendahl@chem.umu.se

BOGNER Franz
University of Education Ludwigsburg
Institute of Natural Sciences
Reuteallee 46
71643 Ludwigsburg
Germany
Boegner_franz@ph-ludwigsburg.de

BOHUON Evelyne
LPA Caulnes
Route de Dinan
22350 CAULNES
France

BORIN Christiane
Ecole Nationale de Formation Agronomique
BP 87
31326 Castanet Tolosan
France
Christiane.borin@educagri.fr

BOULTER Carolyn
Institute of Education,
University of London
47 High Street, Theale
Lukers, Reading RG7 5AH
United Kingdom
c.boulter@ioe.ac.uk

CARVALHO Graça S.
IEC, Universidade do Minho
Avenida Central
4710-229 Braga
Portugal
Graca@iec.uminho.pt

CHRISTEN Franka
Universität Münster
Institut für Didaktik der Biologie
Fliednerstr. 21
48149 Münster
Germany
f.christen@web.de

CLEMENT Pierre
Université Claude Bernard – Lyon1
Bâtiment Forel, Université Lyon 1
6 rue Dubois
69622 Villeurbanne
France
Pierre.Clement@univ-lyon1.fr

COQUIDE Maryline
Université Paris-Sud Orsay
Bâtiment 407
91405 Orsay
France
m.coquide@wanadoo.fr

DESAUTELS Jacques
Université de Laval
Faculté de Sciences de l'Education
Québec G1K 7P4
Canada
Jacques.desautels@fse.ulaval.ca

DU PLESSIS Lynn
University of Natal
School of Molecular & Cellular BioSciences
Private Bag X01
Scottsville 3209, Scottsville
South Africa
Aubrey@futurenet.co.za

DUCAMP Christine
Ecole Nationale de Formation Agronomique
BP 87
31326 Castanet Tolosan
France
Christine.ducamp@educagri.fr

ERGAZAKI Marida
University of Patras
Department of Education
26500 Rio
Patras
Greece
Ergazaki@upatras.gr

FAVRE Didier
LEGTA Tours Fondettes
La Plaine
37230 Fondettes
France
Didier.favre@educagri.fr

FORISSIER Thomas
Université Claude Bernard – Lyon1
Campus de la Doua
69100 Villeurbanne
France
thomas.forissier@univ-lyon1.fr

GIL QUILEZ Maria José
Universidad de Zaragoza
Facultad de Educacion
San Juan Bosco nº7
50009 Zaragoza
Spain
Quilez@posta.unizar.es

GOUREAU André
Ecole Nationale de Formation Agronomique
BP 87
31326 Castanet Tolosan
France
Andre.goureau@educagri.fr

GRACE Marcus
University of Southampton
Research and Graduate School of Education
Southampton SO17 1BJ
United Kingdom
m.m.grace@soton.ac.uk

HAGBERG Mariana
Karlstad Universitet
651 88 Karlstad
Sweden
Mariana.hagberg@kau.se

HAGMAN Mats
Göteborg Universitet
Instutionen för Pedagogik och Didaktik
Box 300
405 30 Göteborg
Sweden
Mats.hagman@ped.gu.se

HAMMANN Marcus
IPN an der Universität Kiel
Olshausenstr. 62
24098 Kiel
Germany
Hammann@ipn.uni-kiel.de

HELLDEN Gustav
Kristianstad Universitet
291 88 Kristianstad
Sweden
Gustav.hellden@mna.hkr.se

HEMPTINNE Jean-Louis
Ecole Nationale de Formation Agronomique
BP 87
31326 Castanet Tolosan
France
Jean-louis.hemptinne@educagri.fr

HERAULT Dominique
LEGTA Toulouse Auzeville
BP 47
31326 Castanet Tolosan
dominique.herault@educagri.fr

HILDEBRANDT Kristin
IPN an der Universität Kiel
Olshausenstr. 62
24098 Kiel
Germany
Hildebrandt@ipn.uni-kiel.de

INGVARSSON Bengt
Kristianstad Universitet
291 88 Kristianstad
Sweden
Bengt.ingvarsson@mna.hkr.se

JANSSEN Anne
Carl von Ossietzky Universität Oldenburg
Dept. of Biology
Brommystr. 14
26121 Oldenburg
Germany
Janssen.anne@mail.uni-oldenburg.de

JELEMENSKA Patricia
Carl von Ossietzky Universität
Oldenburg
Dept. of Biology
Brommystr. 14
26121 Oldenburg
Germany
Patricia.jelemenska@mail.uni-oldenburg.de

JIMENEZ ALEIXANDRE Maria Pilar
Universidade de Santiago de Compostela
Avenida Xoan XXIII s.n.
15782 Santiago de Compostela
Spain
Ddmaleix@usc.es

KAI Pata
University of Tartu
Science Didactics Department
Vanemuise 46
51014 Tartu
Estonia
Kpata@ut.ee

KATTMANN Ulrich
Universität Oldenburg
Postfach 2503
26111 Oldenburg
Germany
ulrich.kattmann@uni-oldenburg.de

KRAMER Boy
IPN an der Universität Kiel
Olshausenstr. 62
24098 Kiel
Germany
Bkramer@ipn.uni-kiel.de

KROMBASS Angela
Ludwig-Maximilians-Universität München
Department I, Didaktik der Biologie
Winzererstr. 45, II
80797 München
Germany
Angela.krombass@lrz.uni-muenchen.de

KROSS - SANDMANN Angela
IPN an der Universität Kiel
Olshausenstr. 62
24098 Kiel
Germany
Kross@ipn.uni-kiel.de

LAPPAILAINEN Annikki
University of Helsinki
Department of Teacher Education
Po Box 38
00014 Helsinki
Finland
Annikki.lappalainen@helsinki.fi

LAQUIEZE Brigitte
Ecole Nationale de Formation Agronomique
BP 87
31326 Castanet Tolosan
France
brigitte.laquieze@educagri.fr

LAROCHELLE Marie
Faculté d'Education
Université de Laval
G1K 7P4
QUEBEC, QC (Canada)
Marie.larochelle@fse.ulaval.ca

LAVERGNE Marie-Hélène
Université du Québec
Dpt. Sciences de l'Education
4250 rue Louis-Lacroix
G8Y 5V2 Trois-Rivières, Québec
Canada
Marie-helene.lavergne@tr.cgocable.ca

LEWIS Jenny
CSSME, University of Leeds
Leeds LS2 9JT
United Kingdom
j.m.lewis@education.leeds.ac.uk

LUDE Armin
Universität Kassel
Didaktik der Biologie
Heinrich-Plett-Str. 40
34132 Kassel
Germany
Lude@uni-kassel.de

MACKENSEN Iris
IPN an der Universität Kiel
Olshausenstr. 62
24098 Kiel
Germany
mackensen@ipn.uni-kiel.de

MAGNTORN Ola
Kristianstad Universitet
291 88 Kristianstad
Sweden
Ola.magtorn@mna.hkr.se

MAGRO Alexandra
Ecole Nationale de Formation Agronomique
BP 87
31326 Castanet Tolosan
France
Alexandra.magro@educagri.fr

MARTINEZ-GRACIA Maria Victoria
IES Medina Albaida
Cesareo Alierta, 104 esc izda 3º, 4
50013 Zaragoza
Spain
Vmarti12@almez.pntic.mec.es

NARANJO Jose Antonio
Universidad de Granada
Facultad de Ciencias de la Educacion
Campus Universitario de Cartuja S/N
18071 Granada
Spain
Jnaranjo@ugr.es

NERDEL Claudia
IPN an der Universität Kiel
Olshausenstr. 62
24098 Kiel
Germany
Nerdel@ipn.uni-kiel.de

NEUHAUS Birgit Jana
Universität Kassel
Didaktik der Biologie
Heinrich-Plett-Str. 40
34132 Kassel
Germany
Birgit.neuhaus@uni-kassel.de

OHLY Karl Peter
Universität Bielefeld
Department of Biology
Universitätsstr. 23
33615 Bielefeld
Germany
Kpohly@uni-bielefeld.de

OTTANDER Christina
Umea Universitet
Dept. of Mathematic, Technology and
Science Education
90187 Umea
Sweden
Christina.ottander@educ.umu.se

PETTERSEN Sverre
Akershus University College
Ringstabekkveien 105
1356 Bekkestua
Norway
Sverre.petersen@hiak.no

PICARD Friederike
Institut für Didaktik der Biologie
Fliednerstr. 21
48149 Münster
Germany
Fpicard@t-online.de

PRECHTL Helmut
IPN an der Universität Kiel
Olshausenstr. 62
24098 Kiel
Germany
precht1@ipn.uni-kiel.de

PRONZATO Nina
Ecole Nationale de Formation Agronomique
BP 87
31326 Castanet Tolosan
France
Nina.pronzato-asloum@educagri.fr

REISS Michael
 Institute of Education, University of London
 20 Bedford Way
 London WC1H 0AL
 United Kingdom
m.reiss@ioe.ac.uk

ROBOTTOM Ian
 Deakin University
 Department of Science Education
 Geelong Campus
 Victoria 3217, Melbourne
 Australia
Ian@deakin.edu.au

RUPPERT Wolfgang
 Institut für Didaktik der Biologie
 Universität Frankfurt am Main
 Sophienstr. 1-3
 60487 Frankfurt am Main
 Germany
w.ruppert@em.uni-frankfurt.de

SANDER Elke
 Carl von Ossietzky Universität Oldenburg
 Dept. of Biology
 Carl-Von-Ossietzky-str. 9-11
 26111 Oldenburg
 Germany
Elke.sander@uni-oldenburg.de

SCHLUETER Kirsten
 IPN an der Universität Kiel
 Olshausenstr. 62
 24098 Kiel
 Germany
schlueter@ipn.uni-kiel.de

SCHMITT-SCHEERSOI Annette
 ZFMK
 Lessingstr. 52
 53113 Bonn
 Germany
a.schmitt.zfmk@uni-bonn.de

SCHNEEBERGER Patricia
 Université Victor Segalen Bordeaux 2
 La Vialonne
 33540 Sauveterre de Guyenne
 France
Schneepat@aol.com

SIMONNEAUX Jean
 Ecole Nationale de Formation Agronomique
 BP 87
 31326 Castanet Tolosan
 France
Jean.simonneaux@educagri.fr

SIMONNEAUX Laurence
 Ecole Nationale de Formation Agronomique
 BP 87
 31326 Castanet Tolosan
 France
Laurence.simonneaux@educagri.fr

SPOERHASE-EICHMANN Ulrike
 Institut für Didaktik der Biologie
 Universität Frankfurt am Main
 Sophienstr. 1-3
 60487 Frankfurt am Main
 Germany
Spoerhase-eichmann@em.uni-frankfurt.de

TIBELL Lena
 Linköping University
 IBK, Department of Cell Biology
 581 85 Linköping
 Sweden
Lenti@ibk.liu.se

TOUSSAINT Rodolphe M.J.
 Université du Québec
 Dept. Sciences de l'Éducation
 CP 500, 3351 Boulevard des Forges
 G9A 5H7 Trois-Rivières, Québec
 Canada
Rodolphe_toussaint@uqtr.ca

TUNNICLIFFE Sue Dale
 Institute of Education,
 University of London
 20 Bedford Way
 London WC1H 0AL
 United Kingdom
S.tunncliffe@ioe.ac.uk

UITTO Anna
 University of Helsinki
 Department of Teacher Education
 P.O. Box 38, Ratakatu 6A
 00014 Helsinki
 Finland
auitto@helsinki.fi

UPMEIER ZU BELZEN Annette
 Universität Münster
 Institut für Didaktik der Biologie
 Fliednerstr. 21
 48149 Münster
 Germany
annette.upmeier@upmeier-zu-belzen.de

URHAHNE Detlef
 LMU München
 Didaktik of Biology
 Winzererstr. 45 II
 80797 München
 Germany
Urhahne@lrz.uni-muenchen.de

VAILLAUD Marcel
 BP19
 37 270 Mont louis sur/Loire
 France

VAN EIJCK Michiel
 Amstel Institute, University of Amsterdam
 Kruislaan 404
 1098 SM Amsterdam
 The Netherlands
Meijck@science.uva.nl

VERHOEFF Roalo
 Centre for Science & Mathematics
 Education
 Universiteit Utrecht
 Dept of Biological Education
 Princetonplein 5
 3584 CC Utrecht
 The Netherlands
R.P.Verhoeff@phys.uu.nl

VIGIER Audrey
 LEGTA Tours Fondettes
 La Plaine
 37230 Fondettes
 France
Audrey.vigier@educagri.fr

VOGT Helmut
 Universität Kassel
 Didaktik der Biologie
 Heinrich-Plett-Str. 40
 34132 Kassel
 Germany
Helmut.vogt@uni-kassel.de

WAARLO Arend Jan
 Centre for Science & Mathematics Education
 Universiteit Utrecht
 Dept of Biological Education
 Princetonplein 5
 3584 CC Utrecht
 The Netherlands
a.j.waarlo@phys.uu.nl

WALLIN Anita
 Göteborg Universitet
 Box 300
 405 30 Göteborg
 Sweden
Anita.wallin@ped.gu.se

YARDEN Anat
 Weizmann Institute of Science
 Department of Science Teaching
 76100 Rehovot
 Israel
Anat.yarden@weizmann.ac.il

ZOGZA Vassiliki
 University of Patras
 Department of Education
 26500 Rio, Patras
 Greece
Zogza@upatras.gr

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