P.L. Lijnse (ed.)

EUROPEAN RESEARCH IN SCIENCE EDUCATION

Proceedings of the first Ph. D. Summerschool

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editor

European Research in Science Education

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Preface

The first of January 1992 was meant to be an important date on our way to a more united Europe. For me, it functioned as a trigger to try to set up some cooperation in European science education research. In a letter to several groups and centres working in this field, I asked their opinion about this idea. As a result, in September 1992, a number of people came together in Utrecht to discuss further possiblities. It was decided that, as a first activity, we would start organising regular PhD summerschools, of which the first trial would take place in Utrecht in July 1993, the second in August 1994 in Thessaloniki. From then on, summerschools may be organised every two years by an European Association for Research in Science Education to be established in the meantime.

As planned, in July 1993, about fifty people, thirty PhD's and twenty staff members, came together in a nice conference centre in Driebergen, Holland, to discuss their research and learn from each other. At the end, everybody present had the opinion that such a summerschool is a potentially very worthwhile activity to be continued and improved.

The present volume contains the proceedings of this first summerschool. As you may notice, it is largely written in broken English. This points to one of the main problems in European cooperation, the many different languages, for which we have to seek and find solutions. It asks from everybody an effort in trying to understand one another. These proceedings have been moderately edited to the extent that at least I myself now have the impression to understand the language of what has been written. I hope that the participants still recognise their contributions. This procedure seemed to me the only one that would not take too much time. Nevertheless, this volume is published much later than originally planned. I'm sorry. May it in bringing together and making explicit part of what is done in Europe, play a stimulating role in extending and intensifying our communication and cooperation.

December 1993

The editor

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Information about the first Ph.D.Summer-school for Research in Science Education

Dates: from Saturday July 3rd, till Friday July 9th, 1993.

Place: Conference Centre 'Kerk en Wereld', Driebergen, The Netherlands

Participants: 30 Ph.D.students and 18 senior staff.

Scope: the summerschool was devoted to 'Research in Science Education'. This included research on:
- learning and teaching of science;
- history and philosophy of science in relation to science education;
- history and philosophy of science education;
- computers in science education;
- developments in scientific literacy, e.g in field centres or museums;
- science aspects of health and environmental education.

Aims: the summerschool was for and by the Ph.D.'s. The aim was to provide an opportunity to learn from colleagues who are facing similar problems. This means that most of the time was spent on letting the students report about and discuss their own research. Another aim was to set up a network of working contacts between students and between research groups. Therefore overviews of research that is done by the participating groups were reported and discussed.

Format: each student prepared an outline of his/her work (2- 3 pages A4). It contained information about: the topic of research, the methodology used, preliminary results and possible questions to be discussed. These outlines were distributed to all participants well in advance. At the school, each student presented the main lines of his/herwork for ca. 20-30 minutes. The presentation was followed by a one hour discussion (so, in total 1.5 hour per student). This discussion was as informal as possible. It was the intention that students got the opportunity to present problems instead of solutions, to ask questions and to have rough data/video's/protocols/lesson materials, etc. available sothat discussions could take place within a 'context of discovery', instead of 'justification'.

To create a 'safe' atmosphere, three groups were formed that stayed together during the week. Each group was led by senior staff members, who acted as discussion leaders, participated in discussions and were responsible for a plenary report about the group work. Sufficient time was programmed for informal and social contacts, and for possible ad hoc activities. A staff meeting took place to discuss further activities.

Staff contributions: These contributions were twofold. Some staff members presented a 'state of the art' view of some important topics. Others presented an overview of the research done in their own group.

Language: the language was English. However, it was the intention to create a 'language-friendly' atmosphere. This meant that in discussions and presentations, one had to be aware of the fact that non-native speakers of English could have difficulty in expressing their views precisely, sothat patience and mutual help could be necessary.

Proceedings: after the summerschool, the outlines of student-research projects had to be 'corrected' and extended (4-5 pages A4), according to the discussions that took place, sothat they could be published in the proceedings. This also applied to the papers of staff members. The main reasons to publish proceedings are: for the students to learn to write a condensed paper about their research; for the research community: to get an overview of the research that is done in Europe.

Certificate: students who attended the summerschool have got a certificate that indicates that they have followed an advanced level course.

Programme:

Saturday July 3rd.

14.00 - 15.00.	Arrival and registration
15.00 - 15.30.	Welcome address(P.L.Lijnse)
15.30 - 16.30.	Plenary lecture (R.Driver) Constructivism: what it says to Research in Science Education.
16.30 - 17.30.	First group meetings: coming to know each other, establishing the order and procedure of presentations.

Sunday July 4th.	
9.00 - 10.15.	Plenary session (J.Ogborn): Research on Modelling and the role of Mathematics in Science Education.
10.30 - 12.00.	Parellel group work
14.00 - 15.30.	Parellel group work
16.00 - 17.30.	Plenary session (research in Utrecht and Montpellier)
Monday July 5th.	
9.00 - 10.15.	Plenary session (L.Viennot): Fundamental Patterns in Common Sense Reasoning
10.30 - 12.00.	Parellel group work
14.00 - 15.30.	Parellel group work
16.00 - 17.30.	Plenary session (research in Leeds and York)
19.30 - ??	Business meeting for staff members
Tuesday July 6th.	
9.00 - 10.15.	Plenary session (P.Adey): Science Education and Research in Cognitive Science
10.30 - 12.00.	Parellel group work
14.00 - 15.30.	Parallel group work
16.00 - 17.00.	Plenary session (research in Bremen)
18.45 -	Coach departure for a boat trip through the canals of Amsterdam.
Wednesday July 7th.	
9.00 - 10.30.	Parellel group work
10.45 - 12.15.	Plenary session (research in Essen and Paris 7)
14.00 - 15.30.	Parellel group work
16.00 - 17.30.	Plenary session (research in Lyon and Thessaloniki)
Thursday July 8th.	
9.00 - 10.15.	Plenary session (J.Donnelly): Science Education and Research on the 'Nature of Science'
10.30 - 12.00.	Parellel group work
14.00 - 15.30.	Parellel group work
16.00 - 17.30.	Plenary session (research in London (I.E and King's)
Friday July 9th.	
9.00 - 10.30.	Plenary group reports
11.00 - 12.00.	Closing discussion

Participants summerschool

Staff

1. C.Macaskill (IE, London)
2. J.Ogborn (IE, London)
3. L.Viennot (Paris 7)
4. E.Sumfleth (Essen)
5. D.Cros (Montpellier)
6. A.Sivade (Montpellier)
7. D. Psillos (Thessaloniki)
8. R.Millar (York)
9. J.Donnelly (Leeds)
10. R.Driver (Leeds)
11. U.Hericks (Bremen)
12. H.Schwedes (Bremen)
13. P.Adey (King's, London)
14. A.H.Verdonk (Utrecht)
15. P.L.Lijnse (Utrecht)
16. H.M.C.Eijkelhof (Utrecht)
17. J.Gréa (Lyon)
18. J.Viard (Lyon)

Ph.D.students

1. F.Chauvet (Paris 7)
2. M.Schwob (Paris 11)
3. A.Pitton (Essen)
4. M.Alonso (Valencia)
5. B.Franc (Montpellier)
6. E.Pittman (I.E,London)
7. E.Maragoudaki (I.E, London)
8. F.Stylianudou (I.E, London)
9. A.Barbas (Thessaloniki)
10. A.Spirou (Thessaloniki)
11. V.Barker (York)
12. M.B.Key (York)
13. P.M.Kind (Oslo)
14. P.Scott (Leeds)
15. E.Alexopoulou (Leeds)
16. C.M.Chang (Leeds)
17. E.Mortimer (Leeds)
18. B.Langensiepen (Bremen)
19. K.Nickolopolou (King's, London)
20. G.Bissuel (Lyon)
21. A.Gay (Lyon)
22. D.Lacroix (Lyon)
23. P.Dekkers (Amsterdam)
24. H.van Keulen (Utrecht)
25. B.van Berkel (Utrecht)
26. A.Jongbloed (Amsterdam)
27. W.Kaper (Amsterdam)
28. G.van Hoeve (Utrecht)
29. M.Vollebregt (Utrecht)
30. C.Klaassen (Utrecht)

Plenary lectures

Welcome address

P.L.Lijnse
CSME
Utrecht University

Dear colleagues,

Welcome everybody at this first experimental European Ph.D. Summerschool for Research in Science Education. As a group we consist of two parts, Ph.D. students and staff members, coming from fourteen different groups, all working on research in science education. The primary aim of this Ph.D. Summerschool is of course to be of some value for the research that you, as Ph.D's, are working on. An aim that is pursued by providing a platform for presentation and discussion of your work, by hearing about what is going on elsewhere and, not the least, by getting to know each other, which may enable the setting up of a network of worthwhile working contacts.

Now, it happens to be the case that the concept of a 'Ph.D. student' is not a very clear one. It needs for some of you maybe even some conceptual change. Some of you are experienced teachers, working parttime on a research project. Others have recently graduated in one of the science disciplines and only followed a teacher training course, as a minimal preparation for working full time on a thesis, while again some others are preparing a thesis as part of their work as a staff member, involved in teacher training and/or other work in science education, based on their experience as a qualified teacher.

Related to this difference in background and experience is a difference in formal requirements as regards postgraduate training, of which this summerschool is meant to be a part. Some of you are required to follow quite a number of courses; some have already done so, as, e.g., for the French D.E.A. or in having obtained a British master's degree in education; while others are not required to follow any formal courses at all. This variety probably mirrors the fact that research in science education is in most countries still a relatively new phenomenon, which implies that it is, both for students and staff alike, useful to try to learn from and help each other. Particularly as the number of people working in our field is in most places, or even countries, relatively small. This means that international cooperation is not only necessary to increase the quality of our work, but it may also be strategically essential for several groups in order to survive in present difficult times. So, therefore, lets join our forces and try to cross the boundaries that are set by languages, national cultures, research traditions and school systems. A timely aim to pursue, I would say, in view of a future Europe.

These were the reasons why, last year, I have taken the initiative to contact a number of groups in order to try to set up a regular opportunity to meet each other. At which we could discuss concrete Ph.D. research projects, in relation to the research programmes of which they are a part and the rationales behind them. The latter reflects my concern that the development of productive research programmes is one of the main difficulties in our field. In order to make progress, we should exchange views and discuss at the programme level, as much research seems to be done rather small scale and accidentally.

In a preparatory meeting in Utrecht, last September, we discussed this matter. The idea of summerschools for Ph.D's was further worked out. It was decided that a first experimental school would take place here, that the main focus would not be on lectures, but on the presentation and discussion of and by the students themselves. This is clearly reflected in the programme for this week. The presentation of the work of the participating groups is chosen as a second focus. I think this to be a first and necessary step in getting to know each other better.

As said, this first summerschool is an experimental one. This means that you should feel free to express your comments about the content, organisation and format. We should learn the most we can from this week, sothat we can organise a better one next year in Thessaloniki.

Nevertheless, I very much hope that already this week will be a successful and useful one to all of you.

Science Education Research and Cognitive Science

Ph.Adey
King's College London
Centre for Educational Studies

1. Introduction

Gardner (1987) defines cognitive science as 'a contemporary, empirically based effort to answer long-standing epistemological questions - particularly, those concerned with the nature of knowledge, its components, its sources, its development, and its deployment' (p.6)

I believe that all educators, and especially science educators, should take an interest in cognitive science because (a) it is a science and (b) it has the potential of unlocking some fundamental laws by which meaning is made and learning takes place. This is expressed by the American philosopher Willard Quine arguing (before the term cognitive science was in common use) for the importance of modern epistemology: 'It studies a natural phenomenon, viz., a physical human subject. This human subject is accorded a certain experimentally controlled input - certain patterns of irradiation in assorted frequencies, for instance - and in the fullness of time the subject delivers as output a description of the three-dimensional external world and its history. The relation between the meagre input and the torrential output is a relation that we are prompted to study for somewhat the same reasons that always prompted epistemology; namely, in order to see how evidence relates to theory, and in what ways one's theory of nature transcends any available evidence.' (Quine, quoted in Gardner, 1987, p.71).

Notwithstanding this rather optimistic stance, it must be admitted that cognitive science is still in its youth. There remains a significant gap between the experimenters working on the detail of memory, perception, neuropsychology, and children's conceptions, and theoreticians who attempt to build explanatory models of learning (how humans come to know things) and production (how they generate new formulations). This gap between empirical data and explanatory model is still a fertile field for hypothesis generation to produce models which save the face of facts as we now know them, but these models are either rather specific to particular situations or too general to allow testable predictions to be made from them. There is a parallel with, say, chemistry at the turn of the century. The ideas of atoms and molecules were pretty well accepted, and Mendeleef had produced a wonderful classification system which allowed predictions to be made on empirical grounds, but until Rutherford, Bhor, and others developed an electronic model of the atom we could not really see *why* prediction from the periodic table worked so well. Cognitive science is after the equivalent of the electronic model of the atom and research in science education can make a contribution to the search.

What I propose in do in this paper is, firstly, to present a rather general way in which current themes in science education research may be categorised and the extent to which research in each theme does address the concerns of cognitive science and, secondly, to describe our own work in cognitive acceleration simply as one example of the potential of science education research for contributing to a long-running debate in cognitive science.

2. Themes in science education research

In this section, current themes in science education research are categorised. The original set of categories was drawn from experience and then the set of papers presented at this summer school (an unfair advantage in being a late paper-writer!) were used to add to, distinguish between, and refine the themes. I then attempted to apply the categorisation system to all papers which appeared in the 1992 and 1993 (so far) volumes of the *International Journal of Science Education*. This led to some further refinement but generally confirmed the applicability of the system. This origin means that the system has a distinctly European flavour, but extension to the *Journal of Research in Science Teaching* would increase its transatlantic reliability. For each category I have provided a name, brief description of what is included in that theme, and a note of the main research goals and the main educational goals of research in that theme. At present I have not provided examples, which would be necessary if the system were ever to have value beyond the present paper.

3. Some provisos

- Any set of objects can be categorised in a variety of ways. A categorisation system has no ultimate validity apart from utility for a particular purpose.

Thus I will not attempt to defend this particular system of categorising themes, or to suggest that it has any use beyond the present paper.
- The categories of themes merge into one another.
- It is rare for any research paper/project to be concerned purely with one theme, some span two or three.
- The order in which they are presented can only show one dimension of a multi-dimensional array of organisation.
- No value judgements are implied either by the order of presentation or by the titles or descriptions of the themes.
- Not included in the system at present are research of an historical or policy-related nature, or descriptions of curriculum innovations whose only 'research' element is evaluation.

4. Categories of themes in science education research

Effective instruction

Investigation into techniques which improve the quality and quantity of scientific knowledge in students. Techniques investigated include various uses of computers, methods of text processing, concept mapping, the use of illustrations or practical work, museum use, and many more.
Research goal: to determine the most effective ways by which students acquire concepts.
Educational goal: the attainment of correct scientific concepts.
There is not a strong relationship between effective instruction research and cognitive science since this theme in the European research tradition is not much concerned with theories of cognition. Rather, it addresses directly the concerns of science educators who wish to improve their practice using empirically validated techniques.

Competence

Describing, cataloguing, and exploring how students acquire general capabilities within specific domains - for example general physics competencies, science process skills, or 'kinds of understanding' children need for science or particular sciences. While not as sharply focussed on particular content as effective instruction research, this theme has a domain specific focus and builds on the procedural knowledge characteristic of that domain.
Research goal: better understanding of the competencies and how they are acquired.
Educational goal: the development of the competencies.

Notwithstanding its more general focus subject-wise, competence research is no more concerned with cognitive science than is effective instruction. Work in this area is somewhat prone to include philosophical analysis of the nature of competence peculiar to the domain of science.

Assessment

Techniques of assessing knowledge, concept, or competence acquisition. Includes analyses of validity and efficiency of assessments.
Research goal: better understanding of the relation between students' knowledge etc. and their output in test situations.
Educational goal: improvement of assessment methods.
Research in assessment tends to be technical and statistical in nature, with a tendency to search for accurate measures of subject's 'true' knowledge, competence, or skills.

Concepts

This is probably the largest current area of research in science education, and we might distinguish two sub-themes:

a. Eliciting, describing and categorising types of conceptions ('correct', 'scientists', 'alternative', 'common', 'mis-' conceptions) held by students at various ages and in various contexts. This includes both children's concepts of physical phenomena and explanations, and also their concepts of the nature of science.
   Research goal: better description of typical conceptions held by students.
   Educational goal: by knowing what students' current conceptions are, the teacher is better equipped to help the child develop more sophisticated concepts.
b. Conceptual development; the progression of concepts with age, or over time, or during an instructional process. Also conceptual profiling - varieties of conceptualisations of a given phenomenon held by one individual according to context.
   Research goal: understanding the process of concept origin (in the sense of origin in the outside world of texts and parents and popular inputs, rather than in internal cognitive structures), formation and development.
   Educational goal: improvement of teachers' understanding of the process of concept development should help them to help children to scientists' concepts.

The main thrust of the very considerable body of research into children's science concepts and their development has been descriptive and classificatory and as such has provided a rich account of patterns of development of concepts within particular science topics. Generally speaking, beyond adopting a broadly constructivist perspective, research in this theme neither appeals to cognitive psychology for justification nor aims to contribute to the development of general cognitive models.

5. Social construction of concepts

Investigation of the dynamics of concept construction in social settings -how groups interact, the influence of peer-group pressure, etc.
Research goal: Better understanding of the social processes by which consensus is reached.
Educational goal: More effective attainment of socially acceptable concepts.
Cognitive science is not much concerned with the social construction of knowledge, and actually seems rather embarrassed by it because of the vast increase in variables which occurs when you add interactions between people to the already profound complexity of individual human cognition. It is symptomatic that Gardner's (1987) widely acclaimed account of the history and concerns of cognitive science contains, in over 400 pages, only one reference to Vygotsky, and that in a list of names of Europeans who were beginning to get some attention in American intellectual circles.

6. Cognitive structure

Again, two sub-themes can be discerned, distinguished by the origin of the curiosity that the research is intended to satisfy.

a. Investigations into the influence on science concept formation of various cognitive schema - how these schema assist in or hinder the formation of science concepts, and how science teaching / learning can help to develop appropriate and useful schema. Schema include mental models, analogies, phenomenological primitives, and those of concrete and formal operations. Clearly this use of the word 'schema' encompasses a wide variety of explanatory models. What they have in common is that they are not obvious, are described with difficulty, remain hypothetical, but have the potential of providing rather general explanations for the patterns of concept formation recorded by research in the 'concept' theme, above.
   Research goal: provide an explanation for patterns of concept formation.
   Educational goal: (somewhat remote) a better understanding of deep structures should help in the design of more effective instruction. Intervention studies have development of the schema as their goal.

b. Uses investigations of science concepts not for its own sake but as a tool or probe to understanding the nature of cognitive structures.
Research goal: understanding the nature of the mind.
Educational goal: remote, maybe none.

It is the difference in their origins and educational goals which distinguish these two sub-themes. While (a) is essentially psychology in the service of science education, (b) is essentially science education in the service of psychology. It is in this theme that there is the most direct link between research in science education and cognitive science and it is from this theme that I will draw the example to be described in the second part of the paper.

7. Nature of science and of science learning

a. Philosophical insights into the methods of science particularly as it relates to the way science knowledge is transferred, shared, or mutually constructed. Essentially epistemological in focus.
Research goal: enriched philosophical insights into knowledge construction
Educational goal: more concerned with broad influences on the style of the curriculum than on specific educational objectives
The quote from Quine at the beginning of this paper indicates the intimate link between philosophical analysis and cognitive science. It is especially in the youth of a new science that philosophy is required to clarify possible types of meanings and suggest what is empirically testable and what is not.

b. Analyses of bodies of scientific knowledge or of materials which present such knowledge. Includes conceptual analysis of the subject matter, or of texts or pictures, and analysis in relation to professional needs.
Research goal: understanding the structure of a subject or of materials which present it.
Educational goal: (rather long term) potential improvement of the instructional process (see 'effective instruction' above).
This type of analysis is more instrumental, and like the 'effective instruction' theme has little to say to cognitive science.

8. Attitudes

The investigation of students' attitudes to science, to learning science, to particular sciences; the development of attitudes, and attempts to change attitudes; gender, cultural, and age variants in attitudes.
Research goal: to investigate correlates of attitudes and possibilities of influencing attitudes.
Educational goal: to improve certain groups' perceptions of the sciences.
Almost by definition, cognitive science is not much concerned with the affective domain, and the same sort of 'arms-length' relationship exists as with the 'social construction' theme.

Cognitive Acceleration through Science Education
I turn now to the second part of this paper, describing one example of research in science education with which I am familiar and seeing how it contributes to cognitive science.

9. Domain specific or domain general?

The 'long-running debate' to which I referred earlier concerns the issue of domain specificity of thinking. Those who encourage us to focus on domain specific skills point to, for instance, the failure of the Newell-Simon General Problem Solver to address other than mathematical or well-defined problems, to the enormous differences between the genius of Einstein and the genius of Piacsso (Gardner, 1983), to the absence of any model of cognition underlying the notion of IQ, and to the well established necessity for experts in a field to have a substantial semantic and procedural knowledge base related to that particular field. On the other hand, those who consider that thinking skills across all domains are controlled by some sort of central processor in the mind hold up as evidence the correlations between performance in a great variety of tasks and the anecdotal evidence of teachers that some children are just generally brighter than others.

On the issue of promoting thinking, domain-specific protagonists emphasise at least the necessity for the knowledge and strategies of the particular domain. More particularly, they would point to the necessity of developing the child's strategic thinking skills domain by domain. They would not consider that apprenticeship into problem solving skills characteristic of one domain, say mathematical thinking, would be likely to have any effect on performance in another domain, such as literary criticism.

The responses of those who focus on a general processor are more equivocal. There may be extreme heredicists and extreme maturationists who say simply that not a lot can be done about promoting general thinking skills, since they are set in genetic concrete or must wait on natural growth processes. I do not think that many now would subscribe to such a deterministic view. But concentration on some kind of cognitive central processor is also a feature of developmentalists who, at the same time, emphasise the importance of the physical, social, and intellectual environment in maximising cognitive development. As soon as we accept that the environment has an effect, we may relate the process of education to the positive manipulation of the child's environment thus opening the way to the possibility of improving students' cognitive processing capability (general thinking skills) by appropriate teaching procedures.

10. Transfer

What would count as evidence for such procedures being effective? Well, it is not difficult to dream up a simple research design in which an experimental group was subjected to some intervention programme aimed at positively affecting their general thinking skills and then comparing their achievement to a matched control group. In particular, what one would be looking for would be evidence of enhanced performance of the experimental group in domains far removed from the domain of the intervention programme. This is what is meant by far transfer, and it has been the relative failure of very many attempts to provide convincing evidence of far transfer which has strengthened the position of those who claim that domain specific strategies are the only ones worth the attention of educators. It remains an open question whether the failures have been due to the actual impossibility of achieving transfer, or to the discovery that the intervention methodology of seeking transfer turns out to be far more difficult and expensive than can be accommodated within the normal PhD span or the period typically supported by research funding agencies. Anyone who allows themself to be deterred from the search for general thinking skills by such an apparent failure should consider of the words of Nickerson, Perkins, and Smith (1985):

If (teaching thinking) cannot be done, and we try to do it, we may waste some time and effort. If it can be done, and we fail to try, the inestimable cost will be generations of students whose ability to think effectively will be less than it could have been. So we are better advised to adopt the attitude that thinking can be taught, try hard to teach it, and let experience prove us wrong if it must. (p.324)

This was the attitude adopted by Michael Shayer and myself in the early 1980s, after our work of the '70s had indicated a significant mismatch between the levels of thinking (described in Piagetian terms) available in the school population and the expectations and demands placed upon their thinking by curricula, especially science curricula. (Shayer and Adey, 1981).

A review of attempts to promote the development of formal operations (Adey, 1988) revealed the usual rather mixed bag of effects but two very useful straws in the wind were provided by Kuhn and Angelev (1976) and Rosenthal (1979). In different ways they avoided attempts to instruct pupils directly in the schemata of formal operations, focussing rather on (a) establishment of the concrete tools which are necessary precursors to the development of formal operations, and (b) putting students in a position where they had to construct the formal schemata for themselves in order to solve problems.

11. The CASE project

CASE stands for Cognitive Acceleration through Science Education. By 'Cognitive Acceleration' we mean bringing forward the use of formal operations, as compared with the norms already established. Science seemed to offer a field in which higher level thinking had already been well-described, but the "through" in the project title is important. We were investigating the possibility of using the domain of science as a gateway into the central cognitive processor.

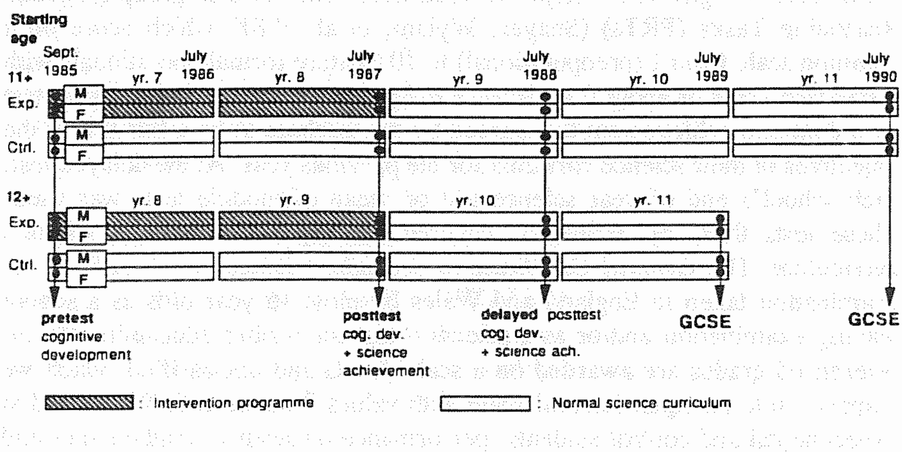

figure 1: The experimental design and testing programme

Figure 1 summarises the experimental design that we used, showing the duration of the intervention and indicating the testing occasions. A total of 20 classes in seven schools representing a variety of environments in England were selected and assigned to experimental and control conditions such that there were experimental and control classes in each school. Four experimental classes were of the 11+ age group (UK year 7), and six of 12+ (year 8). These separate cohorts will be referred to simply as the '11+' and '12+' groups. The ten experimental classes started in 1985 to receive an intervention programme called *Thinking Science* , with one regular science lesson replaced by an intervention activity once every two weeks. Overall the *Thinking Science* lessons took about 25% of the normally allotted science time. The intervention programme was introduced to teachers through a series of one-day workshops followed up by visits to the schools during which lessons were observed and discussed with the teacher. After the two year intervention programme, students were no longer maintained in identifiable 'experimental' and 'control' groups, but mixed together as they chose options for the subjects they would continue with. In the case of three of the 11+ classes, the end of the intervention coincided with the end of the middle school period, and pupils were dispersed to a number of different high schools.

Testing occasions were *pre-test*, before the intervention began; *post-test*, immediately after the two year intervention; *delayed post-test*, one year after the end of the intervention, and the General Certificate of Secondary Education (*GCSE*) taken two (for those who started at 12+) or three (for those who started at 11+) years after the end of the intervention.

The tests of *cognitive development* used were demonstrated group Piagetian Reasoning Tasks (PRTs) (Shayer, Wylam, et al. 1981) which score on a common scale from 1 (preoperational) to 10 (mature formal operational) with a standard error of about 0.4. *Science achievement* was assessed at post-test by a common achievement test agreed by the teachers to be a fair test of the objectives of their science curricula for the previous year. At the delayed test, each school's end of year science test or mean of module tests was used. These tests thus, by definition, covered the objectives of each school's curriculum. The *General Certificate of Secondary Education* (GCSE) is the examination taken in England and Wales by most 16 year olds as a school leaving examination and/or as a selection test for further education. Norm-referenced grades are awarded on a scale A - G and unclassified which we mapped on to an equal-interval scale with values 7 down to 0. We looked at experimental and control students' performance on science, mathematics and English GCSE.

Details of the results have been reported piecemeal as they occurred (Adey and Shayer, 1990; Shayer and Adey, 1991; Shayer and Adey, in press a and b) and the main results explored in some detail in Adey and Shayer (1993, 1994). Here I would like to concentrate on the long term results. Table 1 shows the significant effect sizes in terms of residualised gain scores of experimental as compared with control classes in each school. It can be seen that with the 11+ group, girls who during their years 7 and 8 were exposed to the intervention programme performed significantly better than girls in control groups in national measures of science, mathematics and English language achievement, three years after the end of the intervention. With the 12+ group, boys made significant gains in all subjects, with the addition that 12+ girls made gains in English.

Table 1: Significant effect sizes (in standard deviation units) of gains of experimental group over control group at GCSE, 2 and 3 years after the end of the intervention

Sex and starting age	Science	Maths	English
11+ boys	-	-	-
11+ girls	0.67	0.72	0.69
12+ boys	0.96	0.50	0.32
12+ girls	-	-	0.44

Three important features emerge:
- the effects are long term, showing up 2 and 3 years after the end of the intervention;
- there is far transfer from the science content of the intervention lesson to performance in English; and
- there seems to be some gender-age interaction.

I would like to dispose of the last point first, because although it is tempting to say that the intervention works with girls when they are 11 - 12, and boys when they are 12 -13, the full data do not allow us to be sure about this. There were other systematic differences between the 11+ and 12+ groups which make direct comparison between them uncertain, and results from more recent studies have shown no such gender differences.

Of the the other two features I believe that we can be quite confident. We have long term far transfer. The effects was found across all of the schools in our sample, and was not confined either to the more able or to the least able.

What was the nature of the intervention programme, and by what mechanism do we believe that it worked? Although it has been shown often that the schemata of formal operations such as control of variables, proportionality, and probabilistic thinking cannot be taught by direct instruction, they nevertheless provide a useful framework within which to set a cognitive intervention programme, especially in science. Reviews of the literature (Adey, 1988; Goossens, 1989) on cognitive acceleration had suggested certain features which should maximise an intervention programme's chances of bringing about long-term effects on the general ability of learners. These include:

Cognitive conflict

This is the term used to describe an event or observation which the student finds puzzling and discordant with previous experience or understanding. All perceptions are interpreted through the subjects' present conceptual framework. Where current conceptualisation fails to make sense of an experience, constructive mental work by students may lead to accommodation and a change in their conceptual framework. Kuhn, Amsel and O'Loughlin's (1988) investigation of the coordination of new evidence with existing cognitive schema confirms that instances of cognitive conflict do not automatically produce a 'Road to Damascus' conversion to a new conceptualisation. Younger and less able pupils often seem not to see that there is a conflict, or at least not to be bothered by it. But if there is no conflict, then there is no chance of accommodation. In Vygotsky's (1978) words:

> '...learning which is oriented toward developmental levels that have already been reached is ineffective from the viewpoint of a child's overall development. It does not aim for a new stage of the developmental process but rather lags behind this process. .... The only "good learning" is that which is in advance of development' (p.82).

Concrete preparation

But you cannot hit students with conflicting situations without preparing them first with the language and terms of the problem with which they are going to be faced. Formal operations only operate on a situation that has first been described by the subject in terms of descriptive concrete models. Thus concrete preparation involves establishing that students are familiar with the technical vocabulary, apparatus and framework in which a problem situation will be set. Each activity includes a concrete preparation phase, and some activities are devoted totally to concrete preparation.

Metacognition

It is now widely accepted (Nickerson et al., 1985; Perkins and Salomon, 1989) that students are more likely to develop wide-ranging thinking skills if they are encouraged to think about their own thinking, to become aware of the strategies of their own thinking and actions. This is what is meant by *metacognition*. In a *Thinking Science* lesson, the teacher asks pupils to talk about difficulties and successes they have with problems, both with the teacher and with each other - not just 'that was difficult' but 'what was difficult about it, and how did I overcome the difficulty?'. Students become accustomed to reflect on the sort of thinking they have been engaged in, to bring it to the front of their consciousness, and to make of it an explicit tool which may then be available for use in a new context. Using the words to describe reasoning patterns is another aspect of metacognition. The aim is that CASE students should not only be better equipped to recognise, say, a proportionality problem when they see one but that they should be able to say 'That's a proportionality problem!' and so open the door to a particular set of solution strategies. This is a special application of what Vygotsky (1978) describes as the use of language as a mediator of learning. The language of reasoning mediates meta-learning.

These features, provided with context by the reasoning patterns of formal operations, set the guidelines by which the intervention programme was drafted, pre-trialled, used in the experiment, and subsequently published (Adey, Shayer and Yates, 1989).

12. Mechanisms?

Being a good constructivist I must accept that any proposal I make for a mechanism by which the long term far transfer was achieved will be interpreted through the spectacles of the paradigm within which I am working. Thus my preferred hypothesis for the mechanism involves an influence of the intervention programme on the underlying cognitive structure of the mind such that it now becomes generally more powerful and more effective at processing new data, from whatever domain that data comes. I will, however, entertain some other possible explanations which are often raised at this point when I present our results.

Confidence?

The suggestion is sometimes made that the intervention has boosted the confidence of students in their own abilities, and that this in turn improved learning across domains. The problem with such an "explanation" is that the notion of confidence is not operationalised or made measurable and therefore does not lend itself to further exploration or falsification. As such it does not provide us with an explanation at all. Even if we were to find a way of operationalising confidence, this hypothesis would be faced with the difficulty of explaining why the difference between the experimental and control pupils actually increased as the years went by. One would expect pupils who had been pumped up by being told that they were clever during a special intervention programme would show the greatest effects immediately at the end of the programme, but that the effect would become diluted and waste away with time. In fact, just the opposite occurred.

Language training?

An apparently simple explanation of how pupils who followed the *Thinking Science* programme subsequently performed better in English is that of a direct training effect. This supposes that while the programme was set in a science context, it encouraged reasoned discussion amongst pupils exploring the meaning of new vocabulary in the search for explanations of physical events. This enrichment of language use is then supposed to persist (in memory?) and show up in enhanced performance in general English tests two and three years later. I find it implausible that a language-development effect which is almost incidental to the aims of the programme, and is set in a science context, could be so long-lived and become generalised. A more deep-rooted explanation seems to be necessary.

13. Conclusion

Perkins and Salomon (1989) distinguish between a 'high road' and a 'low road' to increasing academic achievement. Efficient instruction within a transmission paradigm may be described as the low road, while they claim that the high road is achieved when students improve their general cognitive strategies which can be applied across a broad domain or field. The question with which I started this section was 'just how general can those strategies be? Perkins and Salomon's ambition seems to be limited to the sort of possibilities explored by 'competence' research. I suggest that the CASE evidence for long term far transfer implies that there is a deeper level yet of general cognitive structure which can be encouraged to develop through educational intervention techniques. An enhanced central cognitive processing mechanism is able to maximise the effect of the instruction received in a wide range of academic domains.

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Fundamental Patterns in Common Reasoning: examples in Physics

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1. Introduction

Numerous studies about pupils' or students' ideas in physics have been published in the last fifteen years. One of the main features of such research is to be content-specific: starting from the idea that learners actively build their knowledge from 'where they are', and with 'what they have', it is necessary to know as much as possible on these 'where' and 'what' about diverse topics in science , especially about those that are usually taught at school. Different terms were used to designate what was documented in this part of learners' knowledge (Driver e.a., 1985; p.8). From the beginning, we used in our laboratory the word 'reasoning'. Soon, the adjectives 'spontaneous' or 'natural' were simply replaced by 'common', we shall see why below.

This paper draws on fundamentally content-dependent studies, in the sense that all the analysed results concern answers and arguments about physics. Some of these studies have been deliberately focused on transversal aspects of common reasoning, i.e. on aspects that can be observed about very different domains of physics. Some others have been designed to document learners' ideas about very specific content, but have given results that appear as similar from one study to another, if we read them afterwards with certain 'glasses'.

The goal here is to illustrate some of these tranversal aspects, in an organised presentation, and with a stress on what seems the most important, i.e on ways of reasoning used by many persons about many topics. Yet, not everything is said here, of course, nor is the frame used for this paper presented as a theory of common thinking, in which everything else should find its place.

Not much is said about the methodology of the quoted studies. In order to feed a possible oral discussion on this point, semi-detailed examples are given in appendix. In each of the proposed 'sheets', the reader can find outlines of results and instances of questions or investigation materials used in the research.

2. Thinking with 'objects'

A first trend appears as very general in common arguments, from one topic to another: when analysing physical phenomena, people like to put into play 'objects'. Besides real objects, they ascribe a realistic character to physical concepts or models. They build their reasoning on these 'objects' as if they were material. There are diverse aspects in this trend:

"Grasping a thing"

- A signal propagating on a rope is seen as a material object: for instance, it is said that it goes faster if the initial shake is stronger, or its length is unaffected by a change in the rope thickness (Maurines, 1992).
- An optical image seems to be understood as travelling in space as a whole: it is said that it can be seen on a screen without an optical device between the source and this screen, or that a coin on a lens will make a hole in the image previously visible on a screen (Goldberg and Mac Dermott, 1987; Feher and Rice, 1987; Fawaz, 1985; Kaminski, 1989).
- A trajectory is seen as a thing in itself, irrespective of a reference frame: a straight line will remain a straight line in any frame of reference. The same can be said of 'a vertical trajectory' (there are other factors to keep the trajectory vertical: Saltiel and Malgrange, 1980). Travelled distance, a reference-dependent quantity, is also manipulated as an intrinsic quantity, such as the length of a stick .
- A ray of light can be seen as an object, it cannot be divided (refraction and reflection are mutually exclusive)(see for a review: Perales e.a., 1989).
- Microscopic particles are seen as macroscopic objects, and endowed with corresponding properties. Particles would swell, shrink, melt, etc, to account for dilatation, contraction, melting of solids (Driver e.a., 1985; and the 'macro-micro' conference in Utrecht, 1989)

Animism

It has been frequently noted that a certain amount of animism was observed in common arguments, especially, but not only, in children and adolescents: the air 'wants to', 'molecules need room', 'the mass is stronger than the spring', etc. Then not only things are considered as real objects, but they are seen, to a certain extent, as living objects.

Abolute properties ascribed to objects

Driver and al (ibid., p. 194) describe, under the heading 'limited focus', 'the propensity of children to interpret phenomena in terms of absolute properties or qualities ascribed to objects rather than in terms of interactions between elements of a system'. Among the quoted examples, iron would be 'naturally cold', or the fact that 'a substance burns or not' would be 'solely a property of the substance itself'. This aspect of common reasoning meets with what will be said below concerning 'functional reduction'.

'Supplies of...' ascribed to objects

Not frankly animistic, but in fact not very far, is the observed tendency toward ascribing a 'supply of something' to moving things, in order to explain their motion. Especially worth noting is the following type of statements: the upward force of the mass (Viennot, 1979), 'the force stored in the bump' (Maurines, 1991, see also about sound: 1993). Surprisingly enough, this very important aspect of common reasoning, for example in elementary dynamics, has not much retained the attention of the researchers community. It seems in fact quite decisive in the way students analyse situations in mechanics. This trend, indeed, blurs the question of what a force is acting on, and therefore favours an undifferentiation between Newton's second and third laws: interactions are seen as conflicts between objects of which the stronger wins, which leads to the writing of equations between balancing forces which are not acting on the same objects.

In the domain of elementary dynamics as well as concerning propagating signals, this feature of reasoning goes with the idea of 'using up' of the supply - at the top of the trajectory, at some distance along the rope - (Viennot, 1979; Maurines, 1991). The physical nature of the 'supply' is discussed below, but in any case, ascribing it to a moving object fills a need for a cause: the cause is stored in the object, a nearly animistic view, as suggested above. Links between realism in thought and difficulties in dealing with algebraic quantities are very strong: they are discussed in Viennot (1981).

3. Functional reduction: several converging modalities

By 'functional reduction', we mean that not enough variables have been taken into account for the problem considered. Reasoning with only one variable at a time is a well-known tendency (Piaget, 1972, concerning the relationship $L=VT$), and the first reason for this trend is obviously a need for simplicity. I comment here on the importance of this phenomenon for physics, and on its possible reinforcement by other aspects of common reasoning (Viennot, 1988a, 1992).

Understanding of the word 'constant' as 'characteristic of an object'

One manifestation of functional reduction in students' reasoning is a truncated comprehension of statements implying the word 'constant'. Often such statements convey a functional meaning, especially because they refer to non evident independencies. Instead, they seem to be understood as if the word 'constant' was only synonymous of 'characteristic of an object'. Then, only variables that might affect the 'constant' are envisaged, while variables of which the constant is independent, i.e. the interesting ones, are ignored. Results and further analysis can be found in Viennot (1988).

Undifferentiated notions

One of the findings very strikingly similar across different pieces of research is the fact that common arguments put into play undifferentiated notions, or, in other words, mononotional reasoning, where the physicist would use several concepts. Different physical quantities thus appear, in such arguments, as different facets of the same notion. Saying that two or more physical quantities X, Y, ... are 'combined' into an undifferentiated notion does not imply any hypothesis about the genesis of the global notion. It only means, in this paper, that X and Y are indifferently used in common statements. It also refers to arguments that express a systematic co-variation of the 'component concepts X, Y', for instance: 'X $\uparrow \rightarrow$ Y $\uparrow$ ', etc. Such an adherence in fact constitutes a functional reduction since at least two physical quantities are manipulated as a single one.

For instance, 'supplies' mentioned in the preceding section can be indifferently expressed in terms of 'force', 'motion', 'velocity', 'energy', 'impetus'... 'of the mass', on the one hand and 'force', 'velocity', 'height', 'power'...'of the bump' on the other. Such quantities might be, in students reasoning, only different aspects of a kind of 'tonus'. A similar combining of physical quantities is cristallized in the expression 'thermal motion'. Asked about the meaning of this expression, students use nearly indifferently the words 'energy', 'velocity', 'disorder'. Collisions between molecules are also mentioned. It appears (Rozier, 1988; 1991) that mean speed of molecules and mean distance between particles are often manipulated by students as two adherent notions, combined into the idea of thermal motion: 'molecular kinetic energy in a gas is larger than in the corresponding liquid', as students quasi unanimously say about two phases yet at thermodynamic equilibrium. This view might be underlaid by that of a collective 'tonus': 'molecules need more room to move faster'.

Another example is the very well known indifferentiation between current and voltage in electric circuits. Again, one might say that these two words serve, in common statements, as indicators of the 'strength' of 'electricity' (Closset, 1983; Shipstone e.a., 1988)

Considering these 'combined notions', one can envisage them from a causal point of view: 'cause' and 'effect' seem not to be differentiated, with sometimes a misunderstood 'effect'. Thus force and velocity (instead of acceleration), potential difference and current, electric field and current (Viennot and Rainson, 1992), density of charge and potential (Benseghir, 1989). This point of view is probably relevant in the case of 'heat and temperature', one of the most famous couples of undifferentiated concepts.

When the 'effect' is a movement, the causal content of the combined notion is especially manifest, as said before. It is attested, in particular, by the situation-dependency of this feature of reasoning. Thus the 'supply of force' ascribed to a moving body is preferentially invented by students in situations where a motion is salient and not easily explained by a well known interaction force (gravity, push,..) (Viennot, 1979). This is what Gutierrez and Ogborn (1992) call, after De Kleer and Brown (1983), a 'mythical cause'. If only data about forces are given, the same students much less frequently use this combined notion in their reasoning and often correctly associate force with acceleration, i.e., with different possible velocities (Viennot, 1979). This asymmetry with respect to the axis cause-effect can be interpreted in different ways (effect better analysed when not salient, or more frequent non univocity of the cause → effect link as compared to the effect → cause one), but in any case, it seems to confirm the validity of a causal interpretation of the observed amalgams.

Linear reasoning

In fact, the trend towards functional reduction extends much beyond the preceding modalities. When considering multivariable problems, people often give arguments that constitute linear chains of the type: $\Phi_1 \rightarrow \Phi_2 \rightarrow \Phi_3 \rightarrow \Phi_N \rightarrow$ ...., where each phenomenon Φ is specified with only one variable, or more generally corresponds to a single action. In other words, the links are of the type 'one cause → one effect' described also for instance by Gutierrez and Ogborn (1992). One might say: 'one cause is enough for a given effect'. It is worth noting that this feature of reasoning is observed even if other causes have important contributions. An example at university level is the type of comment given to explain the increase of pressure in an adiabatic compression of a gas:

'Volume (V)A $\searrow$ → particle density (n) $\uparrow$ → number of collisions $\uparrow$ → pressure p $\uparrow$'.

Concerning pressure, it reflects an exclusive link of this quantity with particle density. The other relevant factor, namely the mean speed of particles, is twice ignored. This constitutes a 'preferential association', here between pressure and particle density. It is very commonly observed. Reasoning with such linear chains about multivariable problems leads to ad hoc arguments, and to inconsistencies (Rozier and Viennot, 1990): for instance one cannot 'explain' the low pressure in attitude by the implication 'particle density (n) ↑ → pressure p ↑ ', and a hot air balloon saying 'hot air → particle density (n) ↘ ' , without a contradiction concerning pressure inside the hot air balloon. Maurines (1986) also reports on contradictions raised by this one-to-one causal analysis.

Induced chronology and story-like arguments

The status of arrows in the preceding outline given for linear arguments is a very important question. These apparently logical connections in fact reveal to be loaded with a temporal meaning: an arrow does not mean only 'therefore', but also 'later'. The totally ambivalent word 'then' favours this ambiguïty between logical and a chronological levels (Rozier, 1988). These story-like arguments contradict the accepted theory of quasistatic phenomena, in which several quantities change simultaneously under the permanent constraint of certain relationships.

An example at university level, concerns isobaric heating. Arguments frequently have the following structure:
'Supply of heat → T ↑ → p ↑ → V ↑ '.

The apparent contradiction between the statement 'p ↑ ' and the data: 'isobaric heating' disappears if the causal chain in fact is interpreted with two steps: first step with volume kept constant, then second step after the piston is released. This is indeed what some students explicitely specify.

Linear causal reasoning: some consistent features

Rozier (1988) used the label 'linear causal reasoning' to designate a way of reasoning showing the two preceding aspects: linear an chronological. The similarity of the corresponding arguments with stories is striking: simple successive events, which are more or less causally linked. This consistently goes with the following features of reasoning:
A lack of symmetry in arguments: Concerning one of the situations described above, namely the adiabatic compression of a gas, one can find the argument 'V ↘ → p ↑ ' which seems quite acceptable at first sight. In the other situation, i.e., isobaric heating, a common comment is 'p → V', while reversing the above argument would give 'p ↑ → V ↘ '. How is it that this last implication seems so surprising? Also, why does the second implication

seem so natural despite the fact that it contradicts the contravariation between p and V expressed in the first one? This is probably because behind the two first arguments, there are stories instead of relationships. If a relationship such as 'pV = Constant' was the justification adopted for the first implication 'V ↘ → p ↗ ', the reversed implication would seem as natural. More probably, there is a chronology and a particular story implied in each of the easily accepted arguments: 'One reduces the volume of a gas by pushing on it, then pressure is increased' (first implication), or: 'one heats a gas then pressure is increased, then volume gets larger'. Which story might we imagine for 'internal pressure is increased then volume decreases'?

Thus, chronology is the most important obstacle to reversibility in implications, and therefore, as said before, to quasistatic analysis. Gutierrez and Ogborn (1992) comment on this lack of symmetry and use it to interpret some circular arguments, where an increase in a quantity can be seen as its own effect.

Driver et al., (ibid, p. 1985) also describe another type of lack of symmetry, which bears on the sense of variation of quantities: 'Pupils appreciate the effect of an increase in pressure of an enclosed body of gas, yet they have difficulty anticipating the effect of a reduction in pressure'. In this case the predominant aspect of linear causal reasoning is probably not so much chronology than taking into account a single cause - internal pressure - instead of a balancing out between internal and external pressure. At higher academic levels, this type of obstacle is, in this particular case of compression or expansion of a gas, of minor importance as compared with that of an induced chronology. But it is still present, and both linear and chronological aspects of common reasoning seem to reinforce each other in many cases, especially in the analysis of steady-state situations (see below).

Permanency: a forgotten case

Understanding phenomena as successive, consistently leads to seeing them as temporary, or at least hinders a reasoning in terms of permanency. This is indeed what is observed in common reasoning. Steady states of desequilibrium, such as that of a green-house or of a bolometer, often raise such comments: 'more energy gets in than out, so the temperature is higher'. Here the reasoning correctly takes into account two simultaneous flows, but it is implicitly focused on the (previous?) phase of change ('heating') and fails to explain the steady-state (permament high temperature). What would result from unbalanced flows of energy in the long term - an explosion - is not envisaged. This implicit focus on a transient phase prevents one from controlling the validity of the argument with an analysis of the long term evolution of the system. We suggest to complete Driver's et al.'s statement 'an important aspect of childrens' causal reasoning is that change requires an explanation' (ibid. p.195) by the following: 'surprising steady states are commonly 'explained' by an argument implicitely focused on change'.

Spatial order: a support for linear causal reasoning

Quite intentionally, most of the examples given above are not chosen among physical situations strongly determined by spatial order. The sequential character of linear causal reasoning is all the more striking, when, for example, pressure and volume of the same body of gas, in the same vessel, are sequentially coped with. But if spatial order is salient in the situation, the sequential trend is all the more important in students' reasoning. The most famous example is the sequential reasoning in electric circuits (Closset, 1983; Shipstone, 1983). A pioneer work in this field is that of Fauconnet (1981), who in particular very clearly showed the context-dependency of common reasoning, about problems of the same mathematical structure, and the determining impact of a spatio-temporal content. Other examples are available, for instance concerning thermal conduction along a rod (Rozier, 1988) and hydrodynamics (Closset, 1991).

Linear causal reasoning: an extension across different domains of knowledge and teachers.

Economy and ecosystems are among the numerous domains in which manifestations of linear causal reasoning are very common. A topic not developed in this paper.

Also teachers contribute to to these ways of reasoning, in a certain 'resonance' between explanations commonly given and linear causal reasoning. In many pieces of research quoted above, an analysis of teachers' ways of reasoning in the same domains is done. It appears in many cases (mechanics, electric circuits, elementary thermodynamics, optics, etc) that teachers and textbooks often give the same erroneous statements as the students. Popularisation papers also participate in that kind of global reinforcement of common ways of reasoning on the part of the informative or teaching environment.

A point especially worth noting has been made in particular by Closset (1983): a given way of reasoning may seem to have disappeared in a population of higher academic competency, because a typical erroneous answer to a given question is not observed any longer at this level (say: two bulbs in a series circuit are now said to light the same). In fact, this is not the case: the problematic situation in question is mastered, but a new question still unusual to this group raises anew the same feature of reasoning (for instance: two capacitors in series are said to be charged in different times, especially if their capacities are different). A 'local' learning has occured, but the deep-rooted feature of reasoning is still acting.

From the point of view of ways of reasoning, transitions between 'novices' and 'experts' are very smooth (Viennot, 1988b).

Another fact is probably quite determining in students' unawareness about the outcomes of a careless use of linear causal reasoning: when they want to 'make their students understand' using verbal explanations, teachers tend to use story-like arguments. An example is given in Rozier and Viennot (1991): although written by a very good physicist who perfectly masters the topic, a text may be misinterpreted by students because of a resonance between its chronological connotation and the students' trend towards linear causal reasoning.

4. Common reasoning and common experience

Two expressions are often associated in research papers: 'students' ideas' and 'everyday experience', as if this correspondence was straightforward. It is suggested that common ideas originate in everyday life, kinaesthesic and sensorial experience. Certainly nobody can deny the importance of such factors in knowledge development. But one can easily find counterexamples which show that such a link is sometimes very unlikely, at least if it is understood as a direct connection.

Fauconnet (1981), for instance, brings about examples in which students' personal experience about springs cannot directly account for their answers. The same can be said about sequential reasoning in electricity. White and Gunstone (1992, p.47) also give an example of such an apparent disconnection in 13-15 year old Australian students: given equal volumes of water and cooking oil placed during the same time in the same beaker on the same hot plate, students rarely predict that the oil will have a greater temperature when the water is boiling. Their arguments to support erroneous predictions do not rely on everyday experience.

It is not really surprising, in fact, that personal experience does not necessarily 'speak directly' to students. Students' reluctance in admitting 'experimental evidence' has been described by many researchers (see, for instance, Johsua and Dupin, 1989; Driver e.a., 1985). Common ways of reasoning may screen 'everyday evidence' as well as 'experimental evidence' that teachers try to put into play. Most probably, the more transversal the way of reasoning at stake, the harder it is to accept the contradiction of 'facts': a point to document further.

No less probable, such general trends of thought are also rooted in everyday experience, but the link is much less direct. They might be a resurgence of the whole structure of our life, with events succeeding each other, and memories focused on a single dominant feature at a time.

5. The question of pedagogical goals

The research findings presented above may suggest specific pedagogical implications. Given the need for taking into account students' ways of thinking, what more is learnt from the fact that transverse aspects of common reasoning are put in evidence? Does it suggest that we should face these aspects as such in teaching? The preceding results throw some light on the question, but not yet much on the answer. Only some remarks can be made.

Different levels of 'transversality' in teaching goals

The same erroneous common statement can be coped with at different levels in teaching, for instance: *'Collisions between molecules produce heat',*

- any attempt to provoke a conceptual evolution about this idea
- including these attempts in work about
  . heat and temperature,
  . macro-micro relationship
- discussing the problem of steady-states and divergence of unbalanced flows in the long term .
- *'If there is no more lens, the image is no more affected, it goes onto the wall without being reversed.'*
- any attempt to provoke a conceptual evolution about this idea
- work also on the idea that information may be invisible and diluted in space.

Conceptual teaching goals of higher levels are rarely mentioned in syllabuses, probably because they do not easily coincide with a possible chapter in a textbook. Being transversal, they seem to become invisible in official instructions, as if the only general teaching goals worth mentioning, concern attitudes and experimental abilities.

'Higher level' refers, in the preceding paragraph, to the level of transversality. But such teaching goals may intervene at low academic level, with very simple situations. For instance, multivariable reasoning might be introduced about the area of a carpet, or about the volume of an aquarium. More research about teaching-learning processes in this field would be very useful.

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6. Concluding remarks

The role played by causal explanations in reasonings described above is prevalent. By the way, it is possible to see causality in nearly every argument given by students. As shown above, linear causal reasoning is a good candidate to account for the observed comments. However, some different modalities in this very general way of reasoning can be tentatively suggested, following Rozier (1988).

Sometimes, the focusing on a real or invented object (the heroe of a story) goes with arguments in which time plays an explicit role. Often, then (projectile, bump on a rope, electricity, ...), the analysis of variables is simplified by combining several of them in a single ill-defined notion, ascribed to the object. Then, saying that one of the facets is increasing/decreasing (for instance height of a bump) implies that another (for instance velocity of the bump) also increases/decreases. Such a covariation does not imply any shift in real or 'mythical' time: in this sense, causality is not directly in play. By contrast real time is ruling the evolution of the undifferentiated notion in space, with a very simple handling of causality (give, take, using up of a supply, ...).

At the other end of a continuum, the 'heroe' is not globally in motion, and is characterized by several quantities well identified as different (for example a mass of gas). The evolution of the object is then commonly commented upon through a linear causal analysis in which the quantities or simple phenomena are envisaged one by one, in causal chains implying, to various extents, chronology (with real or 'mythical' time). Rozier (1988) suggests that in students' explanations, the two types of complexity - spatio temporal and multivariable analysis - each develop at the expense of the other.

This is an opportunity to come back on the more or less conjectural status of the type of description of students' reasoning that can be proposed. The last remark, done by Rozier, is at such a distance from the 'experimental facts' that we must indeed consider it as rather conjectural, while keeping a vigilant eye on the idea. To which extent are the other ideas in this paper 'validated by the facts'? Certainly each idea is supported by research findings. But is each proposed idea the only way of accounting for these research results? Shall we simply speak of functional reduction or assume the implicit underlying idea of an invented object? Shall we see such and such covariation as simply expressing the simultaneous evolution of two facets of this object, or shall we decide that it is an instanciation of a causal scheme?

More globally, what size shall we aim at for our 'synthetic description', 'theory', etc, of students' reasoning in science? The pitfalls to avoid are, at the two ends of a continuum, a 'not synthetic at all' description, close to a catalogue of types of comments, on the one hand, and such a general theory that it can be adapted to any observed student's series of comments or actions, on the other hand. These two extreme cases have in common the absence of any risk. I suggest we need to work in between these two ends with several sizes of description. It is what I have tried to do in this paper. In order to allow a separate discussion of each 'brick' - a piece of research refering to a chapter of physics, a paragraph about 'constants', 'combined notions', or 'animism', etc - and permit the reader to keep some 'middle-sized descriptions' even if the more global one (linear causal reasoning in Rozier's sense) is not agreed on. This use of different formats of description are, I suggest, necessary to ensure the best possible control concerning the fruitfulness of our conjectures. This is also important, as shown above, to help define teaching goals of different 'sizes', and therefore to contribute to designing teaching strategies.

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Modelling Clay for Computers

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1. Abstract

How can students of all ages use the computer to model the real world? Modelling systems which iteratively solve difference equations are now common, and useful for older students. But they require that the world be imagined as composed of variables, not things. And they need some minimum mathematical sophistication. This paper discusses two new modelling tools suitable for quite young students, which could provide an introduction to modelling. One tool allows systems of variables to be constructed, without having to specify mathematical relations between them. The other provides for interacting objects whose behaviour can be specified, again without mathematics, through drawing 'before and after' pictures to express interactions of objects. It is argued that the different types of models fit naturally into a developmental sequence, matching modelling at various ages to student's intellectual growth. A radical re-sequencing of teaching about Mathematics in Science is proposed.

To create a world, whether constituted of variables or of objects, and to watch it evolve is a remarkable experience. It can teach one what it means to have a model of reality, which is to say what it is to think. It can show both how good and how bad such models can be. And by becoming a game played for its own sake it can be a beginning of purely theoretical thinking about forms. The microcomputer brings something of this within the reach of most pupils and teachers.

2. Iterative modelling systems

We all know how to make simple iterative computational models (Roberts et al, 1983). Like many others I too have written modelling systems which use this idea (Ogborn, 1984; Ogborn and Holland 1986). An obvious example is a model of getting money from the administration for one's department - a matter of wide general interest. If the additional fractional appropriation in any year is proportional to how strongly one argues, but is also sensitive to how near an upper limit of funding one has already got, a model might look like Figure 1, which shows how it would appear on the screen in our Cell Modelling System CMS (Ogborn and Holland, 1986). As is well known, this logistic model will show chaotic behaviour if the growth rate (strength of argument) is too large, which may be true of at least some institutions.

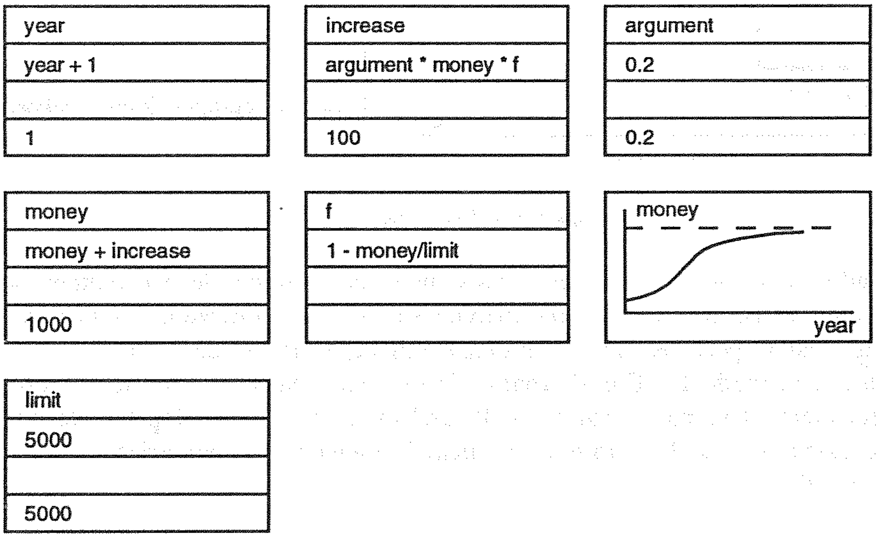

figure 1: Logistic growth model

Such models may be an excellent way to teach calculus. It is easy to build a variety of models, and they can be more realistic than models to be solved analytically. Plenty of suitable systems exist for doing this, from STELLA to one's favourite spreadsheet. The advantages and disadvantages of the computational and analytic approaches look something like:

Computational solutions	*Analytic solutions*
Steps close to physical reality	Formal methods of integration
Accessible early in learning	Needs previous mathematics
Adding complexity is easy	Adding complexity is difficult
Only particular solutions	General, manipulable solutions

Because the existence of analytic solutions is very sensitive to the detailed structure of the differential equations (in particular often requiring them to be linear) adding a small real life complexity to a problem may produce a very sharp rise in the mathematical difficulty of solving it. Figure 2 fancifully sketches a relation between the difficulty of getting a solution and the amount of reality the model includes.

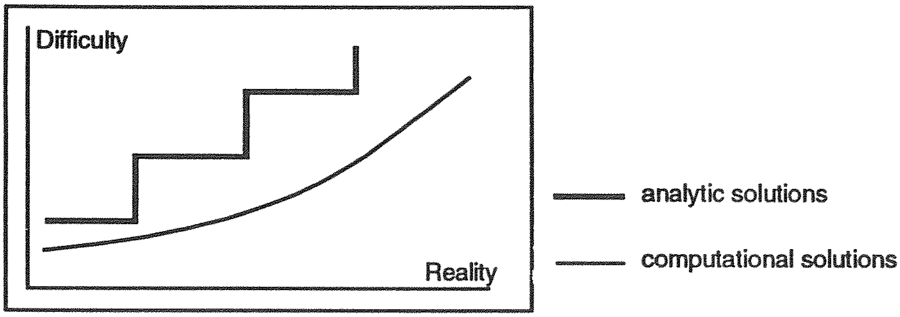

figure 2: Difficulty and reality

Traditionally, we teach Science and some calculus alongside one another, so as later to be able to develop analytic solutions for differential equations. Much later, perhaps only in graduate school, is the student introduced to numerical methods. The alternative is to teach Science by means of some very elementary numerical methods, and to use this to develop the ideas of the calculus so as later to develop analytic methods and numerical methods in parallel.

3. Modelling without mathematics

Up to now, what has been suggested is hardly revolutionary. The next suggestion is more shocking: it is that we need to begin modelling without mathematics. Consider what is needed if one is to make models of the kind discussed so far:

1. Imagining the world constituted of *variables*
2. Conceiving physical relations as *mathematical relations* between variables
3. Giving appropriate *values* to variables
4. Seeing a model as a structure with *possibilities*.

Of these, the first is perhaps the hardest. As scientists we have become so used to imagining the world as analysable as the interaction of quantitative variables that we forget what a huge step in imagination this is. There is good evidence, supported by commonsense observation, that young students see the world as built of objects and events, not as built of variables.
We have built, and tested with students in the age range 12-14 years, a

modelling programme which focuses just on imagining variables and the connections between them, without having to specify the form of mathematical relations. It was developed in the project Tools for Exploratory Learning, in association with Joan Bliss, Rob Miller, Jonathan Briggs, Derek Brough, John Turner, Harvey Mellar, Dick Boohan, Tim Brosnan, Babis Sakonidis, Caroline Nash and Cathy Rodgers. The background to this project is given in Bliss and Ogborn (1988, 1989). The design of the modelling programme is in Miller et al (1990) and results are discussed in Bliss, Ogborn at al (1992) and Bliss and Ogborn (1992). The modelling system is called IQON (Interacting Quantities Omitting Numbers). In IQON one creates and names variables, and links them together graphically. The best introduction is by example: figure 3 shows what an oscillator looks like when expressed in IQON.

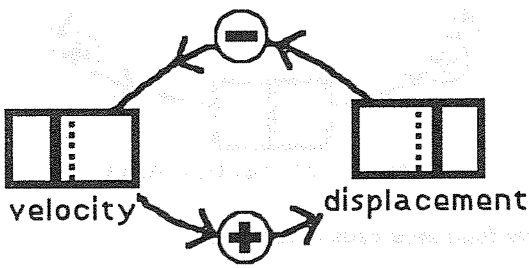

figure 3: An oscillator in IQON

A positive velocity progressively increases the displacement, through the 'plus' link. But a positive displacement progressively decreases the velocity, through the action of a spring, represented via the 'minus' link. The outcome is that the system oscillates, a example of the principle mentioned before, that negative feedback plus delay gives oscillation. What is shown in Figure 3 is all that the user has to do: to create and name two variables and to link them as shown. No equations are written at all.

However, IQON is also intended for thinking about systems where we have much vaguer ideas about quantities and their relationships. Consider the quality of a conference. We may imagine that much depends on the quality of the workshops. If that is high, the participants become happier and happier as the week goes by. But if they are happy they may perhaps participate more actively in workshops, so that the quality of workshops itself increases. Figure 4 shows this idea expressed in IQON.

This model is overly optimistic. It contains positive feedback, so that if as in figure 4(a) the quality of workshops is somehow increased by a small amount, then after some time all the variables are driven to their positive limits. It does not matter whether the model is correct; what matters is that such effects are possible and will certainly arise in some cases, whatever the details of the system. An increase in global temperature causing melting of polar ice, which by reducing reflectivity increases the energy absorbed from the Sun and so leads to a further increase of global temperature is an example.

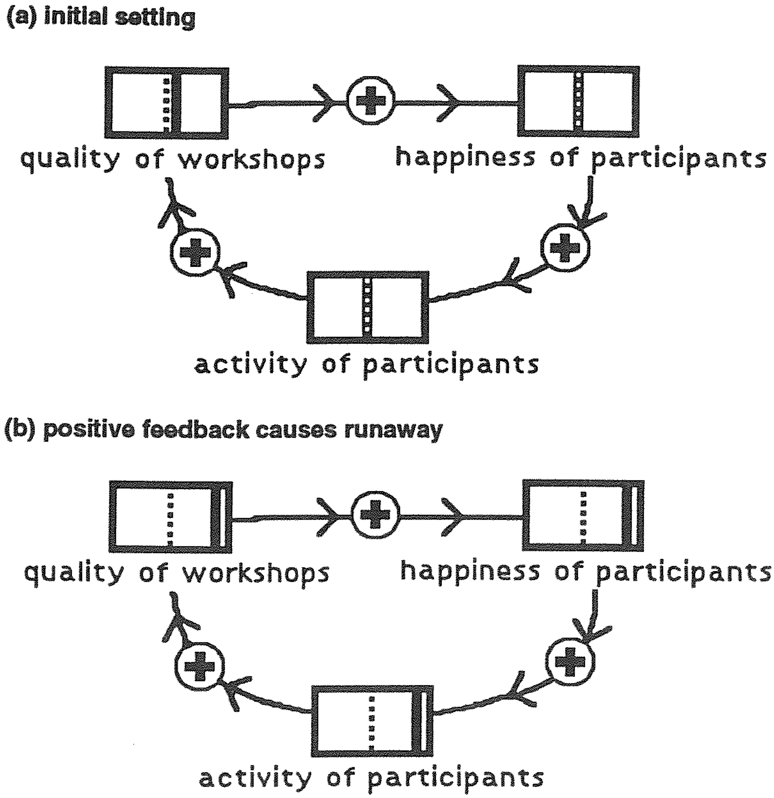

figure 4: An IQON model for success of workshops

In its present implementation, all IQON variables are alike. Any input from other variables simply modifies the rate of increase or decrease of a variable. Each has a central 'neutral' position at which its output has no effect. Figure 5 shows this schematically.

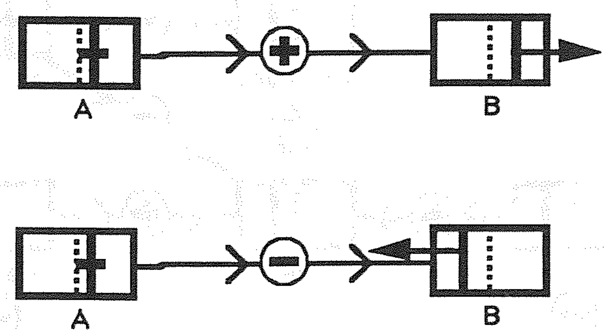

figure 5: Behaviour of linked variables in IQON

If variable 'A' is above 'neutral', a positive link from it to variable 'B' drives 'B' up progressively until it reaches the limit of its box. Similarly, a negative link to 'B' drives 'B' progressively down. Thus 'A' determines the rate of change of 'B'. Multiple inputs to a variable are simply averaged, taking account of sign, to determine the rate of change, though some inputs can be given greater weight than others. The response of each variable is made non-linear, through a 'squashing function' which restricts its values to the range minus one to plus one. A variable also has some (adjustable) internal damping. In fact, the behaviour is similar to that of some forms of artificial neuron (McClelland and Rumelhart, 1987). One may of course also regard a variable as a (non-linear) integrator of its inputs.

These features mean that any system of inter-linked variables a user designs will have a smooth behaviour, with no tendency for variables to go to infinity or to produce large step function outputs, and that any system will have a unique stable condition from a given starting point.

Figures 6 and 7 show two examples of models created by pupils aged about 13 (Bliss and Ogborn, 1992). Nancy (figure 6) sees fitness depending both on general health and on whether one is getting plenty of sleep, and additionally on attitude. Jokingly, she says that if the school gives her a lot of work to do at home she gets less sleep. Health she sees as affected positively by sensible diet and negatively by disease, in both cases sliding a little away from quantitative variables towards events. Disease has a direct negative effect on fitness, and also an indirect effect via attitude. The point is not whether Nancy is right, but that she has produced a model which is discussable, and whose results when run may surprise her and lead her to think some more.

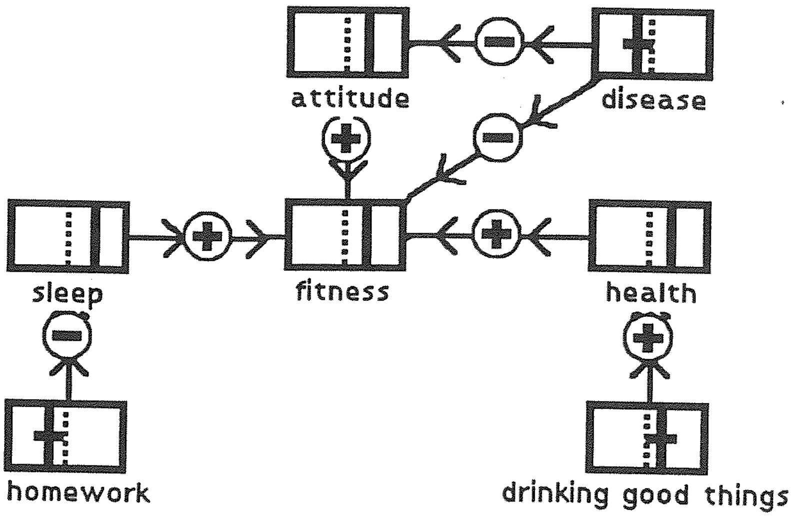

figure 6: Nancy's IQON model for keeping fit

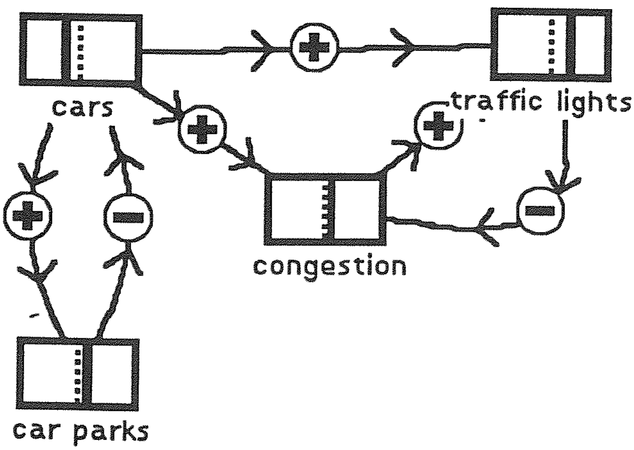

figure 7: Burgess' IQON model for traffic congestion

Burgess (figure 7) was modelling traffic congestion. His 'variables' are more like objects than like amounts of something. Because of the feedbacks in the model, when it is run it can give surprising results. Increasing 'car parks' can at first decrease 'congestion' but, because of the loops between 'cars' and 'car parks' and between 'traffic lights' and 'congestion', the model is liable to oscillate. Again, what matters is that this is likely to lead the pupil to reconsider ideas.

Overall, the results of our studies with IQON (Bliss and Ogborn 1992) can be stated as follows:
- all pupils could make *some* model;
- half or more made models with fairly sophisticated interconnections;
- those who *made their own* models were more radical in criticising or reformulating them than were those who were given previously prepared models;
- many had difficulty creating amount-like variables. The tendency was to create *objects* and *events*.
- some pupils could argue about feedback effects
- most pupils' work produced *discussable ideas*, capable of leading to progress in modelling.

In summary, we have a simple graphic modelling facility, for pupils to build such models out of just a few building bricks, and for them to be able to see some of the basic qualitative interactions at work, without yet having to consider exact functional relations between variables. The significant information is in the *qualitative pattern of relationship and change* amongst variables. In Physics, one might *begin* with such qualitative models. Later, it would be time to see how well defined relationships in similar models can give more precise answers, in numerical simulations.

4. Modelling with objects and events

If one wants to make computational models with even younger pupils - say 8 to 12 years - then it would seem to be a good idea to model not variables but objects and events. WorldMaker (Boohan, Ogborn and Wright, forthcoming) is a system of this kind, largely designed and written by Dick Boohan and Simon Wright. A WorldMaker model of sharks preying on fish might look like figure 8.

A WorldMaker world consists of objects on a grid. Rules telling the objects what to do are defined graphically. Thus in Figure 8, the two kinds of object, sharks and fish, swim around the grid, being placed on it using drawing tools. Rules are specified by drawings, too. A shark next to an fish eats the fish. A shark on its own may die. A shark next to an empty space may breed or may move. The three rules for fish are similar to the last three rules for sharks. All rules have the form 'condition - effect'. Any rule can be set to 'fire' with a probability selected by a slider bar, so that for example relative breeding rates can be altered, or sharks can be made very long-lived. In this model, if sharks breed too fast, they can destroy the fish population and then themselves die out. As is well known, such predator-prey systems can oscillate.

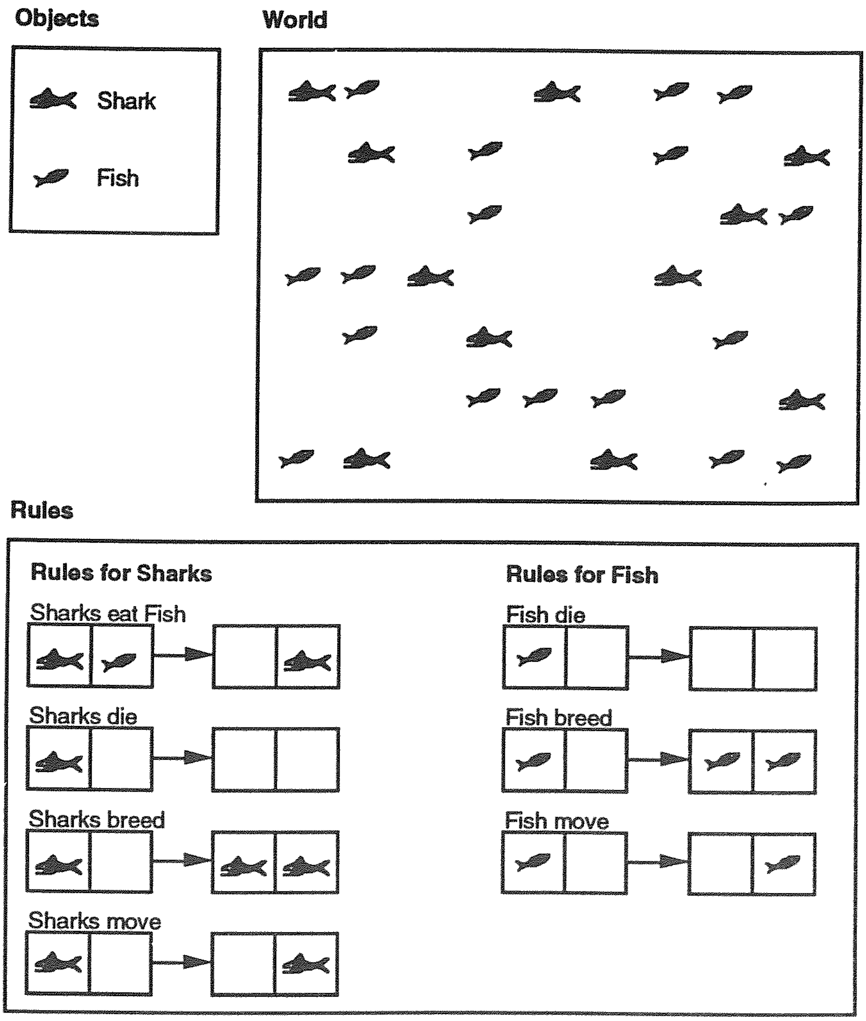

figure 8: Predator and prey in WorldMaker

The concept of WorldMaker derives from that of Von Neumann's cellular automaton (one of the best known instances being Conway's Game of Life), with the addition of moving objects each of which retains its identity, and of the possibility of random choices of allowed changes. A cell automaton consists of an array of cells, each of which has a small finite number of states. The state of a cell changes in relation to its own present state and those of its immediate neighbours. Thus the rules for evolution of the system are local rules, the same everywhere. A useful general account is given by Toffoli and Margolus (1987).

The system as a whole is not represented explicitly at all, but is visible to a person watching the model evolve, as some pattern of behaviour of the assembly of objects. A simple model suitable for young pupils addresses the question why buses in town always seem to come in groups. Figure 9 shows the idea.

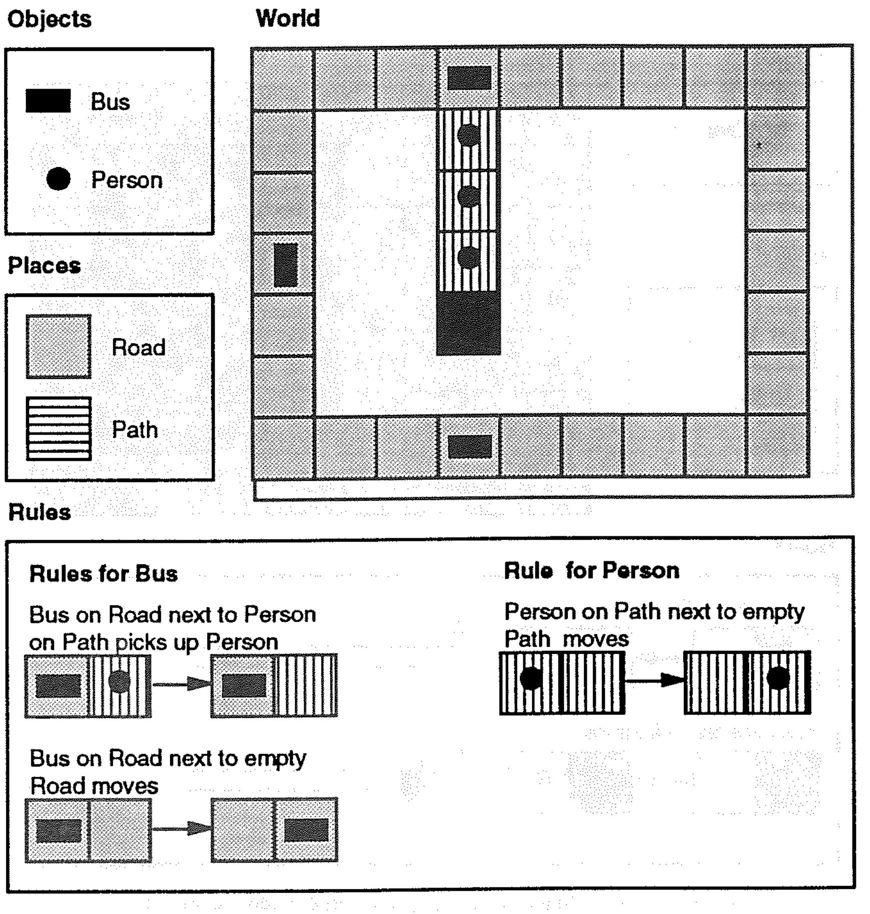

figure 9: WorldMaker model for buses travelling in groups

If buses stop to pick up people when they are there, the buses soon become clustered on the road around which they travel. WorldMaker allows directions of movement to be given to an object by the background it is on, making it simple to construct paths or tracks for objects. The example illustrates one of the several ways in which backgrounds and objects can interact, which include either changing the other into a different one. An example of such changes is a 'farmer' who moves around the grid 'planting crops' (i.e. changing bare earth to plants) and one or more 'pests' who move around destroying the crops. Another is shown in figure 10, in which a creature moves purely at random, but moves more frequently in the 'light' than in the 'dark'. The result is that any initial distribution of creatures ends up with most of them in the 'dark' region.

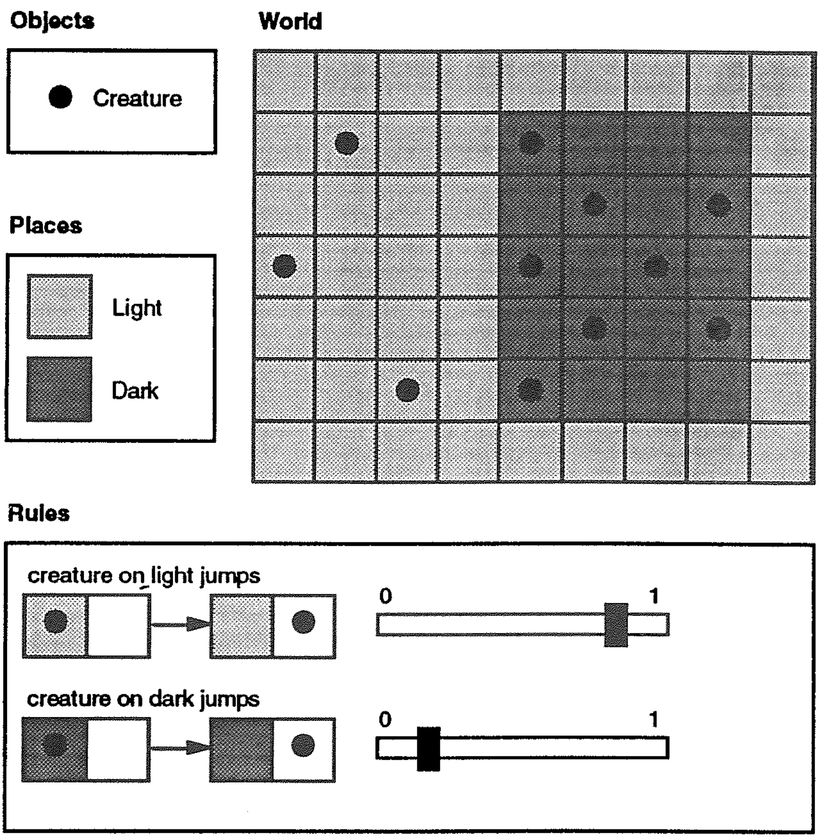

figure 10: WorldMaker model of preferential random distribution

An even simpler system, is able to illustrate molecular diffusion, as in figure 11. The walls can be drawn anywhere one likes, and the initial distribution can be varied. The educational lesson here is important. A large scale, macroscopic appearance of systematic change can be generated by what is

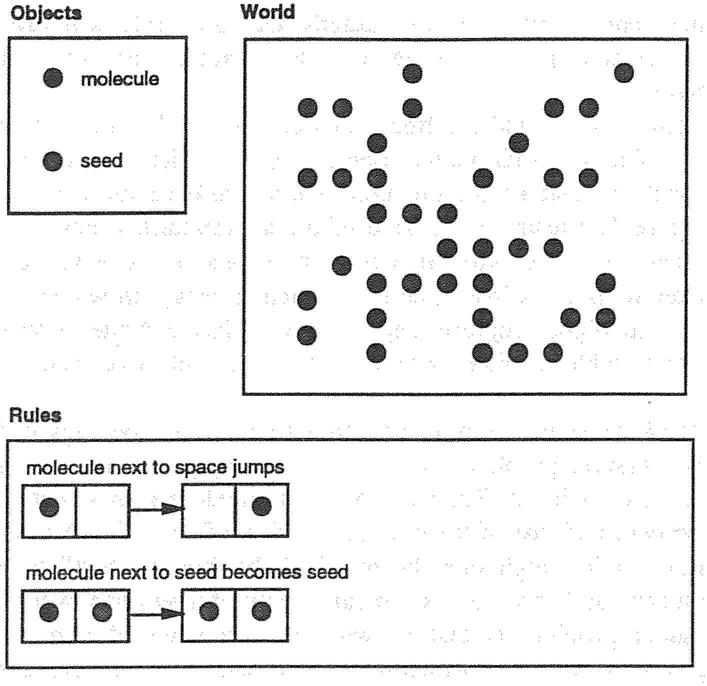

figure 11: WorldMaker model of molecular diffusion

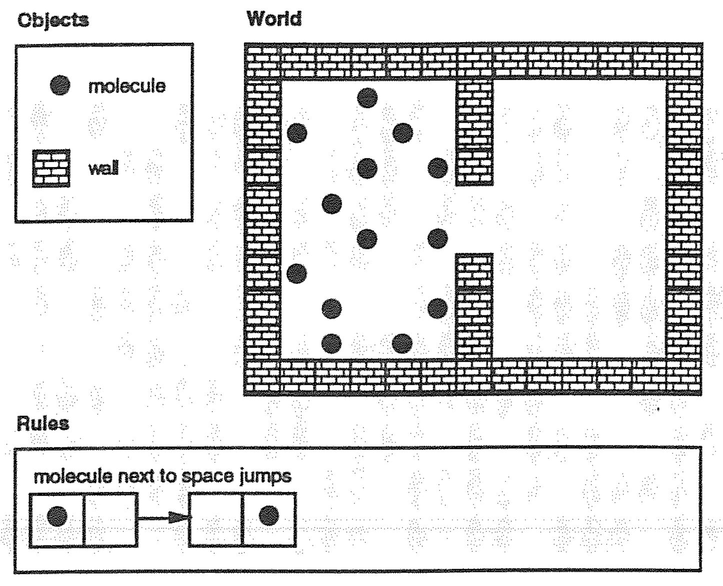

figure 12: WorldMaker model of diffusion limited aggregate

at the microscopic level random. Exactly the same rule will produce the outward diffusion of particles placed in a cluster at the centre of an otherwise empty screen.

An adaptation of the model in figure 11 leads to a model of diffusion limited aggregation. One just adds another object, a seed, which does not move, and the additional rule that a molecule alongside a seed is captured and turns into a seed. Figure 12 illustrates the kind of fractal structure which can result.

Let us mention some other models, simple and more advanced, which WorldMaker makes possible. One is radioactive decay, in which the rule us simply that an object representing a nucleus has a finite probability of changing to a stable nuclide. Such a model is‘ readily extended to a decay chain.

Marx (1984) gives the example of a forest fire, which belongs to the large class of percolation problems. A cell can be empty, or can contain a tree which is alive or is burnt. Trees are placed at random with a certain density over the screen, and one of them is 'set on fire' (figure 13). A tree burns if one or more of its neighbours burns. Will the fire travel all through the forest? It turns out that there is a critical density of trees for this to be likely. An equivalent problem is that of whether a mixture of conducting and insulating grains will be conducting, or of whether there are continuous percolation paths for oil through cracked rock strata. Marx (1984, 1987) gives many other interesting similar ideas.

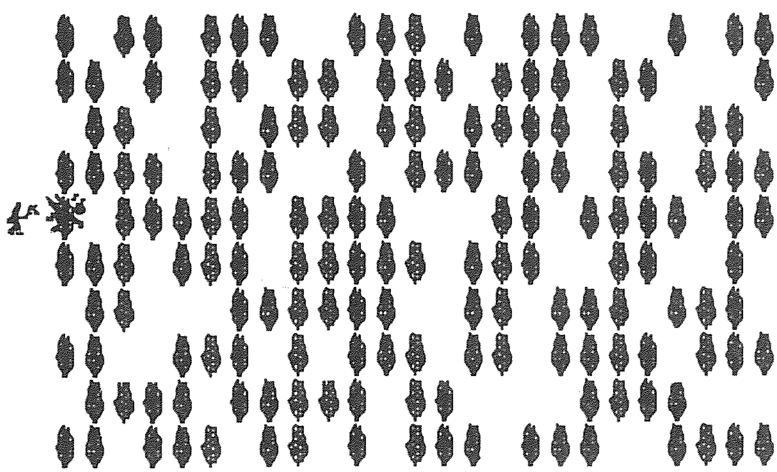

figure 13: Forest fire: one tree is set on fire - will all the forest burn?

Simple examples of chemical reactions can be modelled by having cells filled with two or more species of 'molecule'. Molecules may move to empty cells or may combine with others nearby to make product molecules, which themselves may react in the reverse direction.

All these models have the great advantage that the objects one is talking about are directly represented on the computer screen. If the work concerns sharks eating fish, there are icons of sharks and fish to look at. If the problem is about molecules, one looks at an array of entities representing molecules, not at a display of variables such as temperature and pressure (though the system might in addition calculate these). The behaviour of the whole system is represented to the student by the visible pattern of behaviour of the objects, not as values of system variables. In general, the rules for the behaviour of entities are simple and intuitive, usually relating directly to their behaviour in the real world. Despite this simplicity, quite complex and analytically intractable systems can be studied.

5. Conclusions

I have in this paper suggested three things:

a. that there is an important role in science teaching for quantitative system modelling;
b. that there is scope for qualitative computational modelling of systems of variables;
c. that use can be made of models which manipulate the objects in a system rather than the variables, and that cell automata provide a useful formalism for this concept.

Systems to provide for (a) already exist, and are in use in some schools, mainly in the upper age range. Those who cannot get or afford such a system, or who prefer an alternative already known to many pupils, can do a great deal with a spreadsheet program. The possibility is opened up of teaching Science through modelling without having to wait until students know the calculus, and indeed of teaching the calculus in this way.

Suggestion (b) is more radical. We have built and tested a prototype, and can say that with it quite young pupils can produce interesting models. There are good psychological reasons for thinking that qualitative reasoning about variables is important, because of its pervasiveness in all human thought. The opportunity offers for teaching quite young students about systems of variables and effects of feedback, before they are ready to deal with quantitative formalised relations between variables.

Plenty of simulations which belong within the concept of (c) already exist, and are not difficult to program, though speed may be a problem. What I have suggested is the value of a generalized facility for building such models, and I have described one such system. Here we can see how the idea of modelling could be extended to pupils even in the Primary School. Let me finally try to put these thoughts in a more general perspective. The normal order in which people come to appreciate the role of computational models, is far from ideal. One is first supposed to learn functional relations between quantities (Ohm's law, Newton's laws etc.), then some differential calculus, then integration, then numerical methods, and finally one is expected to see the unity in all this. This path is followed hardly any distance by most pupils, and the whole distance by almost none except the best doctoral students.

This leads me to propose in a sense to reverse the normal order. We should perhaps concentrate from the beginning on form, defined at first loosely and then more precisely. At present we leave form until last, if we ever reach it at all. If it is true that children would find computational representations of objects easier to deal with than representations of system variables, then this suggests one kind of beginning with modelling in which the child tells the objects what to do, not the variables. Form is then represented by patterns of behaviour of collections of objects.

A second beginning, directed towards analysing systems into related variables, might be with modelling systems supporting qualitative reasoning, or patterns of cause and effect, involving variables. Here one has the possibility of looking at form as the typical kind of behaviour of systems with a given structure. The reason why oscillators oscillate is fundamentally the same. The reasons why stable systems are stable are often basically similar.

I want to emphasize the very real importance, equally for young pupils and for the best experts, of qualitative reasoning about form. The young child can often guess how things may go, and can look at a model on the computer to see if it 'goes right' or not. The expert is an expert just by virtue of having passed beyond the essential stage of being able to do detailed calculations, to have reached the even more essential stage of knowing what kind of calculation to do, and what kind of result it will give.

To create a world, whether constituted of variables or of objects, and to watch it evolve is a remarkable experience. It can teach one what it means to have a model of reality, which is to say what it is to think. It can show both how good and how bad such models can be. And by becoming a game played for its own sake it can be a beginning of purely theoretical thinking about forms. The microcomputer brings something of this within the reach of most pupils and teachers.

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3 Technical Reports 2 and 3 *Semi-Quantitative Reasoning, Expressive and Exploratory*
4 Technical Report 4 *Quantitative Reasoning* plus Technical Report 5 *Qualitative Reasoning*

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Constructivist Perspectives on Learning Science

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1. Knowledge as a human construction

The core position of constructivism is that knowledge does not exist independently of knowers - it is a human construction. In terms of individual learning, von Glaserseld expressed this by saying 'Knowledge is not passively received but actively built up by the cognizing subject' (1989; p182). This assertion, which von Glasersfeld describes as representing a position of 'trivial constructivism', implies that knowledge cannot be transmitted directly from one knower to another, through, for example, language - or from direct experiences of the world. The acquisition of knowledge requires active engagement on the part of the knower who uses prior knowledge to construct new understandings. This position is reflected in a range of developments in cognitive science. Research in a number of areas of human cognitive functioning are premised on the notion of mental models or schemes.

> 'Human beings ... do not apprehend the world directly; they possess only internal representations of it, because perception is the construction of a model of the world. They are unable to compare this perceptual representation directly with the world - it is their world'. (Johnson-Laird, 1983; p.156)

Reading theorists suggest that the process of reading involves the active use by the reader of mental constructions or schemata in interpreting what is on the page (Anderson, 1984; Schank and Abelson, 1977). Research on problem solving, particularly in complex and highly organised domains of knowledge such as mathematics or physics, indicates that the problem solver first constructs a representation of the 'problem space' which governs the way encoding of information is carried out (Newell and Simon, 1972; Greeno, 1978; Larkin, 1983). Piaget's influential research into children's cognitive development can also be seen to reflect the core constructivist position. In the case of Piagetian theory, learners are portrayed as evolving progressively more sophisticated content-independent logical structures as a consequence of maturation and experience.

Students' conceptions of natural phenomena, which have been the focus of a great deal of recent research on science education (Pfundt and Duit, 1985; Driver, Guesne and Tiberghien, 1985), can be seen as examples of particular types of mental representations; in this case, representations of aspects of the natural world which influence the way future interactions with phenomena are construed.

2. Constraints on personal knowledge construction

As has been indicated, (at the heart of the Piagetian position and that reflected in studies of the development of context-dependent knowledge schemes), is a view of knowledge as personally constructed there. Furthermore, knowledge schemes are seen to evolve as a result of progressively more complex interactions with the world. This process is seen to result in old schemes evolving into new schemes, resulting in a new knowledge replacing old knowledge. This view of cognitive development, which is clearly portrayed in Piagetian research, is also being put forward as underpinning the development of content-dependent knowledge schemes. The development of children's content-dependent reasoning, it is argued, can be represented in terms of evolution through a series of theory changes. (McCloskey, 1983; Carey, 1985; Karmiloff-Smith, 1978). Evidence is being collected which suggests that these schemes evolve in similar ways among young people in different cultures. For example a study carried out by Nussbaum and Novak (1976) of children's conceptions of 'earth in space' revealed a sequence of five conceptions or 'notions', which progressed from the earth as a flat surface with an absolute frame of reference for up and down through intermediate notions to the scientific notion of the earth as a sphere and up and down being defined in terms of the earth as a frame of reference. This study was replicated in Nepal (Mali and Howe, 1979) and the same sequence of conceptions were identified. As the authors of the article comment, 'the remarkable thing to us is not that the Nepali children are slower in gaining the concept, but that the development of these ideas is similar in such widely divergent cultures' (p.689).

This area has been recently explored again by Vosniadou and Brewer (1990) with Greek and American students. Similar commonalities across language and culture have been found in children's conceptions in other domains, for example, force and motion and air and gases (Brook and Driver, 1989; Seré 1985; Stavy, 1988).

There are differences in perspectives on the types of constraints which act to shape the process of knowledge construction. Both internal constraints, in terms of limitations in processing capacity of the human mind, and external constraints, in terms of influences from both the physical environment and the cultural milieu through language and other forms of communication, are variously recognised as playing a part.

The literature outlined here, suggests that the constraints presented by features of the physical world may act to shape the representations which different groups of people construct.

3. Knowledge as adaptive

The view of the learner as architect of his/her own knowledge is a broadly held assumption. In his writings on constructivism, von Glasersfeld asserts a further and more controversial principle that 'the function of cognition is adaptive and serves the organisation of the experiential world, not the discovery of ontological reality' (1989, p.182). The process by which knowledge is constructed by the learner is portrayed as a self-referential process whereby cognitive schemes are brought into play and assessed in terms of their 'fit' with individuals' experience.

> 'what determines the value of the conceptual structures is their experimental adequacy, their goodness of *fit* with experience, their *viability* as means for solving problems, among which is, of course the never-ending problem of consistent organisation that we call *understanding* ..... Facts are made by us and our way of experiencing'. (von Glasersfeld, 1983; p.51)

The epistemological implication of this view of knowledge as constructed is that to *know* something does not involve the correspondence between our conceptual schemes and what they represent 'out there'; learners have no direct access to the 'real world'. The emphasis in learning is not on the correspondence with an external reality but the construction by the learner of schemes which are coherent and useful to them. This view of knowledge 'has serious consequences for our conceptualization of teaching and learning ... it will shift the emphasis from the student's 'correct' replication of what the teacher does, to the student's successful organisation of his or her *own* experiences'. (von Glaserfeld, 1983; p.51).

4. Personal construction of knowledge - a critique

The perspective on knowledge construction portrayed so far is that it is a personal process whereby individuals develop progressively more complext knowledge schemes through maturation and interaction with their environment. Furthermore, the mechanism which is seen to account for knowledge change is the process of adaptation of knowledge schemes to fit with experience.

This personal perspective on the knowledge construction process is being criticised for a number of reasons. First, it is argued that portraying the knowledge construction process in solely personal terms completely ignores social, cultural and political influences. O'Loughlin (1992) argues that by ignoring such influences, the Piagetian perspective results in learners being portrayed in a deterministic way and that this does not encourage educational interventions which empower people to adopt critically different perspectives.

A second criticism focusses on the theory replacement view of knowledge development. Here, it is argued that there is a great deal of evidence to support the view that people develop and use multiple knowledge schemes which are used in socially appropriate ways. The view that development is characterised by one conceptual scheme replacing an earlier one appears to be an oversimplification.

A third criticism focusses on knowledge development as a rational process. Solomon (1987), for example, argues that young people are as much, if not more, influenced by the need for social agreement than they are by logical requirements in adopted specific knowledge schemes. This calls into question a view of learning as solely a rational process.

The fourth criticism focusses on the status of scientific knowledge as portrayed by constructivists. It is argued that the view of learning as adaptation of learner's knowledge schemes leads to solipsism. Matthews (1992), for example, argues that 'the aims of science as being .... making sense of our sense impressions leads to an instrumentalist interpretation of scientific theory' as opposed to 'science being an attempt to understand something outside ourselves'. This is a criticism which is currently receiving considerable attention in the literature and I would like to address it in more detail.

The core concern being expressed is that constructivism supports a relativist perspective about scientific knowledge and hence about students' knowledge of science. It is alleged that constructivism supports a solely instrumentalist position on knowledge construction in educational settings. This, I believe, is a naive and incorrect portrayal of a radical constructivist position, as reflected for example in von Glasersfeld's writings. First let us consider the issue of ontology. It has been argued that radical constructivism is essentially relativist in its ontology. This is not asserted by von Glasersfeld. He does not refute that reality exists, just that as humans, we cannot have direct access to it. Furthermore, in his writings, he gives an account of how an agreed body of knowledge (i.e. public scientific knowledge) comes about through social agreement. He argues, in the context of mathematical knowledge, that conventional knowledge comes from interpersonal 'fit' as a result of social agreement about the rules and conventions governing the way claims are judged. Not only is von Glasersfeld's ontology not a relativist one, neither is his position on pedagogy. He was clear that teaching is not simply a matter of giving children experiences and letting them make sense of them on their own terms. In describing the teacher's role, he says:

> 'The teacher's role will no longer be to dispense 'truth' but rather to help and guide the student in the conceptual organisation of certain areas of experience. Two things are required for the teacher to do this; on the one hand an adequate idea of where the student is, and on the other, an adequate idea of the destination'. (1987 p.16)

In other words, the teacher needs an adequate representation of the field of knowledge he/she is aiming to develop in young people in order to select experiences and support students in developing specific understandings of them. What von Glasersfeld is saying, however, is that teaching by telling may not be enough to help students to reorganise their ways of seeing the world. Although he acknowledges the place of social agreement in the knowledge construction process, von Glasersfeld underspecifies the features of social interaction which result in such social agreement.

5. Social processes in knowledge construction

So far, the perspective which has been presented is that of individuals, through their own mental activity, experience with the enviornment and social interactions building and restructuring their schemes of the world around them. A most significant additional argument, however, still needs to be introduced. It is the argument relating to the nature and status of science as public knowledge which is also personally and socially constructed (Collins, 1985). Scientific ideas and theories not only result from the interaction of individuals with phenomena, but also pass through a complex process involving communication and checking through major social institutions of science before being validated by the scientific community. This social dimension to the construction of scientific knowledge has resulted in the scientific community sharing a view of the world involving concepts, models, conventions and procedures. This world is inhabited by entities such as atoms, electrons, ions, fields and fluxes, genes and chromosomes; it is helpfully organised by ideas such as evolution and procedures of measurement and experimentation. These ideas, which are constructed and transmitted through the culture and social institutions of science, will not be discovered by individuals through their own empirical enquiry; learning science involves being initiated into the culture of science.

Since the work of Lev Vygotsky has become better known in Europe and North America, the role of social processes has become more prominent in the ways that learning is portrayed. Whereas the personal construction of knowledge perspective places primacy on physical experiences and their role in learning science, a social constructivist perspective recognises that learning involves social processes and being introduced to a symbolic world. This is well expressed in Bruner's introduction to Vygotsky's work:

> 'The Vygotskian project [is] to find the manner in which aspirant members of a culture learn from their tutrors, the vicars of their culture, how to understand the world. That world is a symbolic world in the sense that it consists of conceptually organised, rule bound belief systems about what exists, about how to get it to goals, about what is to be valued. There is no way, none, in which a human being could possibly master that world without the aid and assistance of others, for in fact, that world is others'. (Bruner, 1985; p.32)

From this perspective, individuals are seen to think and act in ways which relate to their physical and social milieu. Knowledge and understandings, including scientific understandings, are constructed when individuals engage socially in talk and activity about shared problems or tasks. Making meaning is thus a dialogic process involving persons-in-conversation. Learning is seen as the process by which individuals are introduced to a culture by more skilled members. As this happens, they 'appropriate' the cultural tools through their involvement in the activities of this culture. A more experienced member of a culture can support a less experienced member by structuring tasks, making it possible for the less experienced person to perform them and to internalise the process, i.e. to convert them into tools for conscious control.

There is an important point at issue here for science education. If knowledge construction is seen solely as a personal process, then this is similar to what has traditionally been identified as discovery learning. If, however, learners are to be given access to the knowledge system for science, the process of knowledge construction must go beyond personal empirical enquiry. Learners need to be given access not only to physical experiences but also to the concepts and models of conventional science. The challenge lies in helping learners to appropriate these models for themselves, to appreciate their domains of applicability and, within such domains, to be able to use them. If teaching is to lead students toward conventional science ideas, then the teacher's intervention is essential, both to provide appropriate experiential evidence and to make the theoretical ideas and conventions of the science community available to students. The challenge is how to achieve such a process of enculturation successfully in the round of normal classroom life.

6. Personal and social processes in knowledge construction

Learning science is not a matter of simply extending young people's knowledge of phenomena - a practice perhaps more appropriately called nature study - nor of developing and organising young people's common-sense reasoning. It requires more than challenging learners' prior ideas through discrepant events. Learning science involves young people entering into a different way of thinking about and explaining the natural world; becoming socialized to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing (ontology) and ways of explaining (epistemology). For this to happen, however, requires individual to engage in a process of personal construction and meaning making. Characterised in this way, learning science involves both personal and social processes.

On the social plane, the process involves being introduced to the concepts, symbols and conventions of the scientific community. Entering into this community of discourse is not something which students discover for themselves any more than they would discover by themselves how to speak Esperanto. (Becoming socialised into the discourse practices of the scientific community does not entail, however, abandoning common-sense reasoning: human beings take part in multiple parallel communities of discourse, each with its specific practices and purposes.)

At the personal level, each individual learner needs to make the new ways of seeing meaningful for themselves. This is not always a straightforward process as new ideas can conflict with already established ways of seeing.

7. Towards a view of teaching which is informed by a constructivist view of learning

In this final section, I outline the main features of what I see to be an approach to teaching science based on a constructivist perspective on learning - an approach which embraces the personal and interpersonal construction of knowledge while recognising that public scientific knowledge is a product of social processes and that learning science requires students to be initiated into this scientific culture (a culture which I would argue is distinct from everyday culture).

a. View of scientific knowledge

Scientific knowledge itself is presented explicitly and implicitly as being personally and socially constructed. Theories are seen as provisional, not absolute. This contrasts with perspectives implicit in other teaching approaches which portray scientific knowledge as 'objective' unproblematic and fixed (often the picture emerging from text books or formal lectures) or as 'discovered' through individual empirical enquiries - a perspective which is implicit in naive process approaches or discovery learning approaches to science teaching. Indeed, the problems that are inherent in the 'discovery' approach where students, despite using the required procedures, fail to 'discover' what was intended, has been well documented (Solomon, 1980).

b. View of the learner

A constructivist perspective views the learner as actively engaged in constructing meaning, bringing his or her prior knowledge to bear on new situations and in some cases adapting those knowledge structures.

c. View of the curriculum

Traditionally the curriculum is seen as 'that which is to be taught'; a list of knowledge and skills to be transmitted to the learner. I would suggest that from a constructivist perspective we may need to reconsider this view. Instead of seeing the curriculum as essentially determined by factors outside the learning environment (e.g. by factors such as the structure of subjects, the values of society) it needs also to take account of what learners bring to the learning situation - their purposes and ideas. If this is done, then the question of what experiences and ideas will be effective in promoting certain learning outcomes becomes an open question. The curriculum as a set of learning activities and interactions which promote particular learning outcomes is not then a pre-determined list, but a legitimate object for research and enquiry (Driver and Oldham, 1986).

d. View of teaching

From a didactic perspective, a teacher is a presenter of knowledge. From a discovery perspective s/he is simply a provider of experiences. In a constructivist approach both these functions are combined. The teacher needs to provide the necessary experiences to enable students' science knowledge to relate to events and phenomena. Experience by itself, however, is not enough. It is the sense that students make of it that matters. Here, if students' understandings are to be changed towards those of accepted science, then intervention and negotiation with an authority, usually the teacher, is essential. Here, the critical feature is the nature of the dialogic process. The task of the authority figure has two important components. One is to introduce new ideas and to provide the support and guidance for students to make sense of these for themselves. The other is to listen and diagnose the extent to which the instructional activities are being interpreted in the intended way in order to inform further action. Teaching from this perspective is also a learning process for the teacher.

> '..... at the heart of any good teaching and learning experience is a critical relationship, that is, a relationship in which teachers and learners alike seek to question each other's ideas, to reinterpret them, to adapt them and even to reject them, but not to discount them. To be critical in this sense, we need to know something of the origins of those ideas, their roots, the frameworks in which they are embedded'. (Rowland, 1984; p.1)

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Science Education and studies of 'the Nature of Science'

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1. Introduction

The phrase 'the nature of science' is one which sits uneasily in modern academic discourse. Its tone is totalizing, suggesting that a single, universal account can be given. By contrast, much of the most influential recent work within meta-studies of science (what will be called here generically 'science studies') takes its inspiration, if not its methodology, from post-modernism and emphasizes the localized and contingent character of scientific practices and meanings[1]. This situation is the more significant because the thrust of science itself is precisely in the reverse direction: from the localized and contingent to the universal. In this discussion no attempt will be made to give a systematic bibliographic survey. Instead some important themes in that contemporary academic work which might be grouped under the title 'the nature of science' will be sketched. A concluding section will discuss the relevance of this work to school science education.

2. 'Traditional' science studies disciplines

Even within the more long-standing academic traditions contributing to science studies, the notion of a unitary approach to 'the nature of science' finds little support. Work within the disciplines of history, sociology and philosophy might each legitimately claim to provide distinct accounts of 'the nature of science'. These long-standing science studies disciplines are probably better described as having passed each other by than as having been in conflict. To the extent that this situation has changed over recent decades, that is, in what might be called the post-Kuhnian period, there has been

1. Z. Parusnikova (1992). 'Is a postmodern philosophy of science possible?', *Studies in History and Philosophy of Science*, *23*, 21-37.

increasingly self-conscious fracture which could be over-simplified as having its main fault line between philosophers and sociologists of science[2].

It might be thought that 'traditional' philosophy of science has succumbed to the pressure of radical sociology, but this is an unsustainable view. Though some work grounded within the philosophical tradition has shown a sustained engagement with sociological categories[3], mainstream philosophy of science is alive and well, and retaining a distinctive institutional and conceptual terrain[4]. The idealist and empiricist traditions have their own potential for radicalism, but mainstream work continues to be linguistic in orientation, and to involve examining the logical nuances a of a science consisting of systems of statements and apparently divorced from any social or institutional context[5]. Given the self-confessedly overdrawn claims made above (i.e. projecting the major boundary as that between sociology and philosophy of science) it might be though that the tension within sociological 'internalist' and 'externalist' perspectives had been resolved in favour of the former. This again would be a premature judgement, as a recent review by Zuckerman, which seeks to rehabilitate the study of the structure and function of scientific institutions and practices along Mertonian lines, indicates[6]. It is also worth pointing out that the more radical sociology comes in a variety of guises, as for example in the Starnberg 'finalization' school, which stresses the historical shifts in the liability of science to external influences, culminating in a 'finalized' state where such influences determine its development[7]. Historical studies, too, while in some cases deploying explicitly theoretical

2. For accounts of the relationship mainly from the point of view of the history of science see Section I of R.G. Olby, G.N. Cantor, J.R.R. Christie and M.J.S. Hodge (eds.) *Companion to the History of Modern Science* (London, 1990). Kuhn's work is commonly thought to have been interpreted more radically in the UK than in the USA. B.Barnes, *T.S. Kuhn and Social Science* (London, 1982)
3. I. Hacking, *Representing and Intervening* (Cambridge, 1983)
4. See any issue of the *British Journal for the Philosophy of Science*.
5. In this universe one is invited, for example, to consider such situations as that of a scientist possessing 'theories A and B which are underdetermined by all actual and possible data' and in which 'there will be some sentence h entailed by A where the negation is entailed by B'.
6. H.Zuckerman, "The sociology of science", in N.J.Smelser (ed.), *Handbook of Sociology* (London, 1988), pp.511-74. Some studies seem to sit slightly uneasily on the boundary R.Whiteley, *The Intellectual and Social Organization of the Sciences* (Oxford, 1984).
7. W. Schafer, *Finalization in Science. The Social Orientation of Scientific Progress* (Dordrecht, 1983).

categories of various kinds, including those of sociology and philosophy, and seeking to generalize about the processes of historical change[8], commonly retain a strongly 'empiricist', or at least self-contained, tone[9].

In sum, it would be a mistake to suggest that any of the three broad disciplinary traditions which claim to address 'the nature of science' has ceased to develop within its own independent conceptual and institutional framework. It is rather the case that the terrain on which work is conducted has been extended and, perhaps, fragmented.

3. Post-kuhnian developments

In the period since the publication of The Structure of Scientific Revolutions, four overlapping strands of argument about the characteristics of physical science have been particularly prominent. Two of these can be seen as more narrowly focused on physical science. They are concerned with the rational and progressive (and perhaps, in this respect, uniquely privileged) character of science and with the ontological status of the entities and theories with which scientific practice is frequently concerned. Sociologists have had some success in forcing these arguments onto empirical terrain, and in particular, relating them to the practices of science (whether understood individualistically or collectively) and the supposed increasing instrumental effectiveness of scientific knowledge. The fractures are not merely cross-disciplinary, and the ontological issue, expressed as the tension between realist and anti-realist positions, is prominent within philosophy of science itself[10].
Two themes with a wider reference are relativism and reflexivity. Relativism is a term with a notoriously unstable usage, but can be found in many areas of academic discourse[11]. It can be expressed in terms of the claim that no 'rational', 'objective' grounds can be found either historically or philosophically for theory choice, and that such choices are made on other bases, commonly the supposed 'interests' of those involved. The relativist pro-

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8. S.Shapin and S.Schaffer, *Leviathan and the Air-Pump* (Princeton, 1985).
9. See, for example, any issue of the *British Journal for the History of Science*.
10. Compare B.C. Van Fraassen, *The Scientific Image* (Oxford, 1980) and W.H. Newton-Smith, *The Rationality of Science* (London, 1981) for anti-realist and realist positions within a largely philosophical discourse, or R. Bhaskar *A Realist Theory of Science* (Leeds, 1975). This is of course merely a small sample of a large body of work, even if one is confined to the English language.
11. R.J. Bernstein, *Beyond Objectivism and Relativism* (London, 1983).

gramme within socio-historical studies has been promoted with increasing confidence, and is perhaps implicit within so-called 'strong-programme' sociology of science. The strategic aim of the strong programme is to explain scientific change by means of categories external to scientific theories and their empirical support[12]. Some of its methodological precepts, notably the need for a symmetrical approach to explaining the supposed successes and failures of science, seem difficult to contest, if only because they are methodological, and as such merely claim the right to investigate scientific practice in a coherent and unified manner. By contrast, the suggestion that sociologists should restrict their attention to what are understood by contemporaries to be the failures of science seems oddly authoritarian[13]. The instrumentalist tone of one rebuttal of relativism (i.e. the appeal to the supposed instrumental effectiveness of scientific knowledge) commonly ignores the relativist inclination to deconstruct this effectiveness. Academic work of this kind often generates a hostile reaction[14]. It also quickly runs into the issue of reflexivity. As the term implies, this argument turns the relativist/strong programme on itself, ostensibly depriving its promoters of a basis for their views. The issue of reflexivity is deployed somewhat triumphantly by those of more traditional inclinations, but also seems to be acknowledged as a threat among radical scholars. It seems that, despite their frequent emphasis on the socially-sustained character of knowledge the latter authors have not shaken off objectivist aspirations for their own work.

It can be argued that the most interesting work within science studies occupies a complex and heterogeneous interface between the three original domains, and one which recognizes and addresses the central issues to which we have referred. Three strands of work are of particular interest, relating respectively to the social and institutional processes of laboratory work, the nature of experimental practice and the characteristics of scientific discourse. Each will be discussed briefly here. The anthropologically-inspired fieldwork

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12. D.Bloor, *Knowledge and Social Imagery* (London, 1976); H.M.Collins, "Stages in the empirical programme of relativism", *Social Studies of Science* 11 (1981), pp.3-10. Terminology in this area is not easy to pin down, but it could be argued that the externalist/internalist distinction already referred to maps against that between the weak programme and the strong programme.
13. L.Laudan, *Progress and Its Problems. Towards a Theory of Scientific Growth* (Berkeley, 1977).
14. M. Hollis and S.Lukes (eds.) *Rationality and Relativism* (1982). For an example of the acrimonious tone of the discussions which can result see 'Symposium on "Deconstructing Quarks"', *Social Studies of Science* 20 (1990), 579-746. This periodical is an important location for these debates.

of such scholars as Lynch, Latour and Woolgar constituted one of the most important resources for the arguments to which we have referred. Their studies focused on sophisticated laboratories, examining the social interactions and other practices by which textual and other forms of output were produced, assimilated and transformed within the wider scientific community[15]. Their work has been extended in several directions, and Latour and Callon in particular have vigorously developed it into actor-network theory, in which the use of ideas and power by networks of actors of various kinds (human and non-human) determines the fate of scientific technological ideas and practices[16]. Overall, these studies suggested that scientific activity is a complex of often localized and contingent practices, considerably removed from any ideal-typical Weberian vision and embodying interests and power. With hindsight such claims may not have been particularly novel, or even unexpected, but they were presented in highly documented form and applied in the context of sophisticated modern science rather than what might be seen as its rudimentary historical form. The claim that they demonstrate social and institutional forces to be constitutive of scientific findings is, at best, premature. A more cautious argument might be that they support altered understandings of the meaning of scientific knowledge, transforming it from an essentialist conceptual framework to a social accomplishment.

One of the complaints which has been made about science studies has been the relative lack of attention to experimentation itself[17]. Over the last decade several studies have been published which explore the detail of experimentation. At the extreme of these in terms of its orientation to laboratory handwork is Gooding's investigation of Faraday's study of electromagnetism[18]. Gooding undertook to recreate Faraday's apparatus and the practical manipulations which he (Faraday) undertook. In a subtle and complex account

15. B. Latour and S. Woolgar; *Laboratory Life. The Social Construction of Scientific Facts* London, 1979). K. Knorr-Cetina, *The Manufacture of Knowledge* (Oxford, 1981). M.Lynch, *Art and Artefact in Laboratory Science. A Study of Shop Work and Shop Talk in a Research Laboratory* (London, 1985).
16. B. Latour, *Science in Action. How to Follow Scientists and Engineers through Society* (Cambridge, MA., 1986). M. Callon, J. Law and A. Rip, *Mapping the Dynamics of Science and Technology. Sociology of Science in the Real World* (London, 1986) One of the characteristics of this approach is the rejection of any boundary between science and technology.
17. A. Franklin, *The Neglect of Experiment* (Cambridge, 1986). D.Gooding, T.Pinch and S.Schaffer, *The Uses of Experiment. Studies in the Natural Sciences* (Cambridge University Press, 1989).
18. D.Gooding, *Experiment and the Making of Meaning* (Dordrecht, 1990).

of Faraday's methods Gooding argues that Faraday's thinking cannot be divorced from the manipulations he undertook. Phenomena were 'construed' through experimental practice and that practice embodied a non-verbal understanding which was in turn articulated and realized through its phenomenal effects.

There is a similarity here with contemporary work on the nature of technological knowing[19]. Studies on experimental practice by Franklin and by Galison have adopted a less radical stance in relation to the rational basis of scientific change than that often visible at the present time. Both argue that experimental practice, while not algorithmic or 'logically compelling', nevertheless provides grounds for 'rational belief'[20].

The final area referred to above is discourse analysis. It is not entirely distinct from the work already discussed, since studies of laboratory practices necessarily include something of the process of textual construction. Latour and Woolgar devoted considerable attention to the process which they called (acknowledging Derrida) 'inscription'. Other studies have analysed scientists' discursive practices more narrowly, leading ultimately into, again, reflexive concerns about textuality, and the use of innovative literary forms in which a privileged authorial voice is eschewed[21]. Some of this work has been extended to a wider body of representational practices[22]. However it is significant that Gooding's study, referred to above, is striking precisely in that it moves outside the overwhelming focus on texts and language in most studies. The concepts and methodologies of discourse analysis have been applied to the scientists' work with minimal strain, revealing a repertoire of practices distinguishable from, though overlapping with, those visible in other areas of social interaction. That the use of rhetorical and other more subtle textual work is required to convert localized and often problematic findings into a generalized and delocalized scientific ideas, and that continued work is needed to maintain order in the representational field of science, may hardly be surprising, but it nevertheless constitutes a key insight for further

19. D. Ihde, *Instrumental Realism. The Interface between Philosophy of Science and Philosophy of Technology*, (Bloomington, Indiana University Press, 1991)
20. P. Galison, *How Experiments End* (Chicago, 1987). A.Franklin, *Experiment, Right or Wrong* (Cambridge, 1990) and 'The epistemology of experiment', in Gooding, Pinch and Schaffer op. cit. (1989), pp.437-60.
21. G.N.Gilbert and M.Mulkay, *Opening Pandora's Box. A Sociological Analysis of Scientists' Discourse* (Cambridge, 1984). Lynch, op. cit. (1985). M.Mulkay, *The Word and the World: Explorations in the Form of Sociological Analysis* (London, 1985).
22. M.Lynch and S.Woolgar, *Representation in Scientific Practice* (MIT Press, 1990).

work. Whether this ultimately undermines the notions of science as a rational practice or social interaction, it seems likely to remove its privileged status. Overall, the notion that meanings are sustained within social practices ('language games' or 'forms of life') rather than through formal linguistic relationships is central in these approaches and it is not difficult to see the influence of the later Wittgenstein. Indeed David Bloor, an early proponent of the strong programme, has sought to install Wittgenstein at the centre of the sociology of scientific knowledge[23]. The phenomenological tradition is another influence in many of these studies.[24]

4. Science studies and science education

One of the ironies of science studies is the fact that the practice of science itself carries on independently of such work, and will continue to do so. Scientists have very effective institutional mechanisms to ensure that they collectively determine their own standards of rationality and progress. Science education, especially at school level, appears much more open to external forces and ideas, including, on the face of it, work in science studies. Certainly attempts to shift the science curriculum often make use of rhetoric loosely derived from the philosophy of science though whether this rhetoric has any effect in practice is more questionable[25]. While more thoughtful contacts between the work cited above and science education (at least at school level) are somewhat tenuous, they do exist. Some professional historians and sociologists of science have written specifically for an educational audience. Studies of school science teaching have rarely figured within the work which has been undertaken, despite the impetus given by Kuhn's emphasis on induction into existing forms of practice. There is some slight evidence that this situation might be changing. There are also signs of an effort to incorporate ideas from science studies into educational thought and the curriculum, though a good deal of what is written appears to be stalled at about 1974 so far as the science studies literature is concerned. A

23. D. Bloor, *Wittgenstein: a Social Theory of Knowledge* (New York, 1983).
24. H.M. Collins, 'An empirical relativist programme in the sociology of scientific knowledge', in K.D. Knorr-Cetina, *Science Observed. Perspectives on the Social Study of Science* (1983), pp.85-115.
25. J.F.Donnelly, A.S.Buchan, E.W.Jenkins and A.G.Welford, *Policy, Practice and Professional Judgement. School-Based Assessment of Practical Science* (Driffield, East Yorkshire, 1993)

recent review indicates the scope of the work which has occurred. A series of international conferences with the aim of increasing the scale of the interaction has been established and an academic journal with this focus is also in existence. Initiatives in the fields of teacher education and curriculum development are well-documented in these sources. The situation in England and Wales is perhaps of particular interest. A requirement that pupils study 'The Nature of Science' (called, within the terminology of the National Curriculum, Attainment Target 17) which reflected some of the newer ideas discussed above, figured briefly within the statutory curriculum for science. This element of the National Curriculum co-existed with a further component, entitled 'Exploration of Science' (Attainment Target 1), which adopted a much more individualist and objectivist stance. Ultimately, however, these two areas of work were merged, and the result, entitled 'Scientific Investigation' was much closer in tone to traditional inductivist approaches. In what ways might the work which has been discussed here be related to science education in schools? Perhaps the most radical approach is to argue that school can be studied as a site of scientific production. Such a claim is in some respects unlikely and in others trivial. However, exploring the parallels and differences between schools and other sites is of interest in itself. At the minimal level it is clear that knowledge is created in the school laboratory. It seems difficult to deny that many of the processes of knowledge production in professional scientific practice have parallels in what occurs in schools, and that these processes are the subject of research in a specifically educational context. Laboratory activity occurs and is validated (or not) by systems which involve the deployment of power. Knowledge is inscribed on blackboards, in exercise books and elsewhere, to a dramatic extent. One can recall here that Latour and Woolgar portrayed 'laboratory activity as the organisation of persuasion through literary inscription' (p.88). Whether school knowledge is 'new' knowledge is likely to be a source of argument, though it is inevitably new to some of the participants. However, the criteria of newness repay examination. Is the differentiation between new and old, in this context, meaningful without taking into account the social and institutional processes and sites of validation in play? Novelty is valued by the research journal referee but rejected by the examiner. Of course it will be suggested that the failed examinee is simply wrong, but such judgements are not unproblematic. What status are we to give to the paper accepted for publication but not yet subjected to further professional scrutiny, or indeed the many papers which are never cited or replicated? Again it might be worth recalling the claim made by one of Latour and Woolgar's interviewees that: '(t)he truth of the matter is that 99.9% of the literature is meaningless'.

If this approach is to be followed through it is perhaps necessary to undermine the notion of school science as a more or less wrong imitation of 'scientists'' science. It might be worth questioning whether the knowledge available to teachers can ever be assimilated to that deployed by 'scientists', or indeed whether the undifferentiated category 'scientists' knowledge' itself can be sustained.

It seems to imply either an archival or transcendental view of knowledge. But how do matters stand if scientific knowledge is seen rather as continually being re-enacted and sustained in social practices? What is enacted by teachers and their pupils may be institutionally specific, but in this respect what are we to make of the differences and commonalities between the knowledge deployed by low level 'routine' scientists such as analytical technicians, research scientists working at the 'frontier' of knowledge and prestigious but largely administrative senior scientists, or, along a different dimension, between specialists and textbook writers?

In any event the suggestion that the teaching laboratory be subjected to the same methodological approaches as scientific practice is hardly radical, because work along these lines is already visible. Studies of this kind may allow a better understanding of the processes of knowledge production in the school environment, and might be seen as contributing to improving the effectiveness with which such production occurs. This perspective is not without its problems, and we will turn to these in a moment.

Better understanding of the processes of science as they are visible within science studies might also influence the science curriculum in more direct ways, and some of the work which is referred to above is of this type. Whether by modelling the practice of science in the way in which science is taught and learned, or by developing specific courses which seek to expose children to it, science education might widen its educational aims beyond the dissemination of scientific knowledge and the production of new professional scientists, towards creating a critical and active citizenry concerned with and knowledgeable about the role of science in society. Evidently such an aim overlaps with that of improving the public understanding of science. Whether it amounts merely to an acceptance of the need for a wider dissemination of the scientific ideas or images of science that scientists and politicians feel should be more widely believed is questionable.

However it is also questionable whether such understanding is best promoted by establishing a form of individualistic 'cottage industry' science in schools, in which children themselves ostensibly replicate investigatory activity in the school laboratory, without any attempt to evoke the institutional and political setting of professional science.

These comments return us to the point implicit in the penultimate paragraph: what are the aims of science education and of science education research? Should the latter merely seek to understand better the process of knowledge creation (or, if you wish, transmission) in classrooms, so that it can be more efficiently undertaken? Are those aims in each case merely instrumental, seeking to influence pupils (and teachers) in quite specific ways, and thus to achieve such changes as politicians, professional scientists and other interest groups see as desirable? This sets both practices in a clearly instrumental frame.

I would like to draw on Jurgen Habermas's distinction between instrumental science, hermeneutic science and critical science. We have just stated the instrumental model of science education (and research into it.) A more humane aim would perhaps be to communicate with children (and teachers) and to share understandings in a non-instrumental dialogue.

This would place both practices within Habermas's hermeneutic, frame in which mutual understanding is paramount. Such an approach may be humane, but is it adequate? Ought not the aim rather to be to assist in the establishment of a critical tradition, in which pupils (and teachers (and researchers)) seek to explore and investigate the underlying agendas through which science (and scientific education (and science education research)) engage with and appropriate the natural and social world, and men and women as part of that world? The issues which these questions raise should be central to both science education (and research into it.) Unless both teachers and science education researchers are willing to act merely as instruments for achieving the ends of only remotely accountable policymakers, we will treat the aims of science education and science education research as matters of ongoing concern. Within the critical practice this implies, a continual evaluation and appropriation of the diverse work on 'the nature of science' is not a luxury but a necessity.

Research in Science Education at King's College London

Ph.Adey

1. Institutional background

King's College London is one of the colleges of the University of London, and like other multi-disciplinary colleges of the university it has many science and arts faculties and is in many ways like a university in its own right. The Department of Education of King's is called the Centre for Educational Studies. It is a purely postgraduate department with responsibility for the professional education of graduates who wish to become teachers, curriculum development, and research in education. Research areas include science, technology, maths, and computer education, health education, educational policy, the education of professionals, and religious education.

There are about 10 to 15 students registered for PhD degrees in science or science related education. Some are full time students from overseas, but many are part time students from the UK. 2 or 3 are actually members of staff, but none of the others are employed at the Centre. They rely on other work or on grants or scholarships to meet their fees and living costs. Training includes a series of seminars and workshops on research methods which are compulsory. Full time students must complete the programme of seminars etc. in their first year, part time students in two years. The most important element of the PhD programme is the original research work under the supervision of a member of staff, leading to a thesis.

2. Main Research Areas

I will attempt to fit the main research activities at King's into the categorisation scheme which I developed for my other paper at this conference, Science education research and cognitive science, with the addition of one extra category, Management and Policy.

Management and policy

- Decision making in science departments. (Justin Dillon). Recent changes in the educational system have changed the nature of decision making required by the head of a science department. It may be that there is less room for curriculum manoeuvre, and more financial accountability. This study uses interviews with teachers and with authority inspectors and advisers to look at the changing role of a head of department as perceived within and outside the school.

- The supply of and demand for analytical chemists. (Robin Murray). A study to determine whether industry is able to recruit sufficient numbers of suitably qualified analytical chemists. Interviews and questionnaires revealed serious deficiencies in full-time chemistry degree courses.
- The implementation of INSET. (Philip Adey and Shirley Simon). This study uses structured interviews and personality assessments to investigate the effects of factors such as communication within a school, the sense of ownership created amongst teachers, and teachers' tendencies to be adaptive or innovative, on the uptake of a curriculum innovation introduced through an extended inservice programme.

Assessment

- National Curriculum Sc1 Investigations. (Julian Swain and Bob Fairbrother). Analysis of student performance in the 1991 Pilot National Curriculum Key Stage 3 science standard assessment tasks. Comparability of the four tasks set and student performance within the tasks in terms of planning, implementing, and concluding to investigate fairness and differentiation.
- Graded Assessment in Science Project (GASP). (Julian Swain) The original GASP project established a detailed and empirically validated assessment framework for all aspects of science in secondary schools. Current work includes the application of this framework to national curriculum requirements at Key Stages 2, 3, and 4.
- Survey of teacher assessment methods. (Julian Swain, Bob Fairbrother, e.a.) 130 schools are being surveyed to determine the methods used by teachers to arrive at national curriculum levels for their pupils in attainment targets Sc 2 - 4.
- Piagetian levels and achievement in science investigation. (Peter Gill and Robin Murray). Pupils' ability to design and carry out investigations is related to their level of cognitive development. Performance is assessed by teachers according to a given schedule, and cognitive development is assessed using Piagetian Reasoning tasks. Results suggest that higher ability pupils are not achieving 'investigation' scores as high as might be expected, and this may be related to difficulties teachers experience with this new area of the curriculum.
- Pupils' achievements in national tests of science and mathematics

compared with their Piagetian levels. (Peter Gill). A detailed examination of the performance of about 150 14-year olds in their national tests in science and mathematics was compared with their cognitive levels established by a Piagetian Reasoning Task. A number of relationships between achievement in different parts of the science and mathematics curriculum were anticipated. In fact the results appear to throw considerable doubt on the validity of the National Tests.

- Teacher assessments of Investigations. (Christine Harrison). Looking at the strategies teachers are adapting for assessment of investigative skills in assessment. Eliciting their perceptions of the role of assessment and evaluating the match or mismatch with their practice.

Concepts

- Children's ideas of combustion. (Rod Watson, Theresia Prieto, Justin Dillon). Questionnaires are used to probe the understanding of combustion by children in the UK, in Spain, in Malawi, and elsewhere. Conceptualisations are categorised, and an attempt made to link responses form different countries with the varying chemical education experiences of pupils.
- Progression in learning in science and mathematics. (Shirley Simon and Paul Black, with Margaret Brown and Ezra Blondel). An investigation of progression in children's learning within linked areas of mathematics and science, through interviews with children aged 7 to 13 years old. Some of the issues underlying the 10-level sequence of the national curriculum are explored, in particular whether progression can be identified and described so that it matches children's observed learning patterns, the extent of invariance of progression in different children and in children of different ages progressing at different rates, and the relation between progression in learning and the teaching experienced.

Competence

- OPENS: Open work in Science. (Bob Fairbrother, Alister Jones, Shirley Simon, Rod Watson, Paul Black). Science investigations are categorised in terms of how open or closed they are in their definition, in the choice of methods given, and in possible solutions. A scheme has been devised to help teachers develop open investigations in science. The scheme focuses on planning the curriculum to include investigations, ways of introducing and organising investigations, and strategies for guiding and assessing pupils as they carry out investigations.

Cognitive structure

- Thinking skills and chemistry. (Juliet Strang and Michael Shayer). The application of some of the methods of Feurestein's Instrumental Enrichment to the identification of specific learning deficits in A level chemistry students, and their remediation through a thinking skills programme delivered within a chemistry context.
- Cognitive Acceleration. (Michael Shayer and Philip Adey). Investigation of the possibility of raising the proportion of school pupils who use formal operations, and the effect of higher level thinking on achievement in science and in other subjects.
- Genetic epistemology and the development of science concepts. (Martin Monk) The analysis of commonly observed 'alternative conceptions' held by pupils in terms of genetic epistemology.

Philosophy

- Ontological and epistemological categories in science education. (Martin Monk). Analysis of Harre's realist science and an investigation into the implications of this both of the teaching of the 'nature of science', and for the possibilities of mapping possible understandings of science on to epistemological stages of development of children.

3. Background

It will be seen that there is a very diverse range of topics being researched at King's. Topics are chosen according to staff member's own interest and expertise, and grants sought from research funding bodies to employ researchers and/or to buy out the staff member's own time. Occasionally the Centre is directly invited to conduct some research for a government or other agency.

The funding of a University department in the UK is significantly affected by the quality and quantity of research which it carries out, and a rating system has been devised. Every 3 or 4 years each department submits a detailed account of its research activities, and is awarded a grade of 1 (poor) to 5 (excellent). King's College Centre for Educational Studies was one of the three university departments of education in Britain to achieve a 5 rating the first time the system was devised, and has retained its 5 rating in the latest assessment. Our concern is to maintain this high standard, and to this end three 'research coordinators' have been selected from amongst staff charged with the task of encouraging, monitoring, and coordinating research in their area.

Research in the Department of Science Education, Institute of Education, University of London

J.Ogborn

1. Framework of research

Our research is of three kinds:
1. research proposed to, accepted by and funded by an outside agency;
2. research done by PhD students;
3. research done without special funding by members of staff, collaboratively or individually.

On average we have between one and three outside funded research projects running at any time, depending on our success in getting proposals accepted. We usually have between four and ten full time PhD students at any moment, many from other countries, and around ten to fifteen part-time PhD students, most of whom are teachers who do their research in addition to their normal jobs.

2. Overview of research

The research is very varied, depending on what we can attract funding for and what research students and staff want to do. But there are some main themes in our recent work, which link together several projects, funded and by PhD students. They are:
- studies of commonsense reasoning and understanding of science development of computer tools for modelling teaching about processes of physical change and energy

Funded large scale research projects in these areas, completed or in progress are:
- Commonsense understandings of science (Leverhulme Trust).
  Children and Teachers Talking Science CHATTS (Funded by British Gas for the ESRC Science Policy Unit.

InService Training Pack for Primary Teachers Understanding Science (British Gas), using ideas and materials from CHATTS.
Tools for Exploratory Learning (ESRC Information Technology in Education Initiative) jointly with King's College London, Imperial College London and Kingston University.
WorldMaker: a tool for modelling with objects (NCET)
Teaching about Processes of Change (Nuffield Foundation)

Other recently completed large scale research includes:
- Exploratory Data Analysis Teaching Experiment EDATE (Nuffield Foundation) involving the development of materials for teaching about simple exploratory data analysis methods to secondary school students, for use across the curriculum, and published by Longman in 1991 as "Making Sense of Data";
- a study of policies and practices in nutritional requirements for school meals, done for the Health Education Council;
- a collaborative investigation with London schools, of possibilities for technology education, with particular attention to water technology ('AQUATECH').

PhD theses completed in the past few years are:
- Vasilios Koulaidis: Philosophy of Science: a study of science teachers' opinions and their implications 1987
- Nilza Maria Vilhenha Nunes da Costa Vasconcelos: Motion and forces: a view of students' ideas in relation to Physics teaching 1987
- Anthony C Wallis: Science teachers' conceptions of energy 1989
- Maria Cristina Dal Pian: The characterization of communal knowledge: case studies in knowledge relevant to Science and Schooling 1990
- Denise Mary Whitelock: Commonsense understandings of motion 1990
- Nancy Wai Ling Law: Eliciting and understanding commonsense reasoning about motion 1990
- Gillian M.Nicholls: Case studies in the use of computer software in the teaching of energy 1991
- Angel D Lopez y Mota: Problems in defining and eliciting 'scientific' processes using practical tasks with primary school children 1991
- Isabel Gomes Rodrigues Martins: Pupils' and teachers' understandings of scientific information related to a matter of public concern 1992
- Maria José Bezanilla Albisua: Pupils' understanding and use of a database 1992
- Arion Kurtz dos Santos: Computational modelling in science education 1992

- Maria Cristina Mariani: Some dimensions of commonsense reasoning about the physical world 1992
- Alfonso Claret Zambrano: An approach to the teaching of energy 1993

Other PhD studies in progress include studies relating to:
use of Hypertext in science teaching; commonsense ideas about reversibility; impact of visits to a 'hands-on' museum exhibition; helping primary teachers of science in Nigeria; integrated science teacher training in Nigeria; modelling in the science curriculum; primary children's ideas about light and colour; teaching about energy and processes of change; children using a computational tool modelling objects and events; language difficulties in science for non-native speakers; methods to promote primary children's scientific thinking; developing children's understanding of the nature of science; Islamic perspectives on the nature of science
- HIV-AIDS Education; development of a coordinated science programme

Individual research interests of members of staff include:
nutrition education; practical work in school science; profiling competencies of student teachers; practices in technology education; diffusion of innovations in the school; computer diagnosis of alternative conceptions; students ideas about physical and chemical change; multi-cultural approaches to science; philosophy of science; explanation in science.

There follows a more detailed account of work on the three main themes mentioned above.

3. Studies of commonsense reasoning and understanding of science

This line of work originated in discussions with Laurence Viennot, Paulo Guidoni and Peter Hewson at the Science Education Research Workshop at La Londe les Maures in 1983. The initial concern was with trying to understand the origins of children's ideas about force and motion, but behind that lay a longer term wish to find ways of seeing what children's ideas about a number of areas of science had in common, a concern shared also with Björn Andersson. Since then it has developed in several directions:
- testing models of children's ideas about force and motion (with Denise Whitelock and Nancy Law);
- a developmental theory of the early childhood origins of conceptualisations of force and motion (with Joan Bliss);

- commonsense thinking about energy (with Gill Nicholls);
- commonsense thinking about reversibility (with Laercio Ferracioli da Silva);
- dimensions of commonsense thinking about physical objects and entities (with Maria Cristina Mariani);
- dimensions of commonsense thinking about events (with Maria Cristina Mariani and Isabel Gomes Rodrigues Martins);
- causal explanations of motion (with Rufina Gutierrez)
- primary teachers' making sense of scientific ideas (with Katherine Hann and Tim Brosnan);
- theories of explanation in science (associated with the ESPRIT Working Group on Teachers' and Children's Explanations, organised by the London Mental Models Group).

The work on force and motion drew on ideas from the Artificial Intelligence field of Naive Physics, particularly those of Patrick Hayes. Denise Whitelock found that a few simple features of a motion, namely whether it required 'effort' and if so whether the effort cam from outside or from within, and was present at the time or only previously, together with the presence or absence of 'support', and its nature if present, and with the animate or inanimate nature of the moving object, could predict with a correlation of about 0.8 the judgements of children over a wide age range (7 to 16) about whether the causes of pairs of motions were similar or not. Three interview studies, by Joan Bliss, Denise Whitelock and Jon Ogborn, by Rufina Gutierrez, and by Nancy Law found that students generated ideas very similar to those above when asked about causes of motion of objects. Nancy Law further found children incorporating such ideas in PROLOG computer programs, as their ideas about why things move.

Joan Bliss and Jon Ogborn developed these ideas into a set of hypotheses, stated as a partly formalised structure, of how basic ideas of force and motion might evolve in early childhood, starting only with simple actions and noticing of movement available to the young infant. This account remains to be tested.

To develop these studies further we have developed a novel method of investigation. Because many levels of commonsense understanding are tacit, and not easily available to conscious reflection, instead of asking subjects what they think about 'X' (where 'X' is some entity of interest, such as energy), we ask a large number of very simple ontological questions, such as, 'Can you touch it?', 'Can it do anything by itself?', 'Is it found in some place?', 'Can it go on for ever?', etc. These questions are based on the Piagetian idea that the meaning of an entity comprises 'What you can do to it', 'What it can do' and 'What it is made of'. Having asked such questions about a range of entities, we can construct a space from how 'close' the answers to pairs of questions seem to be (questions which are "close" have answers which correlate highly). The space is obtained by multi-dimensional scaling, principal components analysis, or factor analysis. The goal is to reduce many questions (typically 50 or more) to a space of a few dimensions, in which entities can then also be located.

Gill Nicholls found that this approach gave two dimensions of thinking about energy, 'producers versus consumers' and 'acts by itself versus is used to act'. Entities fell into distinct groups: fuels were producers used to act; natural phenomena (e.g. wind) were producers acting by themselves; appliances such as an electric lamp were consumers used to act and animate creatures were consumers acting by themselves.

Cristina Mariani investigated which entities were understood as conserved, and why. Two main dimensions were 'conserved versus not conserved' and 'creative versus passive'. Energy was seen as creative but also conserved. More important was the nature of conservation. Entities were conserved when understood to be beyond the effective reach of action, in a strong sense if actions could not affect them in principle (e.g. space) and in a weaker sense if actions could not affect them in practice (e.g. an atom, too small to be acted on).

Cristina Mariani went on to a much more extensive study of dimensions of reasoning about entities such as time, space, energy, matter, light, force, motion etc. She found four very stable dimensions:

- place-like versus localised
- dynamic versus static
- cause versus effect
- discrete versus continuous

Energy, for example is localised, dynamic, a cause and discrete. Space is static, and place-like. Matter is static and localised. Sound is dynamic and localised, effect-like and continuous.

These dimension were stable across a wide age range, from 12 years old to post-graduate physics students. Entities varied in their positions on the dimensions, with age and learning, but the dimensions remained the same. Subjects given the dimensions explicitly agreed with the statistical analysis in their placing of entities.

Cristina Mariani, and now Isabel Martins, have gone on to investigate, in a project funded by the Leverhulme Trust, the ontology of events. Dimensions rather closely related to those for entities seem to emerge. This work will next extend to investigating how metaphors used in scientific explanation may relate to these dimensions. Further work is planned in the history of science, regarding certain major scientific developments as "ontological change" in which an entity changes is deep nature (e.g. the Earth changed by Copernicus from a static place to a moving localised object).

These ideas, and others drawing on theoretical work on the nature of explanation, were used by Katherine Hann, Tim Brosnan and Jon Ogborn in a study of groups of primary teachers discussing science TV programmes, trying to understand and make sense for themselves of the scientific information in the programme. Structured discussion activities were developed which have proved useful enough to be published by British Gas and an In-Service Training pack for primary schools. The analysis of data showed that many of the general ideas thrown up by the above research could be used in understanding the teachers' often successful use of their commonsense thinking to grasp new scientific ideas.

4. Development of computer tools for modelling

Part of this work is described in a longer paper in these proceedings, so it will only be outlined here. Having developed and evaluated two quantitative modelling systems for use in schools (CMS and DMS, the latter adopted in Holland), we went on to work with others on more innovative ideas about modelling systems. One, IQON, was developed in a collaborative project with other London area University departments. It supports qualitative modelling with variables, in which no mathematics is required. Data obtained in this project and by Arion Kurtz dos Santos showed that children could use it to construct interesting and quite complex models, but that both young students (12-14 years) and older ones (16-18 years) still often thought in terms of objects and events rather than in terms of variables. This has led to a new system, WorldMaker, based on the cell automaton concept, in which models are made of objects obeying qualitative rules of interaction with their neighbours (change, move, vanish etc). Research is in progress with Eleni Maragoudaki and Richard Boohan in understanding how children and teachers can use this system.

In the course of this research we have obtained a lot of experience in building a wide variety of kinds of modelling tool, including tools for systemic grammars, for algebraic calculation, and for graph-like data structures.

A basic distinction, introduced in this research and now becoming rather commonly used, is between exploratory and expressive uses of computer tools. In the first, the student uses the tool to explore a model provided by the teacher or by an expert. In the second, the student uses the tool to express his or her own ideas and to experiment with them. The general finding seems to be that students working in the exploratory mode can often cope with more complexity, but that students working in the expressive mode make more radical changes to models and are more critical of models.

5. Teaching about processes of physical change and energy

In the late 1960s Jon Ogborn helped to introduce ideas of statistical mechanics into secondary school teaching in the Nuffield Advanced Physics project. The line of thought that the Second Law of Thermodynamics is, in some form or other, essential to teaching about the direction of processes, has re-emerged under the pressures of changes in the science curriculum towards discussion of energy in relation to life and to the uses of fuels.

A rather new project, with Richard Boohan and Fani Stylianidou, focuses on the fundamental idea of difference being responsible for change. With younger pupils (age 11-13) we focus on intensive differences of temperature and concentration of matter, regarding temperature as concentration of energy. Energy and matter tend to go from where there is a lot to where there is not. Differences tend to go away. We have developed pictorial methods of getting pupils to compare different cases ('How is a cup of coffee cooling like or unlike the Sun radiating heat and light?') and to generalise across classes of examples. This work just requires extra emphasis to be given to things which are often taught in science but not much stressed, and not often compared (e.g. thermal flow and diffusion).

With older pupils we have yet to tackle how to introduce in a similarly simple and qualitative way thinking related to the scientific ideas of negative entropy or free energy (which will not be taught explicitly). We hope to get them to see, for example, photosynthesis as trading one kind of difference for another, with a difference vanishing as hot sunlight is re-radiated into space paying for an increase in difference as dilute atmospheric gases are concentrated and built into complex molecules. But we don't know how to do it yet.

6. The future

We don't know what the future will hold any more than anyone else. We think that the work on commonsense reasoning has built a good platform both for further fundamental studies and for more practical studies relating it to particular ways students think in particular situations, in the way that Laurence Viennot's work (elsewhere in these Proceedings) shows to be essential.

We hope to develop the modelling systems further, and in particular to give IQON the ability to support constraint reasoning with many variables as well as, at present, dynamic causal link reasoning. We also want to get these systems onto other platforms, especially IBM compatible.

Further work at other levels of education, and for teachers, on Second Law aspects of the direction of change is clearly important, if science teaching is to have anything scientific to say about many issues of present public concern. More generally, we continue to share an interest with many others in the world in the scientific knowledge and ability of primary school teachers. So far our approach has emphasised the value that their use of commonsense thinking can bring to their understanding of science, and we expect that to continue.

As previously, however, we expect new research students and staff to bring new ideas to be developed, and we therefore expect the variety of our research to grow rather than to shrink.

Research in the Centre for Studies in Science and Mathematics Education at the University of Leeds

J.Donnelly

1. About the Centre

The Centre was established in 1970 under the direction of Prof.David Layton. Its present Director is Mr.Colin Wood-Robinson. The Centre operates within the School of Education, and at present has actively associated with it some 30 academic and research staff. It acts as a focus for a wide range of research and teaching activity, including technology education as well as science and mathematics (the last will not be further discussed here). Staff from the Centre mount in-service and pre-service courses in science education for both British and overseas students. The Centre has academic links with many other institutions, especially in the British Commonwealth, but increasingly also in both the EEC and Eastern European countries, as well the Americas. The review journal 'Studies in Science Education' is published annually from the Centre, under the Editorship of Prof. Edgar Jenkins. Research training is also given to students working on a full-time and part-time basis for the Ph.D. and Ed.D. degrees in Science Education. The Centre has research students from the UK, Europe and elsewhere. Where possible students work within ongoing larger research programmes.

2. Research in the Centre

The main lines of science education research in the Centre are in the following areas: children's learning in science; historical and policy studies; adult scientific literacy; international education (mainly in developing countries); technological education. In addition the Centre has close links with the Computer Based Learning Unit in the School of Education.

Children's learning in science
The work focuses on three main themes:

1. Studies of the development of children's scientific concepts and reasoning over the school years, including: children's understanding of ecological ideas; children's understanding of the nature of matter; children's understanding of the physical properties of air.
2. Studies of teaching and learning in classrooms, including: the learning of mechanics using computer assisted instruction; teaching for conceptual change at primary and secondary level; action research with teachers to develop curriculum support materials in relation to the National Curriculum for England and Wales.
3. The public understanding of science, including: the development of children's understanding of the nature of science; the public understanding of global atmospheric changes (an interdisciplinary project with the School of Geography.).

A study is also in progress on the learning of science by children with Specific Learning Difficulty (dyslexia).

Historical and policy studies

Much of this work occurs under the direction of Prof. Edgar Jenkins, and includes at the present time:

- an investigation of the development of the primary science curriculum;
- a study of the implementation of the Attainment Target 'Scientific Investigation' within the National Curriculum for England and Wales;
- recent history of the science curriculum in England and Wales;
- a historical study of industrial aspects of the chemical curriculum.

An evaluative study of the implementation of practical assessment in the GCSE (the summative 16+ examination in England and Wales) has recently been completed, and is about to be published. A Centre for Policy Studies in Education has recently been established within the School of Education.

Adult scientific literacy

Some work under this heading has already been referred to. A study of the use made (or not made) of science by such diverse lay groups as local politicians (in waste management), elderly people (in heating their homes) and the parents of children with Down's Syndrome has recently been published.

Technological education

The Education for Capability Research Group focuses a range of interests in this area. Prof. Edgar Jenkins edits 'The International Journal of Technology and Design Education'. Programmes of work on liaison with industrial firms are also ongoing.

International education (mainly in developing countries).

Several collaborative projects with a research dimension are in progress, including:

- in Botswana, studies relating to several aspects of children's learning, such as their understanding of inheritance, and the problems of learning science in a second language.
- in Tanzania and Malawi, work to enhance the science curriculum through local technology.
- in Kenya, work on developing new forms of science teacher training.
- in South Africa in collaboration with SEP (Science Education Project), a curriculum development and in-service project focusing on secondary school science.

The Computer Based Learning Unit

The Computer Based Learning Unit was established in the early 1970s. It is not part of the Centre but has close links with it. The Unit is under the direction of Prof. Roger Hartley. Its main research themes are: design and development of intelligent on-line help systems; text generation; interface design for interactive dialogue systems; knowledge-based tools for representing organised systems; intelligent authoring systems.

Examples of recent publications

Bird, E. and G.Welford (in press). 'The effect of language on the performance of second language students in science examinations', *International Journal of Science Education.*

Buchan, A.S. and E.W.Jenkins (1992). 'The internal assessment of practical skills in science in England and Wales. Some issues in historical perspective', *International Journal of Science Education, 14*, 367-80.

Donnelly, J.F. and E.W.Jenkins (1992). *GCSE Technology: Some Precursors and Issues,* University of Leeds Education for Capability Research Group.

Driver, R. and J.Leach (1991). 'A constructivist view of learning: children's conceptions and the nature of science'. In: R.Yager (ed.), *What Research Says*, NSTA.

Driver, R., A.Squires, P.Rushworth, V.Wood-Robinson (in press). *Children's Ideas in Secondary Science*, Routledge.

Hartley, J.R., M.J.Byard and C.Mallen (1991). 'Qualitative modelling and conceptual change in science students'. In: L.Birnbaum (ed.), *The International Conference on the Learning Sciences. Proceedings of the 1991 Conference*, Charlottesville, Va..

Jenkins, E.W. (ed.)(1993). *School Science and Technology: Some Issues and Perspectives*, Leeds, CSSME.

Knamiller, G., G.Welford and W.Gibbs (1992). 'Narrowing the school-home divide through teacher-training'. In: D.Layton (ed.), *Innovations in Science and Technology Education Vol. IV*, Paris, UNESCO.

Scott, P., H.Asoko and R.Driver (1991). 'Teaching for conceptual change. A review of strategies'. In: R.Duit, F.Goldberg, H.Niedderer (eds.), *Research in Physics Learning. Theoretical Issues and Empirical Studies*, Kiel, IPN.

Twigger, D. et al. (1991). 'The conceptual change in science project'. *Journal of Computer Assisted Learning, 7*, 144-55.

Research in Science Education at the University of York

R.Millar

1. Context

York has a relatively small Department of Educational Studies - at present a total of 14 full-time staff. Four of these specialise in science education. The two largest teaching programme in the Department are initial teacher education (one year post-graduate programme for beginning secondary school teachers); and the MA programme for experienced practising teachers. One element of this MA programme is a two-year part-time MA in Science Education. In addition the Department offers an undergraduate Education course. This is a modular course, available either as a one-third part of combined degrees with other main subjects or, from 1994, as a full BA course in Educational Studies. The Department has strong links with schools in the area and the science education group works closely with colleagues in the main science departments of the University.

The University of York Science Education Group (UYSEG) consists of members of the University Science and Educational Studies Departments and school science teachers currently engaged in development and research work. The Chemical Industry Education Centre (CIEC), jointly funded by the University of York and a consortium of UK chemical industries, also forms part of UYSEG. The Group has strong links with industry. Over the past ten years, the UYSEG has developed a reputation for curriculum development in science. The largest and best known developments have been the Salters' GCSE Chemistry Project, the Salters' GCSE Science Project and the Salters' A-level Chemistry Project - all funded by the Salters' Institute of Industrial Chemistry and consortia of leading UK industrial companies. UYSEG currently employs ten staff, many of whom are teachers on fixed term secondments, on curriculum development projects in science, producing materials to support the teaching of science at all levels from 7 year olds to undergraduates. In addition, the Group currently has four full-time research workers engaged on a range of projects.

2. Research activities

The emphasis in science education research at York is on *applied research*, which links directly to teachers' immediate concerns. Several distinct strands can be identified:

- research related to curriculum development;
- research arising from changes in local or national policy;
- practitioner research (action research or case study) on teaching and learning in the classroom.

The theoretical frameworks supporting most of this research are drawn from current traditions in science education (such as the domain-specific 'constructivist' research programme) and from the traditions of qualitative research and practitioner research which underpin much teacher research in the UK and elsewhere. Research activities in science education at York fall into a number of categories.

Research related to curriculum development

In common with many curriculum development centres, UYSEG has found that it can be difficult to persuade the sponsors of curriculum development to provide additional funds for formal evaluation or research on the effects of these curricula. As a result, we have developed three strategies for supporting research related to, or arising out of, our curriculum development activities.

DPhil projects

UYSEG has, at present, two full-time and several part-time doctoral students. The two full-time projects, which will be presented at the Summer School by the students involved, are both concerned with issues arising from aspects of the curriculum materials developed by UYSEG. Vanessa Barker is investigating the consequences, for the learning of basic chemical ideas, of the unusual structure of the Salters' A-level Chemistry course. The project is not simply a course evaluation; it involves developing instruments for exploring students' understanding of chemistry ideas and the ways these change over a two year course. Mary Beth Key is working on another aspect of the same course, investigating students' ideas and views about the chemical industry and the influence of a course module involving an industrial visit on these understandings. A third DPhil project, by Christie Borgford, is detailed case-study research on the effects of adopting the Salters' GCSE Science course on school science departments. It will provide insights at a detailed level into the dynamics of curriculum change at school department level.

Small-scale low-cost evaluation research

Evaluation data has been collected on the course choices of students after completing Salters' GCSE Chemistry. This has shown significant increases in the number opting for A-level Chemistry. Similar follow-through studies on Salters' GCSE Science students are planned. A questionnaire study (of pupils' views) and an interview study of teachers' perceptions of changes resulting from the adoption of Salters' GCSE Science have been carried out and reported (in *School Science Review,* 1992 and forthcoming) by Judith Ramsden.

MA in Science Education research projects

The MA in Science Education, mentioned above, is awarded on the basis of a dissertation of around 25000 words, reporting a research study undertaken, with supervision, by the student. In recruiting teachers to this course, we tried to attract teachers from schools which had adopted curriculum materials developed at York. They were then encouraged to undertake research projects which were evaluations of aspects of these materials. The MA in Science Education is a new course, which began in October 1992. In the first group, 11 teachers are undertaking research projects which will involve the collection of specific kinds of evaluation data from teachers or pupils in their own schools, or in groups of neighbouring schools. A significant proportion of these projects will, we hope, be written up as journal articles, summarising the results reported in the dissertations.

Research on teaching and learning

York currently has a share in two research projects funded by the UK Economic and Social Research Council (ESRC). One is the *Procedural and Conceptual Knowledge in Science Project (PACKS)* directed by Robin Millar at York and Richard Gott at Durham. Fred Lubben is the full-time research officer on this project at York. Its period of funding ends in August 1993. The PACKS project is looking at the performance of children, aged 9, 11 and 14, on open-ended investigation tasks in science, of the sort required by the National Curriculum in England. Its aim is to produce a model of the kinds of understanding which a child must have in order to respond appropriately to an investigation task, and so to 'map' the kinds of progression in understanding which are involved as the child moves from being a 'novice' towards becoming a more 'expert' science investigator.

The second ESRC funded project is on the *Development of Children's Understanding of the Nature of Science.* This involves a collaboration between UYSEG and the Children's Learning in Science Research Group at Leeds University. The project directors are Rosalind Driver and Phil Scott at Leeds and Robin Millar at York. John Leach is full-time project officer, based at Leeds. Again this project has run for two years and completes its period of funding in August 1993. In the project, we have used a number of interview probes to explore the ideas of 9, 12 and 16 year old children about some key aspects of the nature of science. We have probed their ideas about experiment, theory, the linking of theory and evidence, and their resources for discussing the resolution of controversial issues in (or involving) science.

Other work on aspects of teaching and learning have been undertaken by science teachers following various higher degree programmes in the Department of Educational Studies. Although the research focus of such projects is often determined by the interests of the teacher, some clusters of projects can be identified. One such cluster is a set of studies of the teaching and learning of specific science topics. Work has been carried out by Arnold (on electric circuits and more recently on heat and temperature), by King and Beh (on voltage in series and parallel electric circuits), by Whitworth (on light and vision), by Nicholl (on magnetic fields), by Gill (on radioactivity), by Forsyth (on muscle action), by Hirst (on growth). Reports of some of these studies have been published; others are currently being prepared for publication. Another group relates to the evaluation of changes in school policy or practice. Recent examples include studies of science teaching and assessment in the lower primary school (ages 5-7).

Overseas education

A major project, funded by a grant from the UK Overseas Development Administration involves the development and evaluation of a demonstration module of science teaching material, with a 'technological, problem-solving' emphasis, for use within the curriculum of a low-income country. By involving teachers in the development of the module, the project also seeks to evaluate this approach to curriculum development as a means of in-service teacher education. The project began in January 1993 and is directed by Fred Lubben. We are using a long established link with the University of Swaziland to help us carry out this project, and are using the development method which was adopted for the Salters' projects. A teachers' workshop in Swaziland, led by York staff, has generated a first draft module to agreed criteria. The edited version is now being trialled in Swazi schools. A final edited version will be used a a vehicle to study the effects of the module in use, and of the curriculum development and dissemination strategy as a form of teacher in-service education.

A recently completed DPhil study (Putsoa) investigated the ability of high school leavers in Swaziland to apply scientific knowledge in tackling practical problems. Two further projects arising from the link between the science education groups at the Universities of York and Swaziland were carried out by Lubben (on the perceptions and training needs of non-specialist teachers of physics) and by Manana (on the production of local, low-cost apparatus). Other recent studies have included work on initial teacher education in Tonga, science curriculum developments in Zanzibar and Malawi, the teaching of A-level science and mathematics in Nepal, and the in-service training of teachers in Cyprus.

Some research publications

Arnold, M. and R.Millar (forthcoming). Children's and lay adults' views about thermal equilibrium. *International Journal of Science Education,* in press.

Campbell, B. and F.Lubben (1992). Science teachers' reasons for doing practical work in Swazi schools. *Bulletin of Swaziland Institute of Educational Research,* 12, 25-31.

Leach, J., R.Driver, R.Millar and P.Scott (1993). Children's ideas about the nature of science from age 9 to age 16. In: J.D.Novak (ed.), *Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics.* Ithaca, NY: Cornell University.

Lubben, F. (forthcoming). The convergence of views of teachers and INSET providers on INSET needs: the case of the non-specialist physics teacher in Swaziland. *International Journal of Educational Development,* in press.

Millar, R. and T.King (1993). Students' understanding of voltage in simple series electric circuits. *International Journal of Science Education,* 15, 339-349.

Ramsden, J. (1992). If it's enjoyable, is it science? *School Science Review,* 73, 73-82.

Research in Chemistry Education at Essen University

E.Sumfleth

1. Chemistry Department

The chemistry department of Essen University consists of six institutes: Institute of Inorganic Chemistry, Institute of Organic Chemistry, Institute of Physical Chemistry, Institute of Technical Chemistry, Institute of Chemistry Education, Institute of Environmental Analytics. This department offers several degrees: one degree (Diplom I) is obtained after 6 terms, another type of degree (Diplom II) after 8 terms. The state examinations for becoming primary school or secondary school teacher take place after 6 terms (for teaching at primary and secondary I) or 8 terms (secondary II). A Ph.D. can only be obtained after an 8-term study.

The Institute of Chemistry Education employs three full professors (Prof. Altfrid Gramm, Prof.Dr.Helmut Lindemann, Prof.Dr.Elke Sumfleth) and one researcher (Dr.Karin Stachelscheid) with the status of a civil servant.

Ph.D.Students

On the average, 6-8 Ph.D. students are working at the institute, being part of three different research groups of the three supervisors. Usually they have just finished their first state-examination for becoming a teacher (secondary stage II) when they start their research. They are either employed by the university and paid by the government, or by diverse funding agencies supporting research or financed by grants of different institutions or industry. No formal post graduate training is required but they have to participate in specific research colloquia and to conduct university courses for undergraduates.

2. Consequences of students' preconceptions

Introduction and method

Investigations concerning students' preconceptions and the development of students' knowledge during school-time lead to consequences on the structure of teaching units, on school-book texts and on the learning process itself. The analysis of knowledge used an explanation test (students have to explain various chemical terms), in addition to an achievement test (several problems students have to solve) and a connectivity test (students have to formulate statements concerning chemistry, using terms listed)(Sumfleth, 1988).

Results concerning preconceptions

Results of the explanation test do not allow any predictions concerning students' performance on the achievement test. Students who cannot discern specific correlations working on the connectivity test are also unable to solve problems in that particular area. They have basic knowledge of chemical terms, but do not recognize relationships and are unable to apply their 1knowledge.

Results concerning development of students' knowledge

Investigations concerning students' preconceptions describe the actual inventory. Searching for reasons for students' difficulties, the change in knowledge during schooling is investigated (Todtenhaupt, 1992). This time, both tests, the achievement test and the connectivity test, refer to daily life in order to facilitate answering of younger students. Overall, older students get better results. They have a greater advantage concerning the achievement test than the connectivity test. One reason might be that the terms listed are not only scientific ones. Consequently, the statements of older students deal also with daily life contents. But these statements are often unaffected by chemistry courses so that the advantage of the older students is reduced.

Students answer in a just satisfactory manner, as that will do to meet the requirements of teachers. They accumulate a stock of scientific terms, rules and laws, but they cannot apply this knowledge. Nevertheless they keep it in mind for a long time, sometimes partly distorted. It is extremely unfavourable to introduce rules and laws you have to revise later on. In particular, teachers have to observe use of language, especially concerning discontinuous interpretations.

Consequences on the structure of teaching units

Following this work, teaching units have been developed which emphasize the connection of new information to available knowledge. Crucial phases of the learning process, comprehension of problems and integration of new knowledge into the cognitive structure, are supported by concept maps. Those supporting problem comprehension, include known terms which the students have to apply during the problem solving process. These maps are discussed with students in order to explain the relations between the terms which have been mentioned. This procedure creates a framework for qualitative understanding. Concept maps that support the integration of the new knowledge contain the results and the way of realizing these results. They summarize the problem solving process.

These teaching units have been used in advanced chemistry courses. The learning outcomes are compared to those of other courses. The results of the explanation tests are similar in all courses. All students are able to use the terms verbally. Concerning the connectivity test, the results of the experimental group are better than those of the traditional one. The experimental group shows significantly better results concerning the achievement test than the traditional group. These results verify that use of concept maps in problem solving, facilitates constructing an interrelated cognitive structure and improves problem solving ability (Sumfleth, 1988).

In elementary instruction the use of formal concept maps seems to be unsuitable. They have to be put into more concrete terms:
- by tasks which students have to solve by experiments;
- by use of models which students construct by themselves;
- by use of experiments confronting students with a problem;
- by use of a written exercise pointing out a concrete situation.

When the connectivity test is extended by giving students a chance to check their solutions experimentally, the formal connectivity test becomes a concrete one. This is a way to get information of students' cognitive structures on the basis of actions. After the first chemistry course, the experimental group shows distinctly better results concerning the formal connectivity test than the others. In contrast, results of the concrete test version equal each other in both groups. This means that the concrete version is of great advantage to the group taught normally (Stachelscheid, 1990).

Concerning vocational training, for instance in the hairdressers' trade, biology, chemistry and vocationally orientated contents like hair-dyeing are taught successively. Anja Pitton (this volume) has developed interlinking teaching units to meet the needs of these students.

Consequences on school-book texts

Besides verbal acts of communication, texts are of importance in imparting knowledge. Texts taken from school-books and from booklets published by the chemistry industry are analyzed regarding different criteria of understandability, like simplicity, arrangement, brevity and terseness and in addition stimulus in accordance to the Hamburg concept of understandability (Sumfleth & Schüttler, 1992). A common characteristic of both kinds of texts is stylistic simplicity. Arrangement is obviously different. Chemistry industry booklets are characterized by an uninterrupted line of reasoning. The facts are represented by phenomena. Required scientific concepts are introduced and explained in a manner ensuring an overall understanding without any preknowledge. Concerning the school-book text, interrelations between sentences are diffuse. In order to establish a coherent relationship between text basis and reader's cognitive structure elaborate cognitive processing techniques have to be used. Nevertheless the reader often is not able to follow the chain of reasoning.

These text characteristics should have an effect on reader-text-interrelations and consequently on students' learning outcome. Results of an empirical investigation confirm the superiority of students who read industry booklets. The content arrangement turns out to be the main criterion influencing text understandability. Based on these results a modified schoolbook text is developed. First students have to read the schoolbook text (group I) and the modified version (group II) respectively and then to work on a connectivity test. In order to relate the terms meaningfully the contents have to be reconstructed.

Group II students describe twice as many relations as group I students. Respecting the phenomenological approach, students argue from daily-life experience. Therefore even those students reading the school-book text are able to see some relations, although the text has many jumps. Concerning the sub-microscopic level, students have to activate cognitive schemes which are badly associated and do not have any relations to daily-life. For that reason jumps from one idea to the other in the school-book text cannot be counterbalanced by drawing conclusions using preknowledge.

As well as texts, illustrations determine the communication of school-books. It is undisputed that visual presentation can facilitate learning. This effect depends on clarification and correct application of pictures. Consequently Andrea Gnoyke investigates the meaning of pictorial symbol systems concerning learning processes (Sumfleth & Gnoyke, 1993).

Consequences for the learning process by itself

In general, there is the question which part does imagery of information play. Imagery means developing an image of the information unit in the mind. These images are not mental pictures that are a copy of environment, but mental layouts, that means mentally treated images. The hypothesis that these mental layouts are of great importance is investigated by collecting introspective descriptions of learners (Körner, 1992).

First of all, using a rating procedure, it is invertigated to which degree learners feel chemistry terms are plastic. Learners have to decide whether or not they associate quickly a precise image to a term. By the same procedure the term properties concreteness/abstractness, meaningfulness and understandibility are assessed. The results were mainly high scores. This is surprising, above all with regard to terms which stand for unperceptible entities like atom or equilibrium. Therefore, it is assumed that perception plays no relevant part assessing imagery and other properties. This is corroborated by relating the term assessments of perceptible and unperceptible entities. If perception plays an important part, the correlations have to be high within each group of perceptible on unperceptible entities and they have to be low between these groups. Concerning 16 year-old students and university students of English language clear differences exist between the assessments of both groups. This is shown by low correlations between these groups. Although the correlations within each group are a little bit higher, you cannot differentiate them clearly from the others. There is no reason to believe that perception has an important influence. Regarding the correlations between the properties themselves there is an interrelation between imagery, concreteness and understandibility but meaningfulness plays a subordinated role. Factor analyses verify this result and indicate that the assessments concerning the three interrelated properties are based for two thirds on a common factor and for one third on specific criteria.

Secondly, students have to give reasons for their assessments. With regard to imagery as well as concreteness, only 10% of the students argue by perception. The relevant criterion for assessing concreteness is conceptual definitional knowledge of the information unit. Concerning imagery the statements refer to practical or mental applicability of the terms.

Thirdly, an experimental phenomenon is presented to initiate situations of teaching and learning. First of all the students as learners have to predict the experimental result and then they have to explain the phenomenon. Afterwards they take the part of a teacher and help the next student to solve the problem. Therefore they get different media, which are criticized by the students during a final interview. First, all students, chemistry students and English language students, refer to daily life experience or describe situations which are connected to the presented phenomenon. Nobody argues by theoretical scientific theories. Visual and episodic imagination is in the foreground concerning realization of problems. But a great difference exists between chemistry and English language students concerning explanations of phenomena. While chemistry students early discuss the discontinuous structure of matter to interpret the experiment, interpretations by English language students keep to the continuous level. In this case only the teacher calls their attention to the discontinuous level. 'Teachers' often use illustrations which show matter evaporating discontinuously as particles. They regard these illustrations and the ideas constructed therefrom as connecting links between experiences and applications on a continuous level, and theoretical interpretations on a discontinuous level.

Summing up, above all practical experiences and actions lead to direct imaginations. Students emphasize that visually represented information is used mentally and is processed as if it were knowledge of actions. Here it appears in outlines that visual ideas are the first abstraction of a practical action. 'If you work out an image, understanding follows, otherwise there is only knowledge without understanding.'

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Approaches and projects at the Institute for Physics Education of the University of Bremen

U.Hericks and H.Schwedes

1. Learning as a development of cognitive systems

For about the last 15 years the interest of the 'Institute for Physics Education' has turned from the structure of the subject, physics, to individual students' learning processes. At the moment a wide range of questions is being pursued by the group 'Aufschnaiter/Schwedes' in different research projects. Various research methods are being employed to investigate and describe learning processes of individual physics students. All of the approaches share a core of basic theoretical assumptions which underlies all research done in the group. In studying learning processes we are not interested in the more or less chance behaviour shown by students in response to particular situations encountered in physics teaching. Such 'chance behaviour' includes, for example, students' statements in class tests, which the teacher can classify as 'right' or 'wrong' and which are expressions of short-term knowledge and skills acquired as a result of physics instruction. It is always possible to persuade students to swot and recite formulas or to reel off algorithms. By contrast, in our research we are interested in relatively permanent and stable changes of students' general behaviour showing itself within the context of argumentation in physics classes. To this end a cognitive structure underlying and organising human behaviour has been postulated. Cognitive psychologists call it the cognitive system. Within the paradigm of constructivism the following postulates have been established:

a. Cognitive systems are self-referential. In other words, cognitive systems are semantically self-contained. This means that the assessment standards of stabilising or changing the system lie within the system itself. Self-referential systems construct their own meanings and their own actualities[1].

1. We distinguish between a subjective and an objective reality, or between 'actuality' and 'reality', similar to the distinction between 'Wirklichkeit' and 'Realität' which was introduced by Roth (1985).

Learning as development of cognitive systems is a socially influenced process. Individually constructed meanings underlie consensual processes. The individual interpretation of situations and events will be changed by the social partners till they agree, so that their understanding allows acting together.

b. Because cognitive systems are self-referential systems, a permanent maintenance of their internal structure is essential to them. In principle, this demand for stability and preservation of identity is disturbed by learning processes which tend to change a cognitive system in order to adapt it to environmental requirements. The problem of how to balance the requirements for stability and change is solved by the assumption that cognitive systems are always structured in sections. Learning processes are assumed to concern a few separate sections only. With this assumption it is possible and useful for practical reasons to reconstruct and describe learning processes in physics teaching as the development of such sections. To this end it is necessary to find a model which allows us to structure cognitive systems in sections in a suitable manner.

Its starting point is the insight of Bauersfeld that the competences of a person which are successfully used in one situation are not (necessarily) accessible in another situation, although an observer would regard them to be adequate and useful in this other situation, too. A good example is the eight-year-old girl Alexandria. She could not solve arithmetical tasks like 8 : 4= ?, while she did not have any problems with the (obviously more difficult) task to distribute five dollars among four children fairly. (Bauersfeld, 1983, 3).
Starting from such examples we suppose that each individual constructs his actuality as ordered and structured by classes of situations. More precisely, we suppose that each individual, based on different experiences, brings together different situations of action to classes of action from the viewpoint that in these particular situations similar competences, similar knowledge, similar behaviour patterns and skills are required. Similarity is judged from the viewpoint of the learning individual. Such classes of action are, in accordance with Bauersfeld, defined as domains of subjective experience (DSE) (Bauersfeld, 1983, 28).

DSE comprise the great variety of various fields in which an individual will act. Our starting point is that for different domains of action, i.e., for different DSE, different areas of the cognitive system are 'responsible' in the sense of the organisation of behaviour, which supposes that DSE are considered to be sections of cognitive systems. The general approach of our research thus concentrates on the conception which describes learning as the development of domains of subjective experience.

Organisation of behaviour and perception by DSE takes place in such way, that the cognitive system first attributes a certain situation to one DSE. The situation is recognised within this DSE as 'well-known' and is structured on its highest level of complexity. (In the last few years our group took up and tested in variations a model of Power's in order to analyse the complexity of DSE which we are not going to display in detail here) In physics education we often meet the problem, that by choosing certain examples in teaching, everyday life DSE are activated not evidently showing concepts of physics which therefore are not considered helpful for structuring the situation (see v.Aufschnaiter et al., 1992).

For example, someone who is starting his car and manoeuvering it out of a parking space acts under a pressure quite different from a person who has to explain acceleration of a car in a physics lesson. The first will attribute the situation to the DSE 'driving', proved in everyday life, the second will activate (if already developed) an DSE 'Newtonian mechanics'. The fact that identical objects may occur in different contexts often leads to problems in physics instruction. For example, the task of explaining the acceleration of cars may also activate the everyday life proved DSE 'driving'. In this DSE, however, Newtonian concepts are not evident.

Learning, i.e., development of the cognitive system can be effected in several ways, real learning processes normally comprising a mixture of the basic types.

a. The cognitive system develops the activated DSE towards a higher level of complexity.
b. The cognitive system enlarges the 'broadness of response' of an DSE, i.e., the variety of situations attributed to the DSE is enlarged.
c. The cognitive system 'starts' a new DSE (e.g. an DSE 'Newtonian Mechanics').
d. The system forms one new DSE out of two or more at the same time re-organising these. (The everyday life DSE 'Driving', for example, can be linked to the new DSE 'Newtonian Mechanics': after successful linkage the starting up of a car will be constructed as an acceleration by frictional forces between tyres and street.)

In the development of DSE the discrepancy between expectancy and the facts noticed after action is of particular importance. A slight discrepancy will not lead the individual subject to further develop his DSE, an extreme discrepancy will lead rather to helplessness, and action will be organised inadequately or stopped; also in this case the DSE will not be modified. Between these extreme cases the optimal discrepancy for learning is found.

2. Physics learning as a development of physics competence

In an additional approach, undertaken within our research group, we describe physics learning as the development of physics competence. The previously discussed DSE model refers narrowly to certain categories of situations in physics lessons and seems therefore particularly suitable for describing the short-term range of learning. The competence model, in contrast, seems more suitable for investigating the long-term range of learning, for example investigating how learning is influenced by what we call the personality of the learner, or, vice versa, how the personalities of the physics learners develop whilst learning physics. The DSE model can be viewed as a psychological approach; the competence model can be viewed a didactic approach.

The competence-model was firstly developed and tested by Schenk (1986). In a later study (Hericks, 1993) this approach to investigate learning processes in the field of mechanics was further developed. At a superficial glance 'competence' is only another name for a cognitive system. A more detailed definition of this structure, however, starts from a certain general understanding of physics as a natural science, instead of starting from cognitive psychology as in the approach above. Physics is understood as a science which undertakes to develop theories, to be considered, with T.S.Kuhn (1962), as 'tools' for solving 'puzzles' of a certain type. The task is to disclose, to describe, and to comprehend, with the assistance of those theories, fields of reality as large as possible. It is essential to remark that fundamental established theories of physics are paradigmatic in the sense of Kuhn. That means, they mediate a certain perspective of reality, a certain 'image' or conception of the world.

In education, it is generally accepted that students entering a physics course already dispose of their own problem solving competence for subject matters, which a physicist would attribute to a certain theory of physics (e.g., to mechanics, or to electrodynamics). Such problem solving competence is called 'everyday life theories' in analogy to theories of physics. Similar to theories of physics, everyday language and everyday life theories show a specific 'image' of reality. Research within the competence model focuses on the question in what way the problem solving competence at students' disposal develop in the course of time under the (supposed) influence of physics instruction and approximate the corresponding theories of physics. Research starts from the hypothesis that new tools will only be developed from existing tools. Similar to Kuhns 'normal scientists' students are in the situation of sailors who at most are able to rebuild their shattered ship in such way that the ship at any time remains able to function, but they are not able to pull it down or to replace it. Therefore it is supposed that students at any stage of their learning process dispose of suitable theories of their own, giving them a subjectively satisfactory understanding of the subject matter in question (e.g., the spatial motion of heavy objects). In this context researchers speak of learner theories. The development of physics competence is thus considered as a continuous transformation of learner theories towards the accepted theories of physics.

A special quality of the competence model is the possibility to interpret hopes, expectations and aims students have in mind when learning physics, as well as their view on physics as a natural science not only as frame conditions for learning but rather as integral parts of physical competence.

3. Methodology of the group 'Aufschnaiter/Schwedes'

If learning processes are investigated within the first model, the structure of cognitive systems is of more interest than the structure of the subject, physics, although every construction of meaning is strongly context dependent. In contrast, compared with the DSE model, the competence model is strongly related to physics. It starts with a special supposedly normative understanding of how physicists attain knowledge and the learning of physics is described as the development of individual problem solving competences within the scope of physics. The development starts in the everyday understanding of topics; it takes place in dealing individually with the elaborated theories of physics.

From a more practical point of view both models are 'compatible'. The concrete actions of educationalists investigating learning within the scope of the DSE model and the competence model respectively are not very different. In both cases the cognitive structure of interest is not observable and has to be gained from empirical data (verbal and non-verbal expressions of students) by a suitable hermeneutic procedure. Correspondingly, the methods to observe and describe learning processes developed and used in our research group are added to and orientated to standards of interpretative social research. As regards content, we chose the subjects of electricity and electrostatics.

The most important method used to analyse learning processes is the observation of instruction over a period of time, up to 30 lessons. Because we are mainly interested in constructions and learning processes of individual students, we favour the observation and evaluation of so-called'action-orientated instruction'. That means that students have to be given the opportunity of performing and carrying out experiments on their own and to

communicate with each other. As a rule, groups of about 3-4 students are set up. The work of one or two of these groups is taped by fixed video cameras and microphones. The groups stay together during the time of observation. The analysis of video-tapes starts with transcriptions. All of the students' actions (i.e., their linguistic and facial expressions as well as their gestures) are put down in writing. Afterwards records of action (in German: Handlungsprotokolle) of the people involved, are drawn up. Therein, the observer constructs limited phases of actions from his point of view. The phases of action have to be in accord with the transcripts. They permit analysis of interactions between students, focusing on each student's social accomplishment and analysis of relationships between students.
A further method to analyse video-taped instruction is the construction of profiles of ideas for each student at different phases of the instruction. Such profiles seem suitable to explain students' behaviour consistently. Furthermore they allow one to draw up regarding the cognitive development of students.

Within the competence model reconstruction of students' cognitive developments are performed with so-called evaluation exercises. In such exercises students are asked to work out an extensive problem, for example to compare the energetic 'costs of transport' of 'train' and 'private car' for a school magazine. A suitable structuring of the exercises must ensure, firstly that the problem can be worked out sensible at different stages of the development of physics competence. Students must be able to gain the expectation that their solutions of the problem will satisfy themselves. Secondly, the problem has to tie on to subjectively meaningful interests of the students. Otherwise, for there is no incentive, students will not work out the problem at the highest level of their physics competence. Exercises fulfilling these two conditions are called authentic tasks (see Hericks, 1993, 145). Authentic tasks, when well constructed ought to reveal students' physics competence as well as their general development.

The construction of authentic tasks is prepared and the observed instruction is accompanied by biographical interviews ('semi-structured interviews'), if possible. Here subjectively important interests of students (i.e., in view of the profession one is aiming for, organisation of one's leisure time, etc.), patterns of orientation and pre-experiences with school and physics are ascertained. Pre-knowledge in physics can be ascertained as well. Our group had good experiences with well-directed experimental interviews of duration up to several hours, and with the so-called repertory grid technique. Repertory grid conversations, a special interview and evaluation technique, seems suitable to show off students' personal constructs to special topics like 'electric current', 'physics teaching', 'ideal student of physics'. Furthermore it seems able to work out individual values and meanings of students as well as their self-concepts (Kelly, 1955; Scheer et al., 1992).

4. Research questions and projects

Aiming at creating suitable models for cognitive systems, finding out learning rules and developing a theory of learning, our main research questions are the following:

1. How can we describe learning processes or learning events?
2. How can we influence the creation of specific ideas and change the dynamics of the creation of ideas?
3. Are the creation of an idea and its valuing two phases of learning?
4. How are different DSE connected? (Transfer, analogy reasoning, models)
5. In what way are learning processes influenced by the self-concept of the learner (personality, gender, individual concept of science, vocational aims, (intended) role in society)?
6. What are the dynamics of consensual processes?

To find answers to these questions, the following research projects are being carried out:

a. Manuela Welzel investigates the influence of interactions among students (working in small groups) or between teacher and students on learning processes of individual students. The investigation is based on video documentation of a grade 10 unit on 'electrostatics' (Gymnasium). Burkhard Langensiepen is going to compare the learning processes taking place in different groups.
b. Elmar Breuer studies the influence of generic principles and aims of actions students have in instruction, as well as their epistemological frameworks on the (following) learning processes. Basis of the investigation is a unit on 'electrostatics' in a high-school advanced physics course for the 11th grade (Gymnasium).
c. Carola Seibel is dealing with learning processes in action-orientated instruction on simple electrical circuits in a 5th grade class. Her question is how the formation of concepts is prepared by manual actions.
d. The topic of another project is how analogies influence learning in electricity courses. Wolff Dudeck investigates this question by modelling electrical circuits by an elaborated water circuit model.
e. Hans E. Fischer tries to model cognitive processes (including learning). Structural features of network models are used to interpret instructional ways of learning consistently.

f. Uwe Hericks is going to investigate the influences of generic structures of personality on learning processes in physics classes. In psychology, such structures are described as identity or self-concepts. The aim of the investigation is to identify and describe different types of learners. The investigation will mainly be prepared within the scope of the competence model.

Finally, we wish to remark that our group is co-operating with neurobiologists, physicists, psychologists and cognitive psychologists in an interdisciplinary research group 'Kognitionsforschung' (research of cognition). One of the main topics of this group is the question how neuronal processes are connected with behaviour.

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Research at the Laboratoire de Recherche en Didactique des Sciences Université de Montpellier II

D.Cros and A.Sivade

1. Institutional background

The laboratory of 'Research in Science Education' is part of a 'reception' laboratory for the D.E.A. (Diplôme d'Etudes Approfondies) at the University of Sciences in Montpellier. Six Ph.D. students are actually working at the laboratory: three are students, two are school teachers and one comes from university. They have all got the D.E.A. examination which corresponds to an initiation into didactical research. After 3 years (for students), or after 3 to 6 (for teachers), they will get a thesis in Science Education.

2. Main research areas of the group

2.1 Environmental studies

Why this theme?

Since 1984, the 'International French Speaking Centre for Chemical Education' (CIFEC) (which has been created under UNESCO pressure) has organized different workshops, which objectives were to carry out experiments for the first year at university. Five books have been published. Some of the experiments were linked to the environment in order that teachers may take some examples from everyday life. In 1988 a UNESCO workshop was organized in Berkeley (USA) in which about 50 countries were involved. The participants decided to develop a common view about a teaching module, entitled: 'Combustion and Environment'. A detailed study of this module has been undertaken by our laboratory, with the help of the French Ministry of Education and the CEE, in collaboration with different countries: Belgium, Italy, Portugal, Spain, Tunisia. The production is a module for students of age 16 - 18. The drafting can be adapted to different kinds of teaching. The module is actually being evaluated.

Moreover, the French curricula have been changed in September 1993 and some subjects in chemistry will be related to the environment: 'Natural Resources, Chemistry, Environment', 'Petroleum and Natural Gas: to Burn them or to Transform them ?', in the 5th year of secondary school and 'Energy' in the 6th year. The approach to the 'Energy' concept, at this level, is also made in other subjects. From these themes, it seemed important to us to have a systemic and transdisciplinary approach, enabling to link several subjects together, such as: physical sciences, biology, economy, geography, etc.. To our opinion, only a systemic approach will provide a homogeneous view of the concept 'Environment' and enable to break the barrier which exists between the different sciences.

Which Research Topics?

a. Environment and Energy at the level of the 'lycée' (second cycle of secondary school).

This study is the subject of Catherine Bruguière's thesis. The theme is developed in relation to semantic problems and the necessity of a common language.

b. Environment and water at the level of 'collège' (first cycle of secondary school).

This study is the subject of Gérard Jourdan's thesis. It started with an inventory of conceptions about 'environment' and some related words, as proposed by students of 'collèges', 'lycées', universities, and teachers of secondary schools/universities. After this first step, a module on water (properties, qualities, treatment, ...) for pupils of age 13-15 will be constructed.

c. Impact of environment-related innovations in chemical and biochemical industries.

This research is done in collaboration with a scientific museum 'Palais de la Découverte', in Paris, and the A.D.E.M.E. (Agency for Environment and Mastery of Energy). Its aim is to identify the means used by industries to solve their pollution problems and to sensitize all types of public. What are the concepts that industries use? What are the messages they want to transmit? The final objective is to set up a module for scientific museums.

d. The impact of non-scholastic organisations on scientific education at secondary school. The case of environmental education.

This study is the subject of Bruno Franc's thesis. The theme is developed in a separate paper.

e. Evaluation of environmental education by specialized people at primary school.

This education takes place under the responsibility of an association for three years. Three members of this association go into the classrooms when the teachers ask them. Its main objectives are:

- to sensitize pupils to the 'environment', using local examples;
- to make pupils aware of their responsibilities towards the surroundings;
- to incite teachers to plan some activities concerning environment and energy;
- at the long term, to change the environmental behaviour of pupils.

Three kinds of activities are proposed:

- a short module (1.30 h.) in the classroom;
- a module (1/2 day) at the school;
- a project (during the school year).

The teachers may choose from six themes: the tree/the forest; water; the wasteland; the habitat; the town/the village; waste/recycling.

After three years, this project is in the process of evaluation.

f. International research in the frame of CIFEC (1994-1998)

This study will try to answer the question: 'How to introduce 'environment' in the teaching of sciences in French speaking countries?' Its main objective will be the development of teaching modules with themes that will be specific to a country or to a group of countries (e.g. Energy, Water, ...). The objectives of these modules could be:

- identification of the parts of a system and their relations;
- identification of fluxes inside a system;
- identification of relations between a system and its environment;
- acquisition of experimental know-how;
- research and scientific information data;
- development of links between the countries through research in science education;

2.2 Chemical concepts

Research based on some fundamental chemical concepts is undertaken by several researchers. The study of the 'atom' and 'molecule' concepts, at the level of 'Collège', is the subject of Danie Bréhelin's thesis. After identifying conceptions with several methods (interviews, word associations, questionnaires, drawings), some new approaches have been used that are being evaluated. A transdisciplinary study on 'oxydoreduction' at secondary school and university levels has just been started.

2.3 Experimental teaching

Autonomous experimental work

This study is undertaken both at the secondary school (Danie Bréhelin) and at university level (Daniel Bourret, Danielle Cachau). At university level, the work is undertaken within the frame of pre-service teacher training. Its aim is to train students to be self-sufficient in solving experimental problems and to identify objectives that are considered by students as essential for their self-experience and needs.

Safety problems

This theme is complementary to the former. Its objective is to sensitize and train teachers in safety problems by different means: special cards for chemical, audio-visual documents, etc. The cards for chemicals will be distributed in each 'lycée' of the Montpellier academy in September. An evaluation will be realized next year.

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Research in Didactics from Lyon

J.Gréa

1. Institutional background

Even when they are working all together, science education researchers in Lyon belong to three institutions: the COAST team is a CNRS-ENS-team from the IRPEACS-CNRS Laboratory; the LIRDIMS is a Lyon 1 University Laboratory and the Bio Informatics Laboratory is part of a 'grande école'. Hereafter, a description is given of how it is institutionally embedded.

Graduate School of "Didactiques des Disciplines Scientifiques"
Lyon 1 & Grenoble 1 Universities

	L.I.R.D.i.M.S. Lyon 1 University	C.O.A.S.T. C.N.R.S.	Bio Inform. Lab. ENVL
staff	5	2	1

These teams are working interdisciplinary. We only present here research workers involved in 'didactics'.
Domains of research and number of Ph.D. students (total number = 10)

Biol	Chem	Math	Phys	Phys	Maths	Biol
1	2	1	2	2	1	1

Allmost all Ph.D. students come from the Lyon 1 D.E.A. of didactics. They have both a background in mathematics, biology, chemistry or physics and in didactics. Often, they are teaching in secondary schools, three have the benefit of time for research and one has a grant.

2. Main research areas

Globally, our research is focused on the relationship between learning situations and students' cognitive activities. Therefore we start from students' thinking activities in problem solving situations, and study how they deal with thinking activities in problem solving situations, and study how they deal with knowledge in the learning process.

2.1 Students' thinking activities in problem solving

The situations for this research are paper-pencil problem solving or laboratory situations. We are particularly interested in the cognitive activities involved, that is to say: modelling and prediction-verification .

a. Research on modelling

This aspect focuses on students' modelling activities involved in physics problem solving or in laboratory activities. We consider that there is a modelling activity when students relate different levels of representation of the same material situation, or of an element of this situation. We state that students establish these relations on the framework of their own theorisation. This statement is based on the hypothesis of students' coherence at least from his/her own point of view. The chosen situations in which to study this activity are either physics classroom teaching, with modelling as a necessary task for problem solving, or situations in which modelling is an object of teaching in itself. (CHENE Project)

Two theses are involved in this direction. One is in the framework of physics teaching at the first year level of the French Lycée (16 years old) and it deals with electrokinetics. The research work is focused on the role of the oscilloscope as a particular measuring-instrument, which visualises graphically the numerical values of measurements and introduces the time dimension. In the different tasks students have to interpret the data given by the oscilloscope, in relation to the real electrical circuit on the one hand and the physical quantities on the other. Then students have to relate several levels of representation (natural language, graphs, qualitative and quantitative relationships between quantities). Selected data are transcriptions of video records of the two students who are performing the tasks. They will be analysed in terms of relations between the different levels and students' theories behind these relations, in order to characterise the specificity of the oscilloscope in learning electrokinetics.

The other thesis is in the framework of physics teaching for literary sections at the second year of the French Lycée (17 years old). It focuses on learning of an already established energy model, relevant for everyday use of energy. More particularly, we are looking for the role of information (and the model in particular) in knowledge acquisition of the energy concept. The tasks for which we collected data, consist of drawing an energy chain for different experiments. Our aim is students' construction of meaning of the given model. In these tasks students also have to relate different levels of representation. The research focuses on the role of information in this mapping and particularly in the analogical process involved in mapping.

b. Research on prediction-verification

Two main kinds of decision are involved in a student's activities, during a problem solving process. The different stages a student follows in his strategy for solving a problem seem to be of great importance to us. In this way, the organised problem situation which the student has to deal with, allows the expression of his/her autonomy and could give insight into their knowledge. It is useful to say that in being concerned with predictions, we are not only concerned with events or possible phenomena but also with relations and properties, or even with laws that the physical system in question could follow. The same holds for verifications, which are not only related to results or measurements already achieved, but also to the correctness of the experimental device setting, or the choice of the state of the system under investigation.

So, in the framework of this research, we look for students' productions in terms of prediction and verification. The information we can get in that context will allow us to analyse students' knowledge. In other respects, taking advantage of the results so obtained, allows us to built new situations in which prediction and verification render the students more conscious of their cognitive functioning and so to improve their learning process. It is necessary to set up criteria for the analysis of solving activities to characterise which resemble prediction and verification. We will use them further to ask students to make the elements in his/her problem solving explicit. This will play a role in the student's understanding (in the sense of building meaning of') of the questioning raised by the problem. On the other hand, it allows the researcher to get objective elements about the student's knowledge functioning in the situation and to improve it.

In this context, research on the relationship between students' explanation - prediction procedures and the appropriation of physical concepts is undertaken.

Learning of molar concentration

A first study is related to the teaching of molar concentration in the first and second year of the French Lycée. The chosen physical phenomenon (osmosis) is presented to the students (as an event to be observed) in order to be explained. In relation to their explanation, they also have to predict what will happen if a modification is made to the experimental device. Then they may compare their own predictions with what really happens. This comparison allows them to discuss their explanation and possibly to modify or to reinforce their initial explanation. The experimental situation is chosen in such a way as to lead students to use what they think to be relevant (in the context of this specific physical concept: molar concentration) and to formulate hypotheses to predict and explain. The context of this situation, in which students have to come to decisions, appears to be particularly important. In order to be able to analyse the various types and different levels of explanation produced by the students, all the material elements involved in the situation that allow students to fully integrate the questions, have to be made clear. In the same way, in order to explain students' arguments, a study of the emergence of concepts, needed by physicists in the history of sciences, to explain osmosis is necessary. An epistemological analysis of the different theoretical and causal levels at play for explanation is also of particular interest in this context. The research intends to relate these different theoretical levels to information taken from the situation by students. This research is the subject of a thesis.

Problem solving situation

Another piece of research deals with the teaching of energy in the second year of the French lycée. The problem solving situation was organised such as to give different groups different operational instructions; some of which were traditional classroom teaching problem instructions, others being less usual formulations. The problems were of a paper-pencil or laboratory type. Students, two by two, work out the solution and settle their explanations. We limited our analysis to questions of verification and validation. Thus, we have examined students' knowledge in play to questions of physical knowledge (idea, notion, physical quantities, phenomena, models ...) and to questions of its origins (everyday life, just learned). From this analysis, the role of the structure of the statement in the students' strategy setting for verification or validation procedures comes out.

2.2 Students' attainment of skills through various learning situations

The social aim of general teaching is the acquisition of knowledge, whereas vocational training aims at acquiring professional ability. From an epistemological point of view, we can say, in a few words, that it is the issue of knowledge which is the first purpose in education, whereas it is the mastering of skills and attainments which are the challenge for professional training. Evaluation of students' skills following the training period, presupposes that we can evaluate students' knowledge or skills in terms of quality of his/her performance, but also in terms of the professional and technical practices promoted by the social group concerned (members of the trade or profession).

Our problem relates to the role of knowledge management, its setting up in an apprenticeship situation and in the mastering of skills (as revealed in decision making processes). In this context, we undertook to build a training environment for technicians. This study is done in a collaboration of IPNL[1] and ENV[2]. The professional context and the training partners define the following pieces of research.

The TUTSI project (tutor for signal processing training)

The training situation is that of a technician in an experimental research group (in nuclear physic for example). The first research target is to characterise the kinds of physics knowledge, shared by the different actors in the situation, including the technician. We were led to analyse the different nature of the physics knowledge at play in the situation and to characterise its professional aspects. We observed a realistic calibration of the nuclear event parameter acquisition chain, and met the technicians for an interview. Both were video recorded. The analysis of these data led us to characterise several levels of modelling for the same experimental situation, according to the professional background of the group members. Thus we undertook to simulate the physical phenomena with the help of nested models.

Bio Informatics Lab. (ENVL) in collaboration research

The progressive introduction, for 25 years, of high performance machines in agriculture, has rendered work more intellectual and abstract. It also requires agriculturists to go beyond a Pasteur' view of illness and to work from a multifactorial approach of situations, rooted in the necessity for an equilibrium between animals and their environment. Being more autonomous, paradoxically, workers have become more dependent on collaboration with each other. However, this collaboration should not be reduced to a mere exchange of data, but must extend to a construction of new, shared representations for observed situations and new remediation models. These are research objects for the Veterinary School in Lyon. More precisely, we are trying to:

- Characterise case situations: who does what? Which cognitive processes are at work? Which recurrent ruptures in communication happen (work on conceptions)?
- Collect and reformulate reference knowledge involved (work on knowledge transposition).

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1. IPNL: Nuclear Physics Institute in Lyon - IN2P3 and Lyon 1 University
2. ENVL: National Veterinary School in Lyon

- Build learning situations using a multimedia computer environment to help in decision making.

These devices are evaluated either in initial in service training or in professional situations (at the work place). The particular case we study is the collaboration between veterinary surgeons practitioners and analysis laboratory biologists. The mismanagement of this collaboration has led us to conceive an educational tool for improving medical knowledge for both groups This conception requires a field study and collecting reference knowledge.

Types of knowledge in professional training

An another piece of research is concerned with technology teaching for professional training in French lycée (B.T.S.). The study of differences in technical, professional, scientifc knowledge (including know how) at play in a pneumatic chain calibration situation is the object of a thesis. To characterise these differences in knowledge and the fields of practice to which they refer, we propose the same practical situation to post bachelor students (B.T.S.) (for whom the technical school is the common environment) and to workers in an in-service training course (for which the common environment is a professional one). The task is recorded both in audio and video. The theoretical framework from which data are analysed is two faced. The first is concerned with differences in technical knowledge at work in the set of social situations involved (the technician in his working situation, the teacher in his teaching situation, the citizen in his everyday life). The second is concerned with the set of field-practices for the different actors in the training action (trained, teacher trainer, physics teacher). In particular, we are looking for elements in the behaviour of students or workers that pertain to either the personal actor in a calibrating situation, or to the group of actors as a social institutional structure in the training situation (class, students in pairs, the training team).

3. Background of the research

Globally, our research is focused on the relationship between learning situations and students' cognitive activities. Research in Lyon is rather fundamental. Our rationale behind the topics and methodologies is as follows:

a. Knowledge acquisition and its control by the learner is deeply rooted:
   - in the features of the learning situation; which means that we have to take into account all theoretical aspects of learning and teaching (didactical, psychological and communicational point of view)

- in the awareness of learners of 'characteristics' of the knowledge in play; which means that we have to take epistemological and historical analysis of the knowledge in play.into account.

b. Among the different ways used to collect data about experimental situations, the computer will be considered firstly as a recording device, wich makes it a kind of didactical measurement apparatus, or as an instrument for communication. .

We therefore start from students' thinking activities in problem solving situations, and then proceed with how they deal with knowledge in a learning process.

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Science Education Research at Thessalloniki: a selective presentation

D.Psillos

1. Introduction

Research in Science Education pursued in the School of Education is conceived as an activity closely related to educational practice. This line of research is reflected in the structure of our research group which consists of university staff, and experienced teachers. University staff belong to the '-Technologies, Science and Mathematics Education' Section. In this document we present aspects of research carried out in the Section concerning mainly physics education. However, there are other members of staff which pursue research related directly or indirectly to science education, like the science aspects of environmental and health education. The group collaborates closely in its research and teaching activities with science departments of the university, notably the physics department. Several secondary science teachers, as well as primary ones, are associated with the group, thanks to a regulation allowing them a secondment from their schools for up to three years, in order to work in the university as teaching assistants or research associates. These experienced teachers work on small scale developmental projects taking at the same time activity-based postgraduate training. Able teachers may carry over their work up to a doctoral level. In addition, some young graduates working on grants or private funds carry out research for doctoral theses. Normally, there are 3-5 doctoral students. Up to now there were no formal training requirements for carrying out a doctoral thesis, a situation currently under change. In the near future, a two-year postgraduate degree will be a necessary qualification for starting a doctoral thesis.

2. Assumptions and questions

An assumption underlying our investigations on teaching and learning issues is that at present, there are no comprehensive learning, design and teaching theories that can provide adequate explanation of understanding complex scientific knowledge. Accordingly, our approach is to design a series of case studies in a number of fields and study in depth teaching and learning in the relevant topics. We assume that developments in theory will be helped substantially from partial answers related to content specific thinking.

The first research line is based on a traditional content analysis approach with regard to scientific knowledge. The logic of the discipline, notably physics, provides the basic structure in which phenomena, concepts and their relations are taught. Despite the limitations, materials developed by such an approach (Barbas & Psillos, 1993a) are a good means for communicating with our secondary science teachers, who have an adequate scientific background but only limited pedagogical knowledge. In addition to the conceptual structure of the discipline, we assume that investigation of students' understanding contributes to the building of a research base which can serve as a guide for the development of innovative materials matching their capabilities. In turn, the design and application of materials may and has enriched our research questions. These assumptions are the basis for the second main research line which includes a number of current doctoral theses. More specifically, we focus on:

- modelling of students' conceptions about scientific phenomena and concepts;
- developing teaching materials, guides and curricula several of which are based on a constructivist approach to teaching and learning;
- designing learning environments which potentially facilitate the construction of the desired knowledge by the student him/herself.

The fields investigated thus far are electricity, fluids and energy which are included in the school curriculum but are different in their phenomenolo-gical and conceptual structure. Electricity includes two types of phenomena, static and dynamic, and involves several concepts, macro relations among them as well as microscopic mechanisms. Fluids also include two types of phenomena, liquid and gaseous ones, but are dominated only by a few concepts. Energy has a trans-phenomenological character. We consider that a gradual identification of common and differential features of students' thinking and learning with regard to these topics could be a contribution to research in science education.

Most research issues are being investigated at several levels i.e., primary education, secondary education and, recently, at the level of primary teacher education. Thus, in addition to the features of the topics, in our research we take into account students' conceptual evolution and the purpose of knowledge acquisition and use.

3. Modelling students' conceptions

At a first level we focus on the elucidation, description and classification of students' knowledge in specific topics, namely current and static electricity, liquids and energy. Thus, several large scale surveys have been carried out in the aforementioned topics which aimed at providing inventories of Greek students' conceptions, while at the same time pursuing open world-wide research issues. A recent example is the identification of several models which students hold with regard to liquids which have not been widely studied in the literature. Nevertheless, liquids are taught twice in the Greek compulsory education, which provides opportunity to study extensively students' thinking in this topic (Kariotoglou and Psillos, 1993).

At a second level, we try to go deeper into students' knowledge and reasoning skills and model, on a qualitative basis, the underlying knowledge structures which are likely to be employed in specific contexts. Particular issues under study are how students relate types of phenomena, the features of their undifferentiated notions with regard to the scientific ones and their causal thinking. For example, monitoring of students' reactions to experimental situations revealed the richness of their experiences which do not coincide with the limited experimental field often studied in electricity. Students bring to instruction and make use of evolutionary phenomena like the duration of lighting while the curriculum is focused only on steady state phenomena like bulb brightness. Such findings have led us to design a series of diploma level projects in order to study the properties and events which students take into account when linking electrical phenomena and compare them to the historical evolution of the field.

At the level of concepts, we focus on the identification of students' undifferentiated notions. We consider that lack of differentiation, with regard to the scientific concepts, is a characteristic of students' thinking and we try to identify common features across several of the aforementioned topics (Kariotoglou & Psillos, 1993). Lack of differentiation is studied in close relation to students' reasoning. We put considerable emphasis on the study of the structure and the meaning of students' causal reasoning, which underlies their interpretation and prediction of several types of phenomena in electricity and elsewhere (Psillos and Koumaras, 1991a).

The study of causal reasoning is a part of two current theses which extend our previous studies (Psillos & Koumaras, 1991b). These theses attempt to identify differences among students' and student-teachers' reasoning which should be taken into account for designing learning experiences (Barbas & Psillos, 1993b; Spirtou & Koumaras, 1993) .

The methodologies used by our group include large scale surveys, small scale in-depth investigations as well as the monitoring of the cognitive interactions between the students and specially developed teaching materials in natural settings.

4. Developing curriculum materials

Based on a constructivist hypothesis about teaching and learning we focus on articulating teaching content, developing appropriate materials as well as on designing and implementing teaching strategies aiming at making scientific knowledge more learnable. Conceptual learning in particular fields is considered as a process of evolution and transformation of students' models so this part of our research is strongly related to our investigations concerning students' conceptions. The methodologies used to induce conceptual change include transposition of scientific knowledge, task design and modelling of appropriate teaching strategies.

The complexity of the interaction between students' prior knowledge and scientific knowledge under study presents a number of problems only partially studied in several fields, including electricity, fluids and energy. We focus on an epistemological analysis of scientific knowledge in order to gain insights about its features and the relevant cognitive demands put on students. Accordingly, we have developed instructional models of different complexity for educational purposes in the topics under investigation. One particular line of research concerns the transposition of scientific concepts in order to keep their essential scientific features and become more intelligible by students (Psillos et. al., 1988). For example, in the case of liquids, we have suggested that a constructivist curriculum should be based on the introduction of pressure as a primary concept and not in relation to force (Kariotoglou et. al., 1993). Results of this study are encouraging and show an improvement in understanding the concept of pressure by students and acquisition of its relation to force.

The development of instructional models is based not only on scientific knowledge but also on its relation to an appropriate experimental field and relevant tasks. Accordingly, we investigate what tasks are appropriate for different types of learning, for example conceptual differentiation of undifferentiated notions such as 'current' and 'pressure'. Of particular interest are phenomena that could become discrepant events for the pupils, given their different from the scientists epistemological perspective. In this context, we are investigating what may count as counter evidence for the students at particular phases of their conceptual evolution. For example, our data show that in electricity, experiments considered to be as discrepant events are either predictable or interpretable by the students, depending on the models they employ in particular contexts.

Finally, we study the features and the effects of strategies which may facilitate the construction of new knowledge by students. For example, in our studies we attempt to classify students' conceptions as anchoring intuitions, views that may be modified or as obstacles to further learning. Each of these three categories demands different treatment in the classroom. For the case of liquids, specific procedures have already been proposed for each category (Kariotoglou et. al., 1993).

In the above context two theses are currently carried out. One thesis (Spirtou & Koumaras, 1993) is concerned with the learning of scientific knowledge for professional use. The target group is prospective primary teachers whose scientific knowledge is limited. Thus these student teachers should learn physics and should acquire professional knowledge too. The thesis focuses on the following questions: What is the transformed scientific knowledge and appropriate phenomena that should be taught to prospective primary teachers? What aspects of conceptual change teaching models may be taught to them? Energy, which has a trans-phenomenological character, has been selected as a concept that could facilitate a balanced approach between content and teaching methodology. The thesis involves epistemological analysis of this concept, analysis of conceptual change models, identification of student-teachers' reasoning, development and trial of curriculum materials. The other thesis is at the planning phase. It is concerned with studying and evaluating the elements and the structure of instructional models applicable to the development of self-study modules for teachers concerned with the teaching of scientific topics.

5. Designing learning environments

This is a research area which evolved recently out of the previously reported activities. We take a cognitive approach to the design of computer-based learning environments. One thesis (Barbas & Psillos, 1993b) focuses on the development of appropriate tools for linking macroscopic phenomena to the underlying microscopic mechanisms, an issue well known in the literature. Research is carried out in a Macintosh environment with the use of Hypercard. The application field is electricity and the target population is prospective primary education teachers. The underlying assumption is that primary teachers should possess qualitative understanding and reasoning in the field of basic electricity. These qualities can be obtained through courses based on a set of concepts and procedures which describe a microscopic mechanism underlying the macroscopic behaviour. The thesis involves the selection and articulation of appropriate characteristics of instructional models of the microscopic mechanisms, as well as the development and trial out of appropriate software tools. The latter combine properties of simulation and model building tools. Thus they allow students to express their microscopic view as they construct it, to write down their assumptions at each stage of their work, to challenge their assumptions by comparing them to the proposed ones. These functions correspond to three modules, namely the expressive, the theory and the worksheet ones.

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Research in Science Education at Utrecht University: an outline

A.H.Verdonk and P.L.Lijnse

1. Introduction

The Centre for Science and Mathematics Education (CSMEU) was established in January 1989. It coordinates cooperation of five groups, working on teacher training and on mathematics, physics, chemistry and biology education, respectively. The Centre is involved in educational research, pre- and in-service teacher training, post-graduate research training, and curriculum development. About 45 staff members and 10 PhD's are working at the Centre. This contribution briefly describes the *Science Education* part of the research programme, the mathematics part of the centre activities is not dealt with here.

Research in science education, which, in our system, means research in biology, chemistry and physics education, is done at the following levels:

i Secondary education in biology (age 12-18), chemistry (14-18) and physics (13-18);

ii Tertiary chemical education (in cooperation with the University of Amsterdam).

Rationale behind our choice of topics and methodologies

One could say that the overall focus in our programme has to do with what one could call the problematic relation between the scientific disciplines and their corresponding educations, that becomes apparent in a number of aspects.

1. Analysis shows that at present the scientific disciplines still function largely as the main source for choice of content and aims of science education. This results in a lack of topical matter and a continuous addition of new topics in science education. A necessary broadening of the aims of science education, however, asks for other perspectives also to be taken into account.
2. The scientific disciplines also appear to provide the basic 'logical' structure for the sequence in which concepts and procedures are taught. However, to our opinion, such a structure does not necessarily optimise the teaching/learning process.

3. Finally, in education, the scientific disciplines function as a standard for correctness of conceptual meaning (note the "mis" in "misconception") even though the meanings of concepts and procedures in science itself are not unambiguous and functionality of knowledge may point at more appropriate situated meanings.

These aspects, together with a view on teaching as transmission of knowledge, are at the heart of many problems in science education. Its functioning with respect to professional training as well as with respect to future citizens may be questioned. The content and context of transmitted scientific knowledge and the way of acquiring knowledge have become alienated from the original, as well as from the current creation and use of knowledge. So, two important questions result:

1. How productive are the science disciplines as a source of content, structure, aims and context for science education?
2. How can learning and teaching processes in this field be more productively interrelated?

We view science as well as science education as social processes of conceptual construction and change. In our research we take into account students' and teachers' previous knowledge instead of using a model of conceptual transmission. However, adopting such a constructivist perspective does not say yet very much about how to teach. A basic problem for research on constructivist teaching is how to design science education such that:

i it guides students to construct knowledge 'in freedom', i.e., in a context that has been stated by themselves, and
ii it enables a productive coupling of learning and teaching.

The conceptual structure of the relevant scientific disciplines should then *not* necessarily be the starting point for instructional design and the process of concept development should not be forced upon students, but be driven as much as possible by students' own questions and motivations. As a consequence, the endpoint of such science education cannot be determined in advance.

The design of such teaching asks necessarily for a research effort that is based on the study of teaching and learning processes. In doing so, we are interested in what students are saying and doing not from a 'correct science' perspective (whatever that may be), but in order to learn how to come to mutual understanding, as it occurs in the social process of teaching and learning. Therefore we analyse learning and teaching processes in real teaching situations, by registrating utterances of students and teachers, and modes of working, by means of audio and videotapes. Our focus is on the essential interconnectedness of teaching and learning. In our analysis special attention is given to a *coupling* of learning processes: i.e., science learning by students, and learning to teach and to reflect on science and teaching by teachers.

Most of our work can be characterised as an empirical process of closely interrelated research and development, which we call *developmental research.* We aim at a detailed description and justification of content and context specific teaching and learning activities resulting in an empirical *educational structure.* In that description, we focus on why and how productive qualitative changes may occur, i.e., students and teachers giving new meanings to words and concepts and changing their actions during their learning processes. In developmental research small scale curriculum development is spirally coupled to in-depth research on content and context specific, teaching/learning processes in classrooms. This special method of research is reproduced schematically in figure 1.

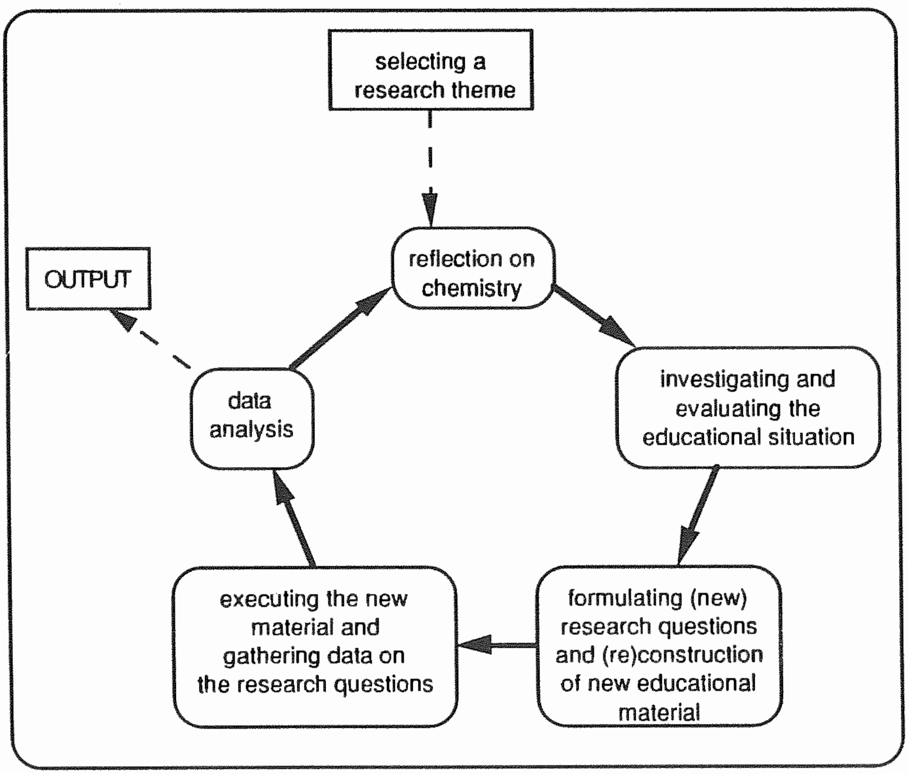

figure 1: The cyclical method

Each cycle consists of:
- registration of the educational situation and its teaching and learning processes and results;
- changing and designing new teaching procedures in close cooperation with the responsible teachers, based on (protocol) analysis and evaluation of the previous cycle;
- trying out the intended teaching processes by the participating teachers, while closely monitoring the resulting learning processes.

The historical, philosophical and educational reflection on science and education necessary in connection with this cycle is not explicitly indicated in fig. 1.

2. Current topics

In agreement with the preceding rationale, our main research interests are:

i new conceptual curriculum structures,

ii conceptual change, coherent from the point of view of productive teaching,

iii development of theory to describe productive science teaching and learning.

Curriculum structures

From a societal point of view a need exists for curricula that are appropriate for the future citizen and for vocational purposes. With respect to the latter we can make a distinction between those leading to professions for which knowledge of science is useful and those training for research in the science area itself. Therefore we work on conceptual structures of school science, bearing two aims in mind. On the one hand we are looking for more consistency within science oriented curricula; on the other we are trying to find criteria for approaches to science education that prepare for citizenship and professions. The structures of the latter not (necessarily) being based on the structure of the disciplines. Topics in citizen oriented curricula that are being worked on are:

i environmental and health education: toxicity and immunity aiming at integration of physiological and social processes, making thoughtful argumentations on waste disposal;

ii physics and chemistry education: radioactivity and risk perception, preparation of materials in a societal context.

In designing teaching for such topics, we start from a 'common sense' network of relations, developing it into what could be called a quantitative macroscopic network, and not necessarily into a submicroscopic network of relations. This means that our primary concern is not with explanations of phenomena in scientific contexts, but with functionality in personal and social contexts..

Coherent conceptual change

Understanding each other in talking about concrete events, especially events that are caused by actions which pupils/students themselves have chosen to perform, is essential in conceptual change from an everyday life, to a science context. The following themes are studied:

a. *Stability and change*
   - biology education: regulation and homeostasis in organisms
   - chemistry education: energy and equilibrium
   - physics education: energy and mechanics

b. *Possibilities and limitations of models*
   - physics education: atomic, nuclear, elementary particles
   - chemistry education: structure and bonding in molecules and lattices; chemical structure and biological function

In this manner we hope to come to, what we call empirically supported (parts of) educational structures of science disciplines.

Educational theory

In our centre there is much discussion about the use and/or development of theories that try to describe learning and teaching as a coherent process of understanding with respect to specific content and context. Such theories could be described as domain specific. At the same time, we try to in corporate useful aspects of more general theories, e.g., constructivist ideas, activity theory (Leont'ev), philosophy of language (Davidson), 'levels of argumentation' (Van Hiele), etc.

More details about our work, can be found in the Ph.D.-contributions in this volume.

Possible future activities

1. Research on the interdependence of different areas of science and mathematics, e.g., the relation between a physical quality and mathematical variable; between mechanical and thermodynamical descriptions; how to measure in different science subdisciplines, etc..
2. The application of educational theory in areas where communication problems between different disciplines or between experts and novices appear.

3. Study of the implementation of research results in larger scale curriculum development and teacher training.
4. Research on the learning processes of (trainee) teachers. Study of the change of their conceptions and strategies with the help of pre- and in-service training courses and newly developed curriculum materials.

Some recent PhD-theses

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H.M.C.Eijkelhof (1990). *Radiation and Risk in Physics Education* (Straling en risico's in het natuurkundeonderwijs.

D.van Genderen (1989). *Mechanica - onderwijs in beweging* (Mechanics Education in motion).

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Ph.D. research

Inter-disciplinary interlinking of contents, relevant for the training in the professional field biotechnology/body care

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1. Introduction

Apprentices in the hairdressers' trade have to undergo three years of practical training, accompanied by three years instruction at a vocational school. It is planned in the curriculum of the subject technology to teach biology - medicine and hygiene included -, chemistry and specific vocationally orientated contents successively during these three years. At this point, students' problems in 'absorbing' and processing knowledge arise. A chronological teaching is quite unfavourable as dividing up topics and contents this way, makes it impossible to discuss a specific problem from the biological, chemical and professional point of view at the same time, that means to teach inter-disciplinary. The individual sectors of specific knowledge remain separate, not linked to one another and lead to isolated, not applicable knowledge (Sumfleth, 1988) But especially in practice, a problem has to be lighted up by an overall view. It becomes necessary that curriculum and teaching methods have to be revised in the context of facilitating the learning process which ease the connected broadening of knowledge. Up to now, apprentices, even at the end of their apprenticeship, still have a scanty, usually not present scientific - especially chemical - knowledge.

Comprehension of a problem substantially depends on mental layouts. Therefore, theoretical, non-practical and non-conceivable contents remain incomprehensible (Werth, 1991) Learners' emotions and attitudes represent a filter for the adoption and processing of information. This is of great importance as usually, the apprentices' interests - e.g. in fashion and cosmetics - are much more outside school. Besides, they are concerned with personal problems which may be related to their stage of development and age impeding instruction at school. Investigations on attitudes, linked with the terms chemistry, biology, and human being, demonstrate that probands show the most negative view towards chemistry (Körner, 1992) The imparting of chemical contents is impeded, biological and medical topics are preferred inevitably.

This leads to the hypothesis that an inter-disciplinary interlinking of the curriculum's contents orientated at experiences, made everyday in the hairdressers' trade should lead to an increase in learning and motivation. This interlinking has to occur on the background of a theory of action-oriented learning. This descriptive and concrete form of learning gives students the possibility to examine problems in their profession more critically and to apply the subject-matter to their own action. In this context, two questions arise:

1. In which way, can the apprentices' interest in chemical explanations for vocationally orientated experiences, made every day, be awakened?
2. How is it possible to moderate or neutralize the present negative attitude towards chemistry to ease the imparting of chemical knowledge?

To moderate students' anxiety of chemistry lessons, the access to scientific subjects must be as concrete as possible. Contents of learning should not only be referable to school and profession, but also to oneself and the daily environment. This should lead to an increase in motivation and a change of students' negative attitude towards learning chemistry could be achieved. An inter-disciplinary interlinking, especially taking into account the biological topics, as biology is not imposed as negative as chemistry - probably permitting a pictorial, processual access could ease teaching of chemical contents: biology is a catalyst in the process of understanding chemical correlations.

2. Inter-disciplinary teaching sequence

To implement the above mentioned hypothesis, interlinking teaching sequences in the subject technology are to be developed on the background of the theory of action-oriented learning, taking into account biological, chemical and vocationally oriented subjects. The sequences, oriented at the plan of distributing subject-matters fixed in the curriculum are:

'Water and detergents': This sequence has already been worked out and taught in several vocational school classes. Following, examining the design of investigation, this sequence is described and first results presented in form of a case-study.

'Allergies in the hairdressers' trade'. The first and second sequence should be taught in the first year at school as the apprentices in practice come into contact with water and detergents very often at that time. Allergical skin irritations caused by products mainly used by hairdressers, have already forced many apprentices to break off their training.

Taking into account the themes 'permanent waves' and 'dying', the most important subjects relevant for the training in the hairdressers' profession are covered.

These sequences have to be tested in selected classes and the success in learning should be determined by the test forms used, consisting of a connectivity test, partially put in concrete terms and an intelligence test. The last one ist not used as an instrument to point out dependencies between intelligence quotient and achieved test results, but only as an aid to distinguish roughly between different capable groups of students. Moreover, an increased comparability of the test results should be achieved by taking into account students' marks in the subject technology too. This method seems to be the most objective to compare the success in learning within one group made by different inter-disciplinary and traditionally taught classes carrying out the same test at different schools.

3. The case-study

3.1 The sequence 'water and detergents'

It covers a volume of eight lessons, 90 minutes each. For every lesson a tabular course of lesson and a detailed preparation is put at the teachers' disposal, including the media needed. The section 'water' starts with a brainstorm, followed by a general introduction into the theme mentioning the water-cycle by making a collage. The lessons two to four impart basic chemistry knowledge about the molecular structure of water and its specific properties. The following courses mainly deal with detergents, their mode of action, and their effect, e.g., on the skin. Finally, a discussion of the sequence is planned, taking into account the brainstorm in the first course.

The fifth course is about surface tension and detergents' effect on it, described below exemplarily. At the beginning of this lesson, a closable glass vessel, filled with water, is placed on a table, containing some living individuals of the water skipper. In advance of the course, students have the possibility to watch the insects. Afterwards, in a short discussion, its biotope is characterized, the individual's development and its possibility to protect itself against wettability. But moving on the surface is not only an ability of the insect, but an interaction between the insect and the surface tension of the water. It must be as strong as to carry the insect, because its feet only dent in the surface, but do not sink as can be observed distinctly. If students know the physico-chemical correlations making surface tension possible, the teacher

can move on to detergents' effect on it. For the students, two questions arise:
1. What happens, if detergents come into contact with water?
2. What happens to the water skipper on the surface of water?
To avoid drowning of the insect, a swimming paper-clip is used as a model in the following experiment. Students observe that the clip is sinking in dependance of the volume of detergents added. In the following, they try to substantiate its sinking. To check the hypothesis that detergents spread on the surface of the water in form of a layer, changing its specific properties, another experiment is carried out. A vessel is filled with water, a thin layer of ground pepper put on its surface. A drop of shampoo is added. Immediately, the pepper is pushed at the wall of the vessel. The detergents must have spread on the surface. Following, the sub-microscopic structure of a detergent molecule has to be cleared up. Detergents serve as a mediator between a polar and a non-polar area with their hydrophilic and hydrophobic part of the molecule, respectively. The last problem to solve in this lesson is to explain the mechanism of the molecules to be associated to the water molecules: Hydrogen bonds are destroyed and the surface tension of water is reduced. It is meaningful to regard the sub-microscopic level of detergents in conclusion: Parallels in the construction of a detergent molecule and the phospho-lipids of the biomembrane, enclosing each cell get visible. It is then understandable that because of such parallels, detergents, e.g. shampoo, daily used by the apprentices and their mode of action can irritate or even destroy the biomembrane and the hydro-lipid coat of the skin.

The sequence is completely observed, recorded and transcribed. This way, an overall view regarding the manner of realizing the teaching concept can be gained, as well as of the insertion of new ideas into the previewed concept on the part of the teacher. Moreover, it is possible to look at interactions between teacher and students. Exemplary, the fifth course is shown: The planned time-table is not met, the course of lesson is partially confused. The students start working on exercises, prepared by the teacher, demonstrating only surface tension. Following, the students' observations are completely summarized by the teacher. Only just, he introduces the water skipper moving on the surface of the water, but only as a 'small performance'. Looking at the insect, different questions arise concerning the biotope, habits, nutrition and taxonomical classification. All students observe that the insect dents in the surface with its feet. Explanations follow daily life experiences which are again summarized and annotated merely by the teacher emphasizing distinct differences between chemico-biological and vocationally orientated contents. At this point, no inter-disciplinary teaching of the section 'surface tension' has taken place. But how should students be able to learn inter-disciplinary, if the teacher does not instruct them this way?

3.2 The intermediate test

The test combination

Having been taught the section 'water', the students have to perform an intermediate test. The same test has to be done by traditionally taught classes to compare the success in learning. It consists of the 'basic intelligence test CFT 3' (Cattell and Weiss, 1980), put at the beginning and a connectivity test, referring to the same content. It is a combination of a connectivity test, put in concrete terms (Stachelscheid, 1990) and a formal connectivity test, exclusively testing the students' cognitive capabilities (Sumfleth, 1988). The connectivity test, put in concrete terms, consists of four questions to be answered within 30 minutes by each student.

1. The students are asked to build a model of a water molecule, using material put at their disposal, consisting of five small and four large balls of pressed cotton wool and nine tooth-picks. The structural formula of their model should be drawn in addition. This question is a repetition of known facts concerning structure and characteristics of the water molecule.
2. The students have to explain the phenomenon that during winter, flora and fauna can survive in a sea, frozen at its surface. The biological example serves as a mediator to describe the anomaly of water. This question refers to the preknowledge of the students, too.
3. Each student is given a beaker with an ice-cube in it. They are asked to note their observations. In this context, the different states of aggregate are to be explained.
4. An illustration of the water-cycle is presented which should be labelled. Second, they have to explain in which states of aggregate water occurs in the illustration. At last, the states of aggregate are to be discussed by the help of particles.

Two questions are not only to be worked on formally, but have been put in more concrete terms, as they appeal to the senso-motoric abilities of the students, developing more concrete imaginations of abstract coherences. This form of learning and broadening knowledge complies with the more practical acting of the students. Although the function of teaching in the secondary stage II, including the vocational school, is to broaden students' preknowledge, students at a vocational school, mainly in their first year of training, should be taught as belonging to the secondary stage I, as their scientific preknowledge normally is so scanty that often no or only rare starting-points exist to extend it.

The formal connectivity test is to be worked on again in 30 minutes. 21 terms are listed in alphabetical order. The students are asked to build sentences in which these abstract terms are related sensibly. This is only possible if their pre- and broadened knowledge is structured in form of a network. This test can hardly be done successfully by writing only mnemonics learned by heart.

Results and discussion of the intermediate test

Performing the IQ-test, testing apprentices at the age of 17 to 22 in the first year of training, their IQs correspond to the Gauss‘ distribution within the commonly used IQ-normscale. The discussion of the connectivity test, put in concrete terms is focused on the first and second question, as students have great problems in working on the formal one.

1. The students have to build a model of a water molecule. A problem is to be solved on the basis of manual acting. A theoretical, chemical idea of a water molecule should be put in concrete terms by a practical approach. Students rarely can solve this problem manually and they are not able to transfer the model into a structural formula. The test results show that this action is only meaningful if a theoretical concept already exists - maybe only shadowy. But if students‘ cognitive structures in a certain field are only rarely developed, they cannot act successfully as there exists no starting-point for meaningful manual acting. Already the terms used in the question or the mode of instructing this theme at school are much too abstract to be understood.
2. How students substantiate the anomaly of water: 54% argue only on the basis of 'temperature', or 'oxygen' referring merely to daily life experiences. Only 11% of the students are able to correlate 'temperature' and 'density' correctly. 35% do not answer. Discussing the test within the class, it reveals that the term 'density' - although explained in detail - is too abstract to be understood. Daily life experiences remain as a basis of explaining a scientific problem.

3.3 The final test

The test combination

At the end of the complete teaching sequence, a final test has to be performed. This test too, is a combination of two tests: a traditional achievement test, developed by the teacher and a connectivity test, put in concrete terms. Both test forms are combined in one class test, the order of questions belonging to one or the other type of test, is mixed up. In the achievement test, chemical contents are tested in form of keywords and mnemonics. The connectivity test consists of four questions out of eight referring to the students‘ preknowledge.

1. The students have to explain in detail, why the water skipper is able to move on the water surface.
2. A model of a tensid molecule is to be build by using given material. It consists of different geometric solid bodies made of polystyrene and eight tooth-picks to join the bodies. Afterwards, the model has to be drawn and the drawing should be labelled.
3. The students have to carry out an experiment. They have to add a drop of shampoo to a beaker filled with water and covered with a thin layer of ground pepper on its suface. The observations should be noted. At last, a given illustration should be completed by showing where and in which manner individual detergent molecules take up to the water molecules.
4. The terms 'hydrolipid coat' and detergents‘ effect on the coat have to be explained.

Results and discussion of the final test

The discussion is focused exemplary on the first question. 22% of the students do not answer this question and a third is of the opinion that the insect‘s possibility of moving on the surface depends only on its weight and/or individual protection against wettability. 17% try to answer regarding the term 'surface tension', mainly without having it understood. 28% try to argue by correlating 'insect' and 'surface tension'. Here too, it must be mentioned that the term 'surface tension' seems to be too abstract as to be understandable. Remembering the transcription of the fifth lesson, it reveals that the section 'surface tension' is not been taught inter-disciplinary at all, but remaining as an abstract physico-chemical term, necessary to learn in correlation with the washing process in the hairdressers‘ trade.

4. Questions

When discussing the sequence 'water and detergents' and its imparting by the teacher in connection with the test results, some questions arise:

1. To what extent, specific problems to be discussed in a hairdressers‘ class, have to be reduced in their abstractness? or: In which way can students‘ cognitive abilities and capacity for abstraction be trained?
   One possible access to scientific problems could be found in the attempt to teach chemistry without the help of particles.

2. Does the teaching sequences have a different influence on students learning process at another type of school?
3. Does a possibility exist to cover the influence of the teacher's personality, including non-verbal communication, on the learning process of students?
4. In which way can the communication between specialists in education at university and teachers at school be optimized to make an efficient inter-disciplinary instruction at school possible?
5. What can specialists in education achieve if a mutual constructive cooperation is impeded by teachers at school?

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Role and impact of out-of-school activities in science teaching: the case of school visits to scientific and technical centres

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1. Introduction

This research work starts from a set of assumptions: schools should have more contacts with the world outside, and interact with society in a more systematic way than today. More and more activities, like museum and factory visits, take classes out of school, while on the other hand organisations come into educational institutions, especially in art and environmental education. At the same time, factories and museums are developing teaching facilities and teams.

These remarks lead to the following conclusion: it is necessary to perform didactic research about the interactions between schools and out-of-school institutions and to study the impact of out-of-school activities in science teaching.

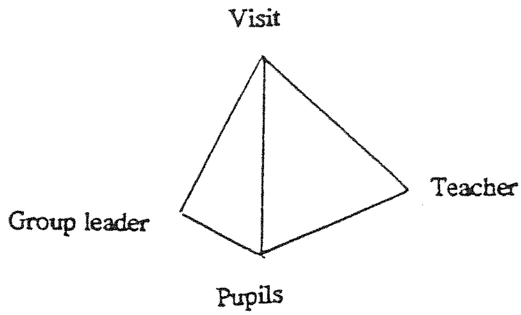
Our research goals are therefore:
- To model this special educational relation.
- To study representations of visits from pupils, teachers and group leaders.
- To study out-of-school activities' impact on knowledge acquisition, and to test hypotheses about this learning step.
- To study how to achieve good results and how to increase the returns of such visits, during their preparation, realisation, and follow-up steps.

2. A first model: who are involved and what are their relations

In order to study the didactic situation created by visits, it is appropriate to adapt the classic didactic triangle to this specific situation.

- Here we have a bivalent 'trainer' pole: it involves two actors with different specifics: the teacher and the group leader.
- The knowledge pole is identified as the visit: the museum or factory visit by pupils, or out-of-school personnel visiting educational institutions. It consists of knowledge, of course, but also of know-how, 'know-being', and 'know-becoming'.

In a first attempt, we may consider that we have four interacting poles (visit, pupils, teacher, group leader) and model their relations by means of the tetrahedron below.



In this first model, we have to study one-dimensional relations (one to one interactions), two-dimensional relations (the tetrahedron is built with four triangular sub-systems), in order to obtain finally a complete three-dimensional systemic view.

2. Visit representations by pupils and teachers

a. Why are we interested in visit representations by pupils and teachers?

In a constructivist approach, as a first step before evaluation, it seems interesting to see what role and what impact school visits could have, in relation to their representations by pupils and teachers. This is useful in order to see whether these different actors ascribe a real 'didactic role' to school visits.

b. Methodology used

In order to develop representations, we use an old tool on which we are working again: word association tests. People have been asked to associate one word with a given word (visit, in my case). The associations are analysed in two ways:

i) focussing on their frequency (or number of citations (n));
ii) focussing on the 'spontaneity' of the citation (p) (order of citation: the word given first is noted 6; the second noted 5, and so on).

These data enable different possible uses:
- Direct word treatment, using a filter system (successive zooms, in order to analyse given words more or less deeply) (Cf. fig. 1 and 4).
- Word classification by themes, or semantic aspects (Cf. fig. 2 and 5).
- Finally we can realise 'maps', with both a statistic and a semantic aspect (Cf.fig. 3 & 6).

Words associated to 'visit' by pupils

Analysis with filters: (fig.1)

	n	p
Research	21	68
Discovery	19	49
Information	14	39
Culture	12	30
Word 10%		Info 42%
To know	10	31
Prevention	10	26
Education	8	27
Information	6	18
Leisure	5	7
Outgoing	4	15
Work	4	10
to understand	4	10
Word 25%		Info 70%
Other words	38	
Word 100%		Info 100%

Semantic analysis: (fig.2)

* Scholar behaviour: 23%
To learn, to know, to understand to write, to watch..

* Subject of visit: 21%
Research, prevention, museum, monument, place...

* Culture: 18%
Information, culture...

* Discovery: 11%
Discovery, exploration, new...

* Leisure: 10%
Leisure, outgoing, relaxation, holidays

* Relation : 5%
Meeting, change, friendly...

187 citations, 51 words, 75 pupils

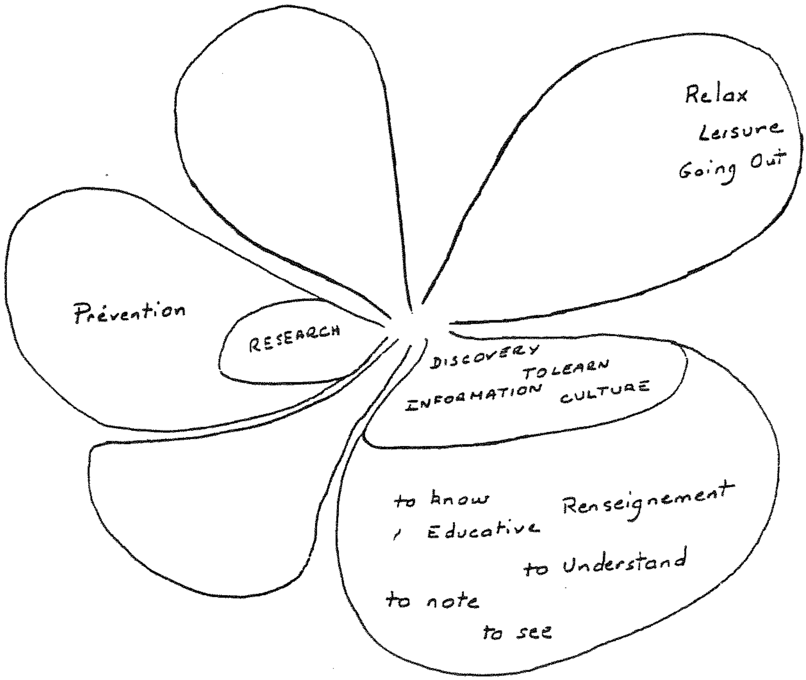


figure 3: Word association map

Words associated to 'visit' by teachers

Analysis with filters (fig.4)

	n	p
Factory	6	36
Contact	5	23
Museum	5	21
Discovery	5	21
Opening	4	21
Application	4	19
Laboratory	4	19
Illustration	4	19
Industry	4	17

Word 14% Info 33%

Semantic analysis (fig.5)

* Visit places : 22%
Factory, museum, laboratory
industry,to write, STCC

* Relational aspect : 17%
Contact, opening, meeting

* Scholar knowledge aspect: 14%
Information, knowledge, Scheme,

Information	3	16
Formation	3	16
To see	3	14
Knowledge	3	13
S.T.C.C.	3	11
Motivation	3	11
Documentation	3	11

Word 26% Info 53%

Other words 48

Word 100% Info 100%

* Work's world discovery: 10%
professional life, formation...

* Reality : 8%
Diary, reality, concrete

* Behaviour : 5%

* Discovery : 4%

* Organisation : 4%

124 citations, 65 words, 33 teachers

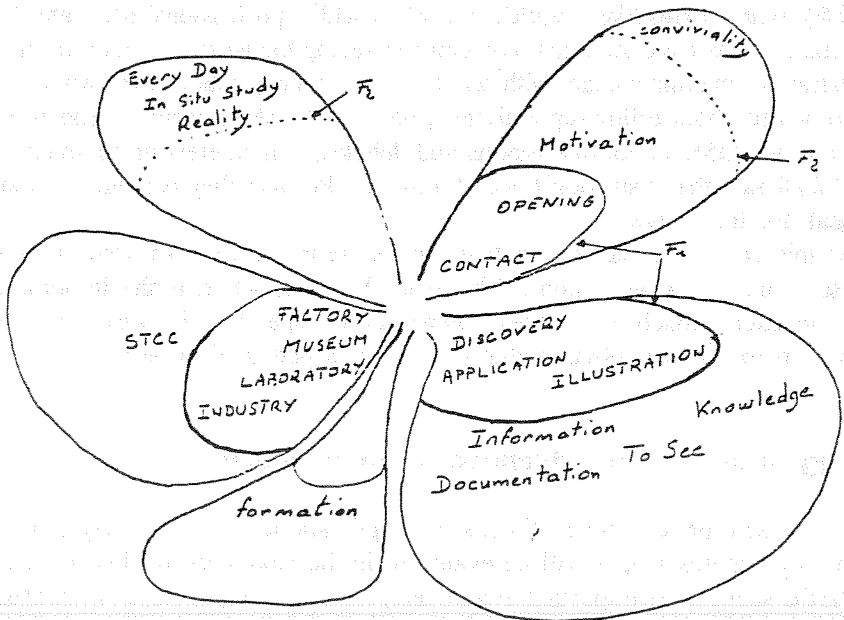


figure 6: Word association map

c. Results

In order to obtain pupils' representation of 'visit', they have been asked to complete a word-association test. From their results, we can see that for pupils, visits have a knowledge acquisition dimension in relation to teaching (words: information, learning, education, knowledge...) and a cultural dimension (discovery, improvement, curiosity...). Reading the words separated by the first filter, we could translate their results by the sentence: 'For pupils, to visit a S.T.C.C. is a discovery that leads them to culture and to information about research'. Furthermore, when they were asked about what they expected from their visit, they particularly emphasized acquisition of information, before promoting curiosity or relaxation.

For teachers, again by a word-association test (in a questionnaire), their representation of 'visit' can, in a first attempt, be described by means ofthree axes:

- Potential places for visits (words: factory, museum, industry...): 22%
- Relational dimension (words: contact, opening, discovery, ...): 17%
- Didactic dimension (words: illustration, information, education, documentation...): 14%.

We can also see the importance attached to discovering reality: 'reality' (8%), with words like: 'reality', 'concrete'...; and discovering the world of work (10%), with worfds like: 'work', 'work's world', 'professional life', etc. For teachers, visits have three main objectives: seeing the world outside; program illustration; making contact with reality. In the same questionnaire, when they were asked about follow-up activities, 45% spoke about written reports and summaries, 35% about discussions and debates. It is interesting to underline that 20% said that visits don't need follow-up. Perhaps they believe that visits 'speak for themselves'.

At this stage, we can notice that pupuls' representation of visits is very close to that of students and of the general public, whereas the importance that teachers attach to 'places' seems to be specific. In view of these representations, it is obvious that visits have a pedagogic role to play.

3. Suggestions for an advanced research project

From these representations of visits, by pupils and teachers, we may propose some hypotheses which will be evaluated in the next steps of this research

- Visits seem to be important at an inter-personal level, to improve contacts between pupils and teachers. This is because, then, the teacher is in a situation where he is no longer the source of knowledge.
- Visits allow knowledge to be fixed in reality, and a 'practical visualisation'

of learning situations. This can be important as the feeling that school is far away from real life is one of the causes that separate pupils and school.
- Visits increase motivation.
- Visits have an important social role to play in pupils' integration, to allow them to place themselves in society and school.

We can also try to evaluate hypotheses about pupils' way of learning during visits.
- Knowledge relationships seem to be constructivist (confrontation between all that pupils see and hear, and their own representations; socio-cognitive conflict; knowledge exposition and institutionalization, eventually in the classroom).
- 'Scientific and technological culture centres' (museum, factory...) allow a 'hypothetico-deductive' scientific reasoning approach.
- Visits may allow children to realise their cognitive reasoning in accordance with their personal rhythm.

Moreover, a deeper reflexion will also deal with school aims, because the role that visits could play is strongly linked to school objectives: only to provide knowledge, or to allow individual cultural development.

How do chemistry courses for students aged 16-18 influence the perceptions of and attitudes towards the chemical industry?

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1. Background

The purpose of this research is to investigate influences that might occur in the teaching of chemistry in an industrial context. It is suggested that students may be influenced with regard to the chemical industry by courses which provide experiences - written and practical work, reading passages in school textual materials, and interaction directly with industry - for them in this area. Whether teachers are also influenced in some way by exposure to industry through teaching about it is not clear, nor is the impact of teachers' views of industry on students. Motives of the industrialists who support such courses may seem obvious and perhaps self-serving (such as those relating to recruitment, public image, and so forth), but might in fact involve a variety of reasons and different perceptions of education which could have considerable implications for schools and curriculum developers.

Do A-level courses influence student perceptions of and attitudes towards the chemical industry, and, if they do, what are these influences and how extensive are they? What are industrialists' motives for supporting secondary education and for enabling industry content to be in courses? As a case study how does the 'Visiting Chemical Industry' unit in the Salters' Advanced Chemistry course influence students and/or teachers? What are industrialists' motives for suggesting school visits to industry?

Current thinking with regard to education in the UK is that more children should not only have the opportunity to pursue education beyond the age of 16 and/or 18, but they should also be encouraged to do so. Additionally, more young people aged 16-18 should be encouraged to study science. There are a number of avenues open for the latter from traditional chemistry in advanced level courses to the chemistry found in modular science courses. A range of secondary institutions exists for educating students aged 16-18, which encompasses traditional independent and state schools as well as colleges of further education. The latter institutions attract some mature students who may opt to continue their studies while employed.

The advanced level (A-level) system has traditionally been the principal conduit through which students must pass to higher tertiary education. It continues to fulfill this role, but it is now one of several options for students. In addition, a greatly revised examination system for sixteen year olds, the General Certificate of Secondary Education (GCSE), has made it possible for more students to have the opportunity for entering the advanced level. At least three major changes have occurred in the last ten years in advanced level science:

1. Some A-level science courses are less content-heavy than they were.
2. Students of a wider ability and interest range are studying science.
3. A-level science students are choosing a larger variety of careers than formerly and more seem to be entering professions other than science.

The UK system of education also offers a variety of approaches to A-level chemistry from the quite traditional, 'pure' chemistry to a context-centered approach. An example of the latter is the Salters' Advanced Chemistry course developed at the University of York. In this new course students learn chemistry first through a context ('the story'), second through activities, and third through theory ('chemical ideas') as they have a 'need to know'. One student [not in the research study described in this paper], who experienced both a more traditional course and Salters' Advanced Chemistry, described the story:

> The Salters' course presents the principles of chemistry in a friendly and undaunting way. Without being too vague or patronizing, it explains the material rather informally, and it is therefore more easily comprehended by students. Students understand material more effectively if it is introduced in a 'story' type of format, rather than a strictly expository textbook format. The more informal structure makes the material more easily interpreted by students.
> But the most important aspect of the Salters' text (sic), that distinguishes it from most.....is that it relates the teaching of chemistry to its real-world applications. As a more effective way of discussing free radicals, rather than simply introduce [sic] them for what they are, The Story' discusses the atmosphere, and the roles that free radicals play in its behavior. This not only makes the concepts more easily understood to the student, but motivates the student more, for he then sees how what he is learning relates to the

world, whereas otherwise he might not realize the point of studying certain topics in chemistry.

2. Description of research project

In the larger view there are four areas to this research:

1. the background and history regarding the will of government and industry to have an influence on the curriculum as a whole; e.g., via the National Curriculum in England and Wales (a national set of standards for teaching subjects like science at the precollege level),
2. the nature of what is happening in the curriculum: that is, the influences on curriculum development and syllabus writers, (3) materials development which provides course materials that teachers can teach, and (4) the effects on students of the first three areas. In a narrower sense, a fifth area emerges -that of the relationship between teachers' profiles, which illuminate their backgrounds and beliefs, and the possible corresponding effects on students.

The overall research strategy for the project involves ascertaining students' and teachers' perceptions of industry, and to this end, it was decided that considerable latitude should be given to study participants so that they could and would provide their own opinions and views as far and as freely as possible. Yet there was also a need for the researcher to be able to gather information from a large sample in a structured manner. Meeting these goals has involved the use of questionnaires and including in those questionnaires questions that enable students [and teachers] to respond in ways which are being suggested here. The resulting questionnaires contain numerous questions which, though open-ended, nevertheless direct the study participants to respond to specific, intended questions.

A challenge inherent in the study is to be able to draw a distinction between the influence on students by a course and the influence on students by factors outside that course -factors which depend on the individual's previous out-of-school experiences and school background. Therefore, there is a need to determine students' views of the chemical industry prior to studying a course involving industry and, if possible, to find out how teachers' views of industry affect students' perceptions. Also important is to distinguish external influences that occur during the course. Some basis for addressing these points was established by probing part of the large body of extant research on attitudes and public understanding, such as described in articles by Aikenhead (1987), Fleming (1987), and Ryan (1987).

3. Project details

To achieve the aims of the project, it was decided that industrialists at the higher levels would be interviewed, teachers would be asked about the chemical industry and the appropriate materials, students would be asked their opinions of a variety of areas relating to the chemical industry, and the four chemistry courses in the study (Table 1) would be analyzed for industry content. It should perhaps be noted that one of these courses requires that students plan and then visit at least one chemical industry site during their two years of work in A-level chemistry. Also a number of teachers of the other courses take their students on visits to industry. In some cases this is because the latter are teaching an industry option.

Table 1: Chemistry courses in study

Chemistry courses	*Brief description*
JMB Syllabus A	A-level syllabus high in industry content— about processes and reactions No required visit, but many teachers do make visits to industry with students
JMB Syllabus B	Traditional advanced level chemistry syllabus Some industry content No required visit to industry
Nuffield	Integrated practical & theory chemistry course No required visit to industry Some industry content
Salters' Advanced Chemistry	New course with innovative approach Considerable industry content in a real world setting Required visit to chemical industry

Teachers and students are being asked to complete three questionnaires,one at the beginning of the course, a second after the industry visit, if there is one, and the third towards the end of the course. The industrial visit questionnaire is meant to obtain students' and teachers' immediate impressions of their visit to industry, so the responses are being requested as soon after the visit as is convenient for teachers. It is necessary to collect the data from this second questionnaire over a period of a year since schools are scheduling the industrial visit when it best fits their own needs (table 2).

Some teachers will be interviewed and special materials on teaching about industry and developed by teachers will be collected from them and surveyed for different approaches and for their breadth of treatment of the chemical industry. Some students will also be interviewed for an elaboration of their responses to the questionnaire.

Interviews of industrialists will be the primary means of data collection from this group. The industrialists interviewed will be from two different groups:

1. industrialists who are in the top ranks of companies and who are therefore decision-makers and
2. industrialists who have direct contact with school groups on visits at a particular company site. Prominent questions to be answered are those concerning whether industrialists want to participate in school visits to company sites, what their perceptions of these visits are, and how much support companies are giving employees who engage in such activities with schools.

Table 2: Structure and timeline

Activity	Time	Description
Pilot study—		
◊ Preliminary questionnaire	Dec/Jan 1991-92	• Questionnaire on visiting the chemical industry • 17 Salters' Advanced Chemistry trial schools
◊ Report on results of pilot		• Results summarized, report given to schools in study
Establishing a basis—		
◊ First student questionnaire ◊ First teacher questionnaire	Sept/Oct 1992	• Critiqued by University of York Science Education Group (UYSEG), then revised • Piloted in two schools outside of the main study, revised again, and finalized • Responses obtained from students at onset of two year A-level chemistry course
Visits to the chemical industry—		
◊ Second student questionnaire ◊ Second teacher questionnaire	June 93 - April 94	• Critiqued by UYSEG and revised • Piloted in two schools, revised, and finalized • Responses being obtained from schools immediately after their industrial visit
◊ Accompany some schools on visits to industry	Autumn 1993	• Collection of on-the-spot data on visits
◊ Industrial interviews	Oct 93 - Apr 94	• Collection of data on industrialists
Finding out what students think at the end of their studies—		
◊ Third student questionnaire ◊ Third teacher questionnaire	March/April 1993	• Same revision and piloting process as before
Research follow-up—		
◊ Letters of appreciation for teachers' efforts to school heads	June-Sept 1993	
◊ Report summarizing findings to be sent to each participating teacher	End of study	

Some teachers new to teaching the particular course have been identified (these are primarily Salters' teachers) and are being followed for information on possible influences on them by the course. The students in the study all started their A-level course at the same time, September 1992.

The study participants are enumerated in Table 3. It should be noted that there are fewer participants from the JMB Syllabus A course because relatively few schools were listed for the 1992 A-level examination, according to the Joint Matriculation Board (JMB), and some of these schools have indicated they have now discontinued the course.

Table 3: Study participants

Chemistry course	*No. Schools*	*No. Teachers*	*No. Students*	*Schools visiting chemical industry*
JMB Syllabus A	16	16	324	12
JMB Syllabus B	37	40	815	18
Nuffield	32	29	722	15
Salters' Adv Chemistry	42	48	628	All
Total in study	**127*	*133*	2489	*87*

* There are 122 *different* schools, as some schools offer more than one of the chemistry courses in the study. Eight women's schools and seven all male institutions have been identified among the 122.

The number of industrialists has not been determined, but approximately forty in as many different companies is the likely target.

4. Strategies being used in the analysis of the questionnaires

The methodology employed in analyzing the first set of data involves two levels of coding: (i) categorization of the focus of the questionnaire questions and (ii) coding of the actual student responses. In beginning the data analysis, an initial question was addressed: *Should the questions in the questionnaires be categorized at face value or could they be more effectively categorized in the light of the way students responded to them?* Although the questionnaire questions were originally grouped when developing the questionnaire, in the light of student responses, a new grouping emerged. The following summarizes the various stages of the analysis. Precedent for the type of analysis coding used in the research is found in the work of Strauss and Corbin (1990).

Detailed analysis (Open Coding)

As the *first* stage to the analysis, a selection of the completed student questionnaires was perused to ascertain the variety of responses to be expected from students in the study. General key word categories were then proposed for the open-ended questions. These categories were sent for validation to six outside reviewers at York, whose responses were varied, wider ranging than anticipated, and extremely helpful. As a result of the reviews, a fresh approach was taken in the analysis, which was hoped would prove to be both tighter and at the same time more flexible.
The ideas gained from the review results and a more detailed survey of the responses given by a larger sample of students in the study led to the *second stage* of analysis. New categories were set up for use in coding answers to

open-ended questions and a sample of student answers was coded to see if the coding categories were usable and of sufficient depth and breadth to classify all possible answers. They were not, and a third approach was undertaken.

During the *third stage* of the analysis decisions were taken to group the questionnaire questions according to the kind of information they were *likely* to yield. [This was a further refinement to the grouping determined in the original questionnaire design.] Four clusters of questions emerged: (1) miscellaneous, (2) knowledge of the chemical industry, (3) sources of knowledge of the chemical industry, and (4) views (Table 4). The knowledge and views groups contain those questions to which students gave answers appropriate to these categories; that is, the student answers helped place the specific questions in a group.

Table 4: Student questionnaire categories

Question Group	*Explanation— what information is likely to be gained*
Miscellaneous (factual)	All questions involve some factual information which needs summarizing; e.g., the number of students who have read newspaper articles about the chemical industry.
Knowledge of the chemical industry (open-ended)	Student responses indicate what general knowledge students have of the chemical industry.
Sources of knowledge of the chemical industry (factual)	The researcher gains an insight into the ways students have been exposed to knowledge about the chemical industry.
Views (open-ended)	The researcher gains an insight of students' impressions of the chemical industry.

Sub-categories were set up for classifying student answers to open-ended questions, 'knowledge of the chemical industry' and 'views'. Because students' answers were used to define the sub-categories, there was some variation in the latter from question to question. [In other words, students sometimes answered specific questions in ways which were unanticipated.]

The *fourth stage* of the analysis was two-fold: (i) a preliminary survey and collation of the short answer, factual question data [such as the breakdown of students by sex and by GCSE science course] and (ii) a detailed coding of student answers to the open-ended questions. The latter involved some revision and refinement of some categories and sub-categories.

Overview analysis (axial and selective coding)

The *fifth stage* of analysis involves perusing a question group [such as 'views'] and the analysis of it to find data trends and to answer specific questions of the researcher. Overview questions [for axial coding] should arise from the detailed analysis results.

5. Some projected outcomes to the research

From the analysis there should emerge secondary research questions. As one example, the analysis could give a picture of students' knowledge of the chemical industry; i.e., how complete a picture students had of the industry as they began their A-level chemistry studies and the picture they have at the completion of their A-level chemistry course. What I hope to do is to be able to develop models or pictures of how groups of students visualize the chemical industry. It might be useful to relate the models students have to other models, such as the one suggested by Aitken (Figure 1). More data and a more complete analysis of it might also lead to a refinement of the Aitken model and other models from other sources.

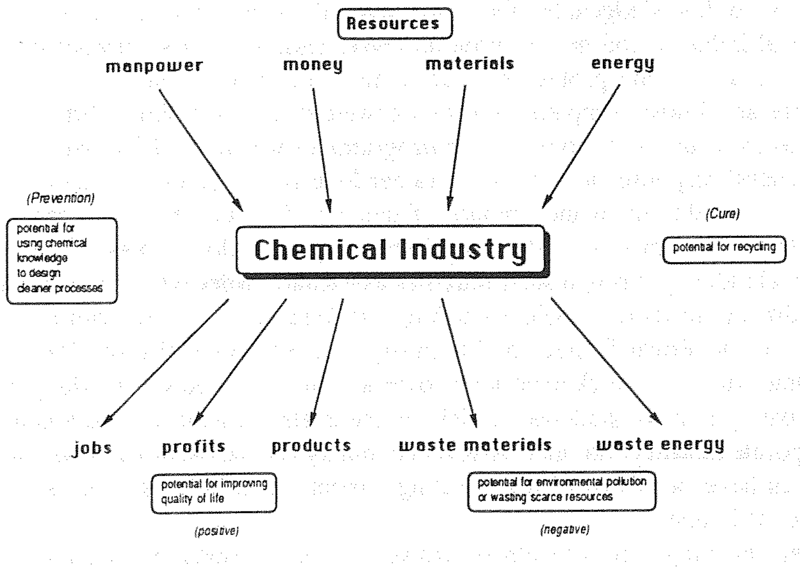

figure 1: A view of the chemical industry (Aitken 1993)

The coding scheme will be used as a guide for determining profiles of different kinds of students. Since the quantity of data is quite large and the research is still ongoing, the results cannot be summarized here. Also, the analysis of the data is incomplete so it is not yet possible to identify how many kinds' of students there are based on a level of knowledge and/or the views. However, use of the coding scheme should ultimately enable the researcher to determine answers to specific questions, such as 'what proportion of students demonstrate a knowledge of the chemical industry and seem to have particular views of it'.

6. Profiles

Student responses have ranged from some very positive or very negative perceptions of the chemical industry to seemingly quite balanced responses in which the same students have mentioned *both* positive and negative aspects of it. That is, the latter students seem to be saying that the chemical industry is neither all good nor all bad. Students have also indicated by their responses that by the time they are sixteen and beginning their A-level chemistry course, some in the study have already had a high degree of exposure to industry through viewing topical television programmes and reading newspaper and magazine articles, through videos seen as part of school science courses and visits made to science and industry museums, and even through visits to the chemical industry and/or work experience there. Some students seem quite knowledgeable about the overall or general structure of the chemical industry and demonstrate an awareness, albeit a somewhat limited one, of many of the problems it faces. In contrast, other sixteen-year-olds indicate an almost complete lack of knowledge and seemingly little or no obvious exposure to it [no television programmes watched, visits made, etc.).

Teachers' responses to the initial, rather long five page questionnaire have been overwhelming in the amount of detail and in the thoughtfulness and breadth of the answers. Most teachers have had close contact with the chemical industry through such activities as vacation work while in university, secondments to industry while teaching, attendance of courses run by such bodies as the Royal Society of Chemistry and the University of York, and for some, full-time work experience over a period of some years. Many have also taken groups of students on visits to the chemical industry and a number incorporate industry into their A-level chemistry courses in other ways. Some teachers have been involved in writing curriculum materials about specific aspects of industry.

Given the range and breadth of answers from the study participants, it is quite probable that a series of profiles will emerge from the data and from the analysis of the textual course materials. It is expected that there will be a broad range of *student* profiles, each containing a proportion of the students in the study. The profile rather expected to arise from the *teacher* data is that of a 'typical' A-level chemistry teacher with respect to teachers' views, knowledge, and experience of the chemical industry. It is questionable whether teachers of different A-level courses will have differing and distinct profiles from one another. A profile of *industry-related material* in each of the four A-level chemistry courses in the study is also expected from the research, as well as one highlighting the motivations of industrialists with regard to their involvement in education. There will probably be one general *industrialist* profile, although possibly more specific ones will emerge, depending on the quality and quantity of the interviews undertaken.

7. What's next? Anticipated outcomes of the research

The next stage of the research is determining what subsidiary questions there are on the nature of the theories which might emerge from an examination of the data. (Also answers to such questions will in part determine the content of the third student questionnaire.) Some limitations are certainly:

1. that the students in the study do not represent the average student population in the UK, since many students here do not take A-level chemistry and one presumes that those who do probably represent a population which is more positively disposed to the chemical industry than is the average student.
2. that the teachers also do not represent the 'average' teacher. However, since the primary purpose of the study is *not* to determine the teachers' views of the chemical industry *in order to compare them with those of other teachers,* this may not be a serious limitation.

I have some notions of the intended audience of this research. Clearly, different depths of analysis of this data might be more fruitful for the different audiences. It should be useful for industrialists, teachers, and curriculum developers in this particular area of the curriculum. Industrialists will want some fairly global statements of direction- things that might influence investment of time and/or resources. Teachers may want details of good and interesting practices and they may want general guidelines to inform practice which are illustrated by specific examples.

Teachers may also be interested in general principles about industrial site visits by students. These principles of general practice will be illustrated by specific case studies of good practice. (Some data on this has already emerged from responses to the first teacher questionnaire.) Curriculum developers will be looking for some sort of general principles.

The influences of the responses and of the analysis of the responses on the rest of the research exist on two levels. The first level may be described as a sort of framework of guidance which might be useful to curriculum developers and others. Outcomes in the second level have to do with the Ph.D. thesis and the ideas which arise from the data. As already suggested in this paper, there is some likelihood that I will be able to put forth a theory that sets out a collection of profiles, or sets of profiles, of student perceptions of and attitudes towards the chemical industry. In any case, it will be interesting to obtain more comprehensive ideas about the views and perceptions of students and teachers regarding the chemical industry and those of industrialists regarding the role of the chemical industry in education.

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An investigation of 16 - 18 year old students' understanding of basic chemical ideas

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1. Background, post-16 education in the UK

This paper presents preliminary findings of a longitudinal study to investigate 16 -18 year old chemistry students' understanding of basic chemical ideas. To monitor change in their thinking, students are being asked to complete a pencil-and-paper test of 22 diagnostic questions at three points over their two-year course. Results from the study will help to fill a gap in our knowledge of students' understanding of basic ideas in chemistry, since at present most published work focuses on 5-16 year-olds.

Compulsory education in the UK ends at the age of 16 after students have taken GCSE (General Certificate of Secondary Education) in a range of subjects, including Science. At present, most students who gain high grades (A, B or C) at GCSE choose to continue their education by taking Advanced ('A') level courses in three or four subjects. Chemistry is a popular choice for many, as it is needed for a wide range of university courses and other careers.

1.1 Two types of A level chemistry course

A 'core' of chemical ideas to be included in all A level courses is agreed nationally, so both well-established, 'traditional' courses and the new Salters' Advanced Chemistry (SAC) course both teach the same chemistry, but they do this in very different ways.

Traditional

Traditional A level chemistry courses follow detailed syllabuses which may be taught in any order. Chemical ideas are treated as individual topics, each taking on average 12-16 hours. Textbooks and course materials are selected by the teacher - there is no prescribed order for teaching the syllabus. The chemistry is applied to contexts where appropriate, usually to help reinforce learning.

Salters' Advanced Chemistry (SAC)

The SAC course was developed in York, sponsored by the Salters' Institute of Industrial Chemistry and a consortium of UK chemical industries. The course comprises 14 'units'. Each unit has four parts - the *Story*, the *Chemical Ideas*, the *Activities* and the *Teachers' Notes*. The *Story* describes chemical contexts, using these as a starting point for teaching the *Chemical Ideas*. The *Activities* include practical experiments which are often also related to the *Story*. Enough chemistry is taught to understand the context. More than one chemical idea may be needed to explain the context (*Story*), so several ideas may be taught at once. Thus, chemical ideas are revisited, as small pieces of information are fed into the course as the contexts demand. The Salters' course is said to have a 'context-theory' approach.

It is possible that the type of course students take influences what they learn. The traditional student may have more knowledge about each individual chemical idea, but the SAC student may have a more complete understanding of how these ideas fit together into the overall 'picture' of chemistry.

The SAC project provides a particularly good opportunity for studying the development of chemical ideas in pre-university students, as students will have been introduced to chemical ideas in a planned sequence. This allows the possibility of linking changes in understanding to course content taught in the period between tests.

2. Research questions and methodology

Three research questions which will be addressed are:

1. In what ways is student learning affected by the context-theory approach?
2. What level of understanding do students have of basic chemical ideas at various points in an A level course?
3. Do SAC students and traditional students differ in the way they respond to diagnostic questions?

A longitudinal study of the 1992-1994 A level cohort is in progress. 400 SAC and 100 traditional A level students in 36 schools and colleges around the UK are involved.

Chemical ideas to be included in the research were selected by applying four key criteria: that the idea should be included in GCSE courses; studied to greater depth at A level; essential to chemistry and the subject of earlier research (to allow comparison of findings with those of previous studies). These concept areas were identified: conservation of matter in chemical reactions; the distinction between elements, mixtures and compounds; chemical bonding; thermodynamics; rates of reaction.

Students' progress is being monitored by use of 22 diagnostic questions presented in a one hour written test. The questions aim to probe what students *think* rather than testing what information they *recall*. Students' responses will be collected three times - at the start, the mid-point and towards the end of the two-year A level course. Test responses will be explored further by interviews with selected students.

Progress to date

A preliminary study using possible test questions was carried out in March - May 1992. The test paper was devised after studying students' responses to the pilot questions. The test was administered to students for the first time in September 1992. A sample of students was interviewed to validate their responses. Students' responses to all questions have been analysed. The test has now been administered for the second time and responses are being analysed in the same way as the first survey.

At the time of the summer school, only two questions had been coded for the second time: *Petrol* and *Phosphorus*. (This question is a slightly modified version of one used in the APU (1984) surveys). These are in the group of seven questions investigating students' ideas about the conservation of mass in chemical reactions. As this is the area in which most progress has been made, the remainder of the paper will focus on these questions.

3. Students' ideas about the conservation of mass in chemical reactions

A full explanation of the coding of responses to all seven questions cannot be given in the space available - further information is provided in a more detailed paper (Barker, 1993). However, details about the coding of *Phosphorus* and *Petrol* are provided and the seven questions are given at the end of the paper.

Initially, the number selected by the student was used as the basis for the code. So, responses to *Phosphorus* were coded by giving an 'A' code to responses where the student selected '400 g', while the alternatives, 'less than 400 g' and 'more than 400 g', were coded 'B' and 'C' respectively. Numerical sub-codes were used to denote different explanations within the same response type. A similar procedure was used for *Petrol*, but in this case the expected response was a figure greater than 50 kg, so this received an 'A' code. Responses stating '50 kg' were coded 'B' and those suggesting that the mass would be less than 50 kg were coded 'C'. Numerical sub-codes were used in the same way as for *Phosphorus*. The proportions offering the responses in the two surveys are shown in the columns, '%1' and '%2'.

Phosphorus - 1st and 2nd surveys

	1st	2nd
Number of scripts	500	395
Number of responses	478	381
Response rate	95.6%	96.5%

RC	Description		%1	%2
A0	400 g	no explanation	2.6	3.3
A1	400 g	the flask is sealed/nothing can escape	51.8	50.9
A2	400 g	formal conservation statement	0.4	4.3
A3	400 g	the number of particles is unchanged	3.8	7.6
A4	400 g	elaborate accurate reasoning	3.8	8.1
A5	400 g	elaborate incorrect reasoning	6.2	2.3
A6	400 g	uncodeable	0.6	-
A	Total		69.2	76.5
B0	<400 g	no explanation	1.8	1.3
B1	<400 g	because gas/liquid weighs less than solid	9.0	8.1
B2	<400 g	because phosphorus is used up	4.2	3.0
B3	<400 g	because water evaporates	0.4	0.5
B4	<400 g	because energy is lost from flask	1.8	1.8
B5	<400 g	mass decreases because P dissolves	3.4	1.5
B6	<400 g	uncodeable	0.4	0.3
B	Total		21.0	16.5
C0	>400 g	no explanation	1.2	0.2
C1	>400 g	solid weighs more than gas/liquid	0.4	0.2
C2	>400 g	because more reactant made	1.2	0.8
C3	>400 g	because energy is absorbed from the sun	0.6	0.5
C4	>400 g	because mass increases on dissolving	0.6	1.3
C5	>400 g	because smoke is heavy	0.4	0.2
C6	>400 g	uncodeable	1.0	0.3
C	Total		5.4	3.5
NR	Total		4.4	3.5
	Overall totals		100.0	100.0

Petrol - 1st and 2nd surveys

	1st	2nd
Number of scripts	500	395
Number of responses	407	348
Response rate	81.4%	88.1%

RC	Description		%1	%2
A0	>50 kg	no explanation	0.6	2.0
A1	>50 kg	petrol reacted with air/oxygen	11.8	22.8
A2	>50 kg	petrol reacted - particle statement	0.2	0.3
A3	>50 kg	petrol mixes with oxygen	0.4	0.2
A4	>50 kg	calculation used	0.2	5.3
A5	>50 kg	uncodeable	0.8	1.0
A	Total		14.0	31.6
B0	50 kg	no explanation	7.2	6.6
B1	50 kg	what goes in must come out	19.2	17.7
B2	50 kg	formal conservation statement	0.6	1.5
B3	50 kg	petrol is converted to gas but mass is unchanged	5.4	6.0
B4	50 kg	petrol is burned	12.0	8.9
B5	50 kg	petrol is used up	2.4	2.3
B6	50 kg	petrol is converted to energy	-	-
B7	50 kg	uncodeable	1.2	0.8
B	Total		50.8	43.8
C0	<50 kg	no explanation	1.4	1.3
C1	<50 kg	gas is lighter than liquid	3.0	3.0
C2	<50 kg	petrol vapourises or condenses	0.8	1.5
C3	<50 kg	petrol is burned away	1.2	-
C4	<50 kg	petrol converted to light/heat/energy	2.8	1.8
C5	<50 kg	petrol is used up	2.2	1.8
C6	<50 kg	only a proportion/% of petrol is used	2.4	1.8
C7	<50 kg	uncodeable	2.2	1.5
C	Total		16.0	12.7
U	Nonsense explanation only		0.6	-
NR	Total		19.2	11.9
	Overall totals		100.0	100.0

Phosphorus and *Petrol* ask about closed and open system reactions respectively. The data indicate that students find open systems far more problematic, since approximately 70% and 14% gave the expected responses on the first survey. The second survey shows a small improvement in this figure for *Phosphorus* (A code up to 76.5%), but a significant increase for *Petrol* (up to 31%), suggesting that a proportion of respondents had learned about open system reactions in the intervening period.

Common to both questions are responses including the absorption or release of energy (*Phosphorus* B4 and C3; *Petrol* B6 and C4) and those suggesting material disappears or is created when a reaction takes place (*Phosphorus* C2; *Petrol* B5, C3 and C5). A later stage of analysis will explore whether the same students use this sort of reasoning in several questions.

The responses to *Petrol* also indicate the tendency of some students to use chemical language in a lay sense - note 'burned' (B4) and 'burned away' (C3). While the latter category does not feature in the second survey responses, about 9% used 'burned' but offered '50 kg' as the mass of exhaust gas. This habit appears to be ingrained and difficult to change. Again, work is in progress to establish whether the same students reason like this in both surveys.

Accurate figures for students offering non-conservation responses are difficult to assess using this coding, since some responses, for example B1 and C1 (Phosphorus) and C1 (Petrol), suggest the students are conserving the amount of material but think mass changes when state changes. A second coding was therefore carried out in which responses were grouped by explanation alone. This will now be explained.

Second analysis - misconceptions and misunderstandings

Although the first coding gave a good picture of students' understanding, a slightly different picture was obtained when responses were grouped by explanation alone. This second coding allows us to see more clearly the proportions of students who did not conserve mass in chemical reactions.

Students whose explanations suggested they understood that mass was conserved were grouped together to form the L code. Explanations where the student implied the *amount* of material may be conserved, but that mass changes when state changes (categories B1 and C1 above) were coded M. Also placed in this code band were responses suggesting the student did not understand the chemistry in the question. The third code, N, was reserved for the responses of students who seemed not to conserve mass in chemical reactions.

Taking *Phosphorus*, as an example, the responses coded A0 - A4 and A6 became category L; A5, B0, B1, B3, B5, B6, C1 and C4 were placed in M;

B2, B4, C0, C2, C3, C5 and C6 were placed in N. Similar regroupings were carried out for all six sets of codes producing these data:

Question	L(%)	M	N	NR	Total
Phosphorus (1st survey)	63.0	22.2	10.4	4.4	100.0
Phosphorus (2nd survey)	*76.5*	*16.5*	*3.5*	*3.5*	*100.0*
Precipitation	44.0	31.2	12.6	12.2	100.0
Solution	55.4	28.6	12.4	3.6	100.0
FeS	48.2	34.4	8.2	9.2	100.0
Carbon & Power Station	11.4	54.8	26.2	7.6	100.0
Petrol (1st survey)	14.0	49.8	17.0	19.2	100.0
Petrol (2nd survey)	*31.6*	*46.1*	*10.4*	*11.9*	*100.0*
Mean (1st survey only)	39.3	36.9	14.4	9.4	100.0

These data confirm the variation in the level of difficulty of the questions. *Carbon and Power Station* (two questions analysed together) and *Petrol* consider open system chemical reactions. The high percentages in columns M, N and NR (No Response) indicate that this type of system is perceptibly more difficult for students.

Further, these data suggest that about half of the students give the expected response where closed system chemical reactions are considered (column L, *Phosphorus, Precipitation, Solution and FeS*). Column N indicates that about 10% of students do not conserve mass for closed system chemical reactions.

The second survey figures for *Phosphorus* and *Petrol* indicate that improvements have been made in students' understanding and imply that some students have changed their thinking between the first and second surveys. The next step in the work is to establish the patterns of thinking of individual students using a database of the codes for all the questions. Students whose reasoning has altered markedly will be interviewed to establish whether they can identify specific causal events which changed their thinking. Such events may differ between SAC and traditional students.

4. Conclusions

Several points can be discussed in conclusion. First, approximately half of the students apply conservation ideas in a conventional way. This is shown by the numbers giving conservation of mass responses (column L) to *Phosphorus*, *Precipitation* and *Solution*. This figure compares favourably with those cited by Andersson (1984) and Briggs and Holding (1986), who used similar questions with younger students. Nevertheless, all students in this research project had chosen to study chemistry for two more years following their successful completion of a GCSE course. This suggests that many students' thinking about conservation of matter in reactions is unchanged from their earlier years of secondary education.

Second, some students seem to conserve the amount of matter present, but think that the mass changes when state changes. Their responses are those in category M of the last table above. These students are operating at a fairly primitive level, since even naive conservation responses (like '400 g, the flask is sealed') do not come easily to them. Perhaps of greater concern to the chemistry teacher, however, are the approximate ten percent who do not conserve the amount of material present in reactions. This group think that new substances are present or that mass is 'used up' (column N). Such students are likely to struggle with the demands of an A level course. Monitoring their future development may indicate their progress towards conserving mass conventionally.

Third, it will be possible to discern whether students apply the same reasoning consistently across questions. These students may be said to operate specific frameworks in their understanding of chemical ideas. Changes in these frameworks will be determined as the study proceeds. Further, events which prompt these changes may be investigated and may relate to the course the student is following.

The study has already produced much data of interest to chemical educators of which only a small fraction is presented here. Future papers will focus on the responses to questions set on other chemical ideas, differences between SAC and traditional students and students' reasoning across questions. Overall, the project will help in furthering our understanding of students' learning processes.

This work was made possible by research grants from ICI and Shell(UK) and is supervised by Robin Millar in the Department of Educational Studies at the University of York.

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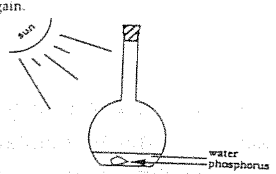
The Questions

Phosphorus

A piece of phosphorus and some water were placed in a flask. The flask was sealed with a rubber stopper. The mass of the flask and contents was 400 g. The sun s rays were focused on the phosphorus which caught fire. White smoke was produced which slowly dissolved in the water. The flask was cooled and its mass measured again.



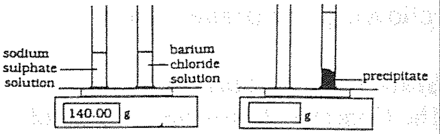
Would you expect the mass to be:

more than 400 g
400 g
less than 400 g?

Explain why you chose your answer.

Precipitation

Aqueous solutions of two salts, sodium sulphate ($Na_2SO_4(aq)$) and barium chloride ($BaCl_2(aq)$), are placed in separate measuring cylinders on a top pan balance. The total mass is recorded as 140 g.



The sodium sulphate solution is poured into the barium chloride solution. Both measuring cylinders stay on the balance. A precipitation reaction takes place.

What will the mass reading be after the reaction?

Less than 140 g
140 g exactly
More than 140 g

Explain why you think this.

Solution

20 g of sodium chloride is dissolved in water. The mass of the water and beaker before any sodium chloride is added is 200 g.

What is the total mass of the sodium chloride solution and beaker?

Less than 220 g
More than 220 g
220 g exactly

Explain why you think this

Iron Sulphide

Iron and sulphur react to form the compound iron sulphide. 56 g of iron and 32 g of sulphur produce 88 g of iron sulphide.

$$Fe\,(s) + S\,(s) \rightarrow FeS\,(s)$$
$$56\,g + 32\,g \rightarrow 88\,g$$

What would you get when twice as much iron, 112 g and more than twice as much sulphur, 80 g, are made to react?

Carbon

Use the equation below to estimate the mass of carbon dioxide produced when 24 g of carbon is burned in 64 g of oxygen gas. The equation for the reaction is :-

$$C(s) + O_2\,(g) \rightarrow CO_2\,(g)$$

Relative atomic mass values are:- C = 12. O = 16.

Power Station

A coal-burning power station burns 1000 tonnes of high quality coal each day.

Estimate the mass of carbon dioxide which will go up the flue chimney each day.

Petrol

A car with a mass of 1000 kg has 50 kg of petrol put in its tank. The car is driven until the tank is completely empty. The car then has a mass of 1000 kg again. What is the approximate mass of exhaust gases given off while the car is being driven?

The approximate mass of exhaust gases is ....kg

Explain your reasoning as fully as possible.

A conceptual structure of school chemistry curricula

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1. Introduction

This paper consists of two parts: 1) a shortened version of my Summer School outline, and 2) a condensed report of the discussion following my presentation.

Statement of purpose
The Conceptual Structure of School Chemistry (CSSC) research project aims to contribute to present reforms of secondary chemical education by developing a *domain specific* curriculum theory, starting from a validated formulation of a coherent conceptual structure of school chemistry curricula.

Background of the CSSC project (1990-1995)
Two important factors which have led to the establisment of the project are the research on concept development (1982-1990) in our department, and the 'wave' of new curriculum projects of the 80's and 90's. Most of our department's research focuses on parts of chemistry curricula as often found in chapters of chemistry textbooks (chemical equilibrium, electrochemistry, chemical bonding, organic synthesis) by performing a conceptual analysis accompanied by the development and investigation of educationally structured curriculum material.

The CSSC project deals with chemistry curricula as a whole. It is a macro-curriculum project dealing with questions raised in micro-curriculum research related to its macro-structure, which are elucidated by performing a content analysis of the entire curriculum from a chemical and chemical-philosophical point of view. The research questions the project addresses, took their final form against the background of recent attempts in several countries to modernize and/or reform the content of secondary school chemistry. It was felt in Utrecht that such reforms stand the risk of affecting the current curriculum only temporarily and at a superficial level as has happened to a great extent with the first wave of modernisation projects of the 60's and 70's

(Fensham, 1992). This calls for the development of a domain specific curriculum theory that can be used by researchers and developers of chemical education, chemistry teachers and teacher trainers for making informed decisions with regard to the content, structure and goals of any traditional and/or new secondary chemical curriculum. I will proceed by formulating my research questions (RQ), mentioning the research methods used to answer the questions (RM) and finally giving some preliminary results.

2. Research questions, research methods and preliminary results

RQ(1) What are the key concepts in a chemistry curriculum, how are they interrelated and to what extent do they form a coherent conceptual structure?

Content analysis from a chemical and a chemical-philosophical point of view (RM) of schoolbooks and syllabi of several countries, reveals a hard core of chemical concepts, with chemical (pure) substance, chemical reaction and chemical element as basic concepts. Some other key concepts found are atom, molecule, valency, structure, chemical bonding, energy and chemical equilibrium.

'Reaction'-chemical concepts are found to be interrelated through theories on element conservation, thermodynamic stability and kinetic stability. 'Structure'-chemical concepts are interrelated through theories on structure and bonding e.g. by macro-micro relationships such as element-atomic species and pure substance-molecular species. (See Ref. below)

RQ(2) Which views on chemistry, science and chemical education underlie school chemistry curricula?

Content analysis from i) a chemical-philosophical point of view, ii) a philosophy of science point of view, and iii) a chemical educational point of view (RM). Preliminary research leads to the following categorisation: i) from a chemical-philosophical point of view: ia) chemistry as a pure science, ib) accumulation of chemical facts, theories and methods, ic) theoretical, physico-chemical orientation; ii) from a philosophy of science point of view: iia) positivism/scientism, iib) focus on explanation and prediction; iii) from a chemical educational point of view: iiia) student as future chemist, iiib) direct transfer of selected facts, and iiic) simulation of scientific method.

A central problem that emerges from this analysis is the tension between new goals for chemical education e.g. chemical literacy, STS and the traditional content and structure of school chemistry. It seems to be that 'school chemistry', its content, structure and aim, has endured a remarkable tenacity through the years even when subjected to large scale curriculum reform such as occured in the 60's and 70's. Will it show the same tenacity in the curriculum reform projects of the 90's?

RQ(3a) Is the explicated CSSC (inter)nationally valid?

A Delphi method is used on data produced by a group of correspondents of the 'International Forum on Structures of School Chemistry' (IF) mainly established at the 11th ICCE, York, August 1991; the same method is used with participants from the Netherlands in the forum 'Structure of School Chemistry' (NF) established May 1993. Forum members are asked to comment on our papers and to answer questions we put to them. A second communication of the International Forum will follow soon. The last one will be in the form of a seminar by and for members of the International Forum. The Dutch Forum will be concluded by a seminar to be held at Utrecht University.

The analysis of the first round of responses, which were in many respects of a critical nature, has substantially clarified some central ideas in our work, for instance on the nature and structure of 'school chemistry' and the degree of uniformity of 'school chemistry' across countries. The results of analysis are instrumental in formulating questions for the second communication of the International Forum.

RQ(3b) Is the explicated CSSC historically valid?

The study of the history of school chemistry will be based on primary sources for the Netherlands; for other countries, secondary sources will be used (RM). Preliminary research on the history of chemistry as a school subject indicates that - although origins and roots may differ nationally - a tradition of teaching chemistry as a science in a pure and abstract way soon became dominant in most (Western) countries. School chemistry meant in most cases preparing students for a chemistry based career by teaching the required stock of chemical facts, rules and theories and by training students in chemical methods and techniques to produce new chemical knowledge.

RQ(4a) Which function can the explicated CSSC have for research in chemical education?

Content analysis, classroom based methods, e.g. observation and audio-taping (RM).

Through analysis from the conceptual-structural point of view of innovative secondary curricula of chemistry, I will try to assess the extent to which these curricula, e.g. Salters' Science (UK), are still determined by the traditional conceptual structure of school chemistry. Two chemical Salters' units have been extensively researched in the classroom. The research material thus collected will be analyzed.

RQ(4b) Which function can the explicated CSSC have for developers, teacher trainers and chemistry teachers?
Content analysis and in-service based research (RM). Explicit knowledge of the conceptual structure of school chemistry may also help developers, teachers and teacher trainers in structuring their courses.and lessons. It may also help to clarify their school chemistry-related views on science, chemistry and education. The project develops an in-service course on the conceptual structure of school chemistry. The second version of this course will be given both in the Netherlands and in the USA in the Fall of 1993. Developers from the Science Education Group of the University of York (UYSEG) working on an innovative A-level science course have asked the Department of Chemical Education of Utrecht University to comment on the pilot material they are developing from our conceptual-structural point of view.

3. A report of the discussion

The following questions for discussion were handed out in group I:

1. What is the epistemological status of the conceptual structure of school chemistry (CSSC): a common core of syllabi, a construct, a world 3 entity (Popper)?
2. Is the explicated CSSC about school chemistry or about teaching school chemistry?
3. Is it helpful for purposes of analysis and teaching to present the conceptual structure of school chemistry as a scheme of concepts or maybe several such schemes?
4. Does or should a research problem define a research method or does or should a research method define a research problem? Should I study the literature for methods of content or textbook analysis or should I work out some domain-specific content analysis, a chemical conceptual analysis, as I go along? Or both? Group 1 consisted of Carol Macaskill, Andre Sivade and Elke Sumfleth, Philip Adey, Jean Grea (groupleaders, members of staff); Anja Pitton(1), Eleni Maragoudaki (2), Alexandros Barbas (3), Alain Gay (4), Kleoparta Nickolopolou (5), Chang M. Chang (6), Berry van Berkel (7), Peter Dekkers (8), Mary Beth Key (9), Monique Schwob (10) The numbers refer to the order in which the PhD students gave their presentation. Also present at this session was staff member Adri Verdonk.

The discussion took about half an hour. What follows is a condensed report. Additional comments in brackets and small print are mine.

Peter Dekkers: It seems now that chemistry includes nuclear physics, because new substances are formed? [Peter is referring here to the definition of chemical reaction given by Clynes, S & Williams D., General School Chemistry, London, 1960, p.18 and discussed in my talk: "A chemical change is accompanied by the formation of new substances while a physical change is not."].

Berry van Berkel: nuclear reactions are normally excluded from school-chemistry [yes, new substances are formed but at the same time the principle of element conservation is violated. So, nuclear reactions are not chemical reactions]

Jean Grea: Clynes' notion of substance is not the same.

Alain Gay: Is it your observation that students are treated as future scientists? Is it done like that in schools?

Berry van Berkel: My observation is mainly based on textbook analysis and partly based on classroom observation; on the way students are addressed in books using the inclusive form of 'we' [e.g. 'we needed to know what weight of A combined with what weight of B' (Clynes, S & D. Williams, p.79 op. cit.). Monique Schwob also mentioned in her talk these grammatical forms: nous, on]

Monique Schwob: a) What does a world 3 entity (Popper) mean and b) What does Delphi method mean? [see Questions for Discussion 1 and 4(i)]

Berry van Berkel: First b) Delphi method means in my case to organise a structured correspondence with the members of the International Forum, anonymously with respect to their statements (IF) and identity (NF) on the complex topic of our explicated CSSC, in order to have as many comments and criticism as possible ['a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem', Linstone, H.A. and Turoff, M. (1975)]. Now a) the philosopher Karl Popper propounded the so-called three world theory according to which: world 1 is the material world consisting of material objects or entities such as mountains, chairs and atoms, world 2 consists of psychological entities such as perceptions, thoughts or cognitive schemes and world 3 consists of the contents of our thoughts i.e. the logical relations between statements, e.g. in problem-situations, explanations or arguments. I was wondering - I guess I was really flying a kite here - if our our explicated CSSC can be seen as a world 3 entity [Later in the discussion Philip Adey referred to CSSC as 'the logical structure of chemistry' and Mary Beth Key mentioned 'the logic of the concepts' influencing teachers and textbook writers. I guess the question for me here is: Can Popper's three world theory help explain characteristics of the tradition of School Chemistry e.g. its tenacity. See RQ(2)]

Jean Grea: You choose for your description the inside analysis of chemical concepts. If you begin with that it is very difficult to manage another side of analysis. Just an example. Not all elements are nowadays known. Just four years ago three missed. Chemistry created elements and give name and there was a struggle which name to give to Bohrium: is it an element because you can do chemical reactions with it? So, I think that another kind of looking for difference between physics and chemistry, one, only one, is to look in what way chemistry creates the world, in what kind physics creates the world. I think that physics creates, divides it in phenomena. I think, superconductiviy does not exist before ten years ago. It is a phenomena which is created, created by physics nobody can do it before, but in chemistry it is not that kind of thing that science creates. It is really the object that chemists use, that is created. I think element, pure substance, I think is historically defined. [see Questions for Discussion 1 and 2].

Berry van Berkel: Thank you. What I am trying to do here in relation to school chemistry is just to describe as coherently and as structured as possible how the distinctions and the concepts are made there. I think you gave an analysis of how chemists or physicists as researchers are seeing things [Jean Grea: not only they] but I want to restrict it to whatever has been said within the context of school chemistry. I realize that there are other positions possible but my first task is just to explicate what has been said overall in traditional textbooks.

Jean Grea: but to explicate you have to take a point of view and you always take the internal point of view. To explain what is in the manual you started from the chemical description of the thing. So, how do you go out?

Berry van Berkel: I start from the chemical point of view but not from the most recent one at the front of the research [Jean Grea: of course] I start from the point of view to which school chemistry leads in the university curriculum. So I am looking from the tertiary...you could say from the intended endpoint of the secondary curriculum I look back to the begin point.

Jean Grea: May I give you a metaphor. In physics we have quite the same thing in the curriculum, you know, we have a lot of disaster in teaching physics. In France it is very evident. When we look to the curriculum in physics you see that you have to teach: kinematics, statics and dynamics. You can do a lot of work about how manage a concept of forces, masses, Gallilean reference, interaction etc. And a lot of work has been done. And you can do another kind of analysis with exactly the same material. What happened when the masses were created? Because mass is a created concept. Perhaps tomorrow mass will be...collaps or dissappear to another concept, possible. And you know that the mass never been created by Newton at once: he created a relation and like element, substance and reaction is one concept, mass, force and acceleration is one concept in the Newton theory because acceleration is a concept inside the concept of mass not outside, but in the manual outside [see Questions for Discussion 1 and 2].

Mary Beth Key: Could I just summarise what I think you said? If he looks at it from the perspective you have just described that may take him to perhaps an even more objective view of school chemistry.

Philip Adey: I think the chemists amongst us might be able to agree relatively easily on what are the boundaries of chemistry and what are the core principles but when it comes to the pedagogy, the teaching of it, we are in a completely different ballgame. You are looking at what is and we know you cannot get an "ought" from an "is"; we cannot see what is and then say this is the way textbooks are. Textbooks are like this only partly because of the nature of chemistry, but partly because of the way children learn. And we may very well know how chemistry is, but we cannot take that and put that in children and so empirically teachers for the whole century have discovered that you cannot do that, and so they designed books in different ways and if you now want to move from the "is" of chemistry textbooks as they are at the moment and the communalities of those in different countries to what you are moving towards at the end, which is an 'ought', the way chemistry could be taught. I am still talking within pedagogy now, then in addition to the logical structure of chemistry, you touched on them already, you have to talk about cognitive psychology: what are the difficult ideas, what is easy for a bright 16 year old and what is difficult for an average 14 year old, you have to consider the sort of thing Anja Pitton was talking about like motivation and what is useful to the people in their work, all those things, which I am doing, which you may need to look at in addition to the logical structure. So, the 'is' and the 'ought' and the logical and the pedagogical [see Questions for Discussion 2 and 1].

Berry van Berkel: First of all, I do not want to go from 'is' to 'ought' (it is even logically impossible) but also in my research, I do not want to work on that. I make a distinction between the logical structure of school chemistry as it traditionally is, and what other possible choices or assumptions are possible. I think it is up to each and every country or curriculum developer to set goals and to make choices here. So I want to restrict my research to the explication of the logical structure of school chemistry, that is the only thing I want to do, so that there is as it were a reference situation [see Monique Schwob's paper] for everything else which might be possible [Philip Adey: I agree you need that reference situation]. It also goes back to that I want to focus on the intended curriculum and not on the different teaching structures, or even cognitive structures pupils might have. Or to put it in other words: there might be a sort of common logical structure of school chemistry, and that is my job, which might be compatible with lots of different teaching structures, depending on the aim which is set for a particular group and the way you sequence the concepts in time [Philip Adey: and select] in order to... There might be hundreds of them and to find those is something to do for other researchers and developers and which this thing might assist in clarifying. There is a lot of other work to be done, this is certainly just a little piece of the solution. You could say that as it transpires from analysis of textbooks, that the logical structure of school chemistry, in the eyes of a lot of people, has been identified with just one or two of those teaching structures, so people tend to think that the teaching structures are very limited because the teaching structure is dictated to a great extent by the logical structure and this is the thing I want to fight. I want to say, okay, there is this logical structure of school chemistry but still there is a lot of room to arrange other teaching structures. It is not so that these two coincide.

Peter Dekkers: I am a bit at loss because I am way out of my own field here. It is a comment on your presentation. You gave a number of candidates for describing the structure of chemistry [Peter is referring to structural features of school chemistry I talked about: demarcation of school chemistry from school physics, introducing general/ abstract concepts, principles of structure and bonding e.g. micro-macro and three coherent conditions for reactions] and you often indicated their relations with small arrows. It would have been, I think, very helpful for me to understand what you were talking about if you would not just draw an arrow but label it, describe the relations perhaps in a few words. or make a concept map where the relations are labeled [see Question for Discussion 3].

Berry van Berkel: Yes, that is a very good suggestion [in my talk I dealt with the relations between the concepts of chemical (pure) substance, chemical reaction and chemical element and also with the relations between the three conditions for chemical reactions: element conservation, decrease in Gibbs-energy and kinetic instability].

Mary Beth Key: I think there is a third thing behind organisation of concepts in textbooks. It is not childrens' conceptions, the way children learn, it is not some other outside structure. I think it is that most textbooks in chemistry are designed the way experts see the logic of the concepts and they are not designed from the standpoint of how the naive learner actually builds his concepts together. So, I think, that might be something to keep in mind. Often these two things coincide, but often they do not.

Berry van Berkel: Yes, either through experts or through teachers who are trained in a certain way to look at chemistry, they emphasize the logic of the subject. There are a lot of studies which say that even with textbooks that try a somewhat different approach such as the Nuffield approach, when they are done by teachers who have not had in-service training the end result is that the way the curriculum is taught is much more on the structural side than on the other aspect, the processes. What I am saying is that this logical structure of the school subject is not just in textbooks, it is also in the heads of experts and teachers and this influences , whatever textbook they are using, the way they are teaching.

Mary Beth Key: In what sense do you mean teachers, all levels, tertiary?

Berry van Berkel: Secondary I am talking about.

Mary Beth Key: Well, I think you have to include the tertiary level too. Because that is what I am talking about. In the US the textbooks are written by professors in chemistry at the university level and teachers also write textbooks but they all to a certain extent are building the concepts in the order that they see as being logical from an expert point of view.

Carol Macaskill: You mentioned in your talk this new wave of curricula, presumably within those there have been attempts to address that problem, have you found what is new about this new wave?

Berry van Berkel: The example I am most aquainted with is the Salters' curricula in the UK, developed in York and they use what they call a context and activity oriented approach. So instead of starting with concepts like I did here and building a conceptual structure they start with a context, e.g. of a building what are the materials of the building, or food, or drinks, which students touch on in daily life and they do some activities. From the context and activities they extract the chemical concepts, so the chemical concepts come somewhat later and only at the stage - at least that is their philosophy - that they are needed in order to explain these contexts and activities and as much as is needed. So they try to use as few chemical concepts as possible and the number and order of the concepts is then dictated more by the context and the activities than by the logical structure of the concepts. This meant that when they were developing Salters' Chemistry for 13-16 year olds some traditional concepts were not dealt with. They did not have electron configuration: it was not needed, did not come up; they did not have the periodic table, it was not needed. And I know from an interview that they had to bring their syllabus to an

Examination Board and some people said: The Periodic Table is not in there! After a compromise they put it in somewhere to please the examiners and got away with it. As I remember just because of the support of a certain industrialist at the committee who said: I have seen so many syllabuses but this is the only one which at least touches upon daily life and some things connected with industry.
I will look [from a conceptual-structural point of view] at the Salters' Chemistry curriculum as a candidate which might be in a different position, which has at least a different teaching structure, that is for sure. Also I am wondering to what extent they use, in a slighly different way (no electron configuration, no periodic systeem) the logical structure of the subject. At least they do not let themselves be dictated by this logical structure to make a curriculum for students 13-16 year old, they are led by other criteria as well, that have to do with teaching and learning; another example might be ChemCom (US).

Mary Beth Key: In your outline you said: A central problem that emerges from the analysis is the tension between new set goals for chemical education such as chemical literacy and the traditional content and structure of school chemistry I think that is a very important point. Do you see your research at the end as being able to make some recommendations, at least global ones.

Berry van Berkel: It is not the central part of my research. It is too soon too tell but if I do come up with any sensible things to say, I will certainly do so.

Postscript

The discussion dealt with all of the questions for discussion mentioned above, some at greater length than others. I found the presentation and the ensuing discussion most helpful and I think productive for me as well. I would like to thank the people present at my session for their contribution and hope that they do not mind, maybe enjoy, reading the discussion of which they formed an integral part. It is included here in the hope to keep alive the Summer Schools 'context of discovery'.

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Looking for children's modelling abilities with particular interest in children's use of formal rules

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1. Research problem

Computer modelling is increasingly being seen as a valuable educational activity, as well as taking on increasing importance in commerce and industry. Its value for pupils is that it allows them to express and test their theories about the world and thus, it gives them the opportunity to realize how good and how bad their models of the world can be. By being simpler than the real world, models may help pupils to gain insights into the real world, and to make connections and see similarities between apparently disparate phenomena. Up to now, several computational tools have been developed to ease the exploration of models and to make the modelling process more accessible to students. These tools can be classified as quantitative, semi-quantitative and qualitative.

The majority of them are derived from an approach which describes systems in terms of variables and the relationships between them. This kind of modelling can be difficult for children, who may not be able to specify the mathematical relationships between the variables. Besides, young children think of the world in terms of objects, not in terms of variables. This suggests modelling in which the child tells the object what to do, not the variables. One way to do this would be to use a cell automaton type of model.

2. WorldMaker

The design of the software called WorldMaker was motivated by the realization that young pupils' access to such modelling facilities (cell automaton type, description of a system at the level of objects, use of qualitative rules e.g. if a fox is next to a rabbit, the rabbit disappears) was very limited. It was developed at the Institute of Education (University of

London) to meet the modelling requirements of the National Curriculum for England and Wales. The idea of WorldMaker is that:

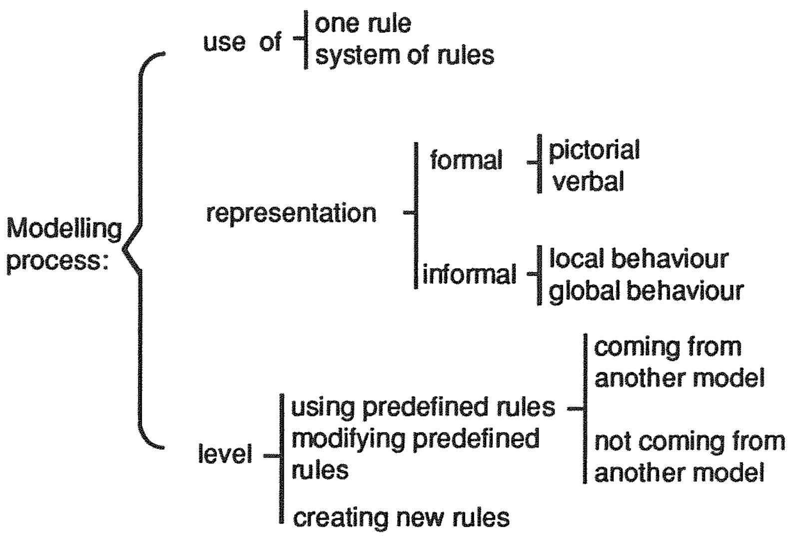
- a world consists of backgrounds and objects which interact. Their behaviour is defined by qualitative rules (do this or do that).
- the rules which govern the interactions of backgrounds and objects, are determined by what is happening in adjoining cells. However, objects and backgrounds may also interact within the same cell.

Because in modelling the very point is to know about the rules that govern a model and at a higher level to be able to change them, my initial research question was formulated as:

- to what extent, when pupils are dealing with the modelling process, do they understand and use the rules which describe the behaviour of a model?

This question concerns 9 to 10 year old children, because according to the National Curriculum this is the age at which children should begin to be able to use a computer model, to detect patterns and relationships and to see how the rules governing the system work.

Before planning my research, the following network was drawn up to represent some possible approaches to the modelling process using the WorldMaker software and with reference to the rules:



There are essentially three levels at which WorldMaker may be used as indicated in the network above:
1. Using predefined rules, coming from another model or not.
2. Modifying predefined rules.
3. Creating new rules.

In addition, I designed some fairly simple computer games, in which children would have the opportunity to use WorldMaker at these three levels in the context of a game. One of them is the 'Gardeners' game. It has as protagonists two different gardeners, one who likes to grow daises and another who likes to grow roses. The winner is the one who has most of his flowers when the grid is full of roses and daisies, or the gardener who is able to move while his/her opponent is not.

Also, as the realizations that 'each rule describes what is happening in adjoining cells', and that 'the picture of each rule shows a condition and an action to be taken if the condition is met', are key ones for the understanding of the way that a computer model evolves over time, I decided to 'transform' the computer games to paper ones. I made the hypothesis, that if children work in a paper game first and then go to the computer game, maybe they have a chance to appreciate more the above realizations, because playing the paper game they have an appreciation of the behaviour of a rule at a local level, while in the computer game they get to see only the global behaviour of a model.

Furthermore, the paper and the computer game differ in relation to the kind of feeling that the player (in the case of the paper game) or the operator (in the case of the computer game) gets about the roles of errors, strategies, rules and fairness in a game, as shown below:

Paper game	Computer game
error	no error
strategy	no strategy
open rules	closed system of rules
fairness	fairness is not a clear idea

So, in my pilot research children followed the sequence:

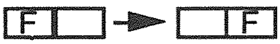
1st session: 'Gardeners' game (paper game first and then computer game)
2nd session: 'Farmers' or 'Hunters' game
3rd session: Read the rules and put them in a story
Find out the rules describing a story, and
Decide about 'possible' and 'impossible' rules

Now I will give a broad picture of the data I have collected (children's written responses to the tasks and transcripts of interviews), related to the use of WorldMaker during the modelling process.

3. Use of predefined rules

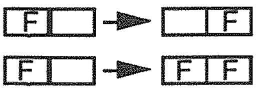
Children used predefined rules in five different tasks. In one case children explained the kind of action that a rule describes considering its formal representation. Then, they answered one or more of the following questions:

- What is this object doing?



"A fox is moving"

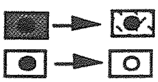
- What are the necessary conditions for the action to take place?



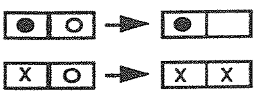
"There is nothing next to the fox, so it moves"

"The fox doesn't eat the rabbits, so it makes new foxes"

In the case where a set of rules were given to children and they had to make a story using them, they put the rules in a familiar context 'foxes eating rabbits', or not. Two stories of the second kind are the following:



"A magician changes his background, or even his colour"



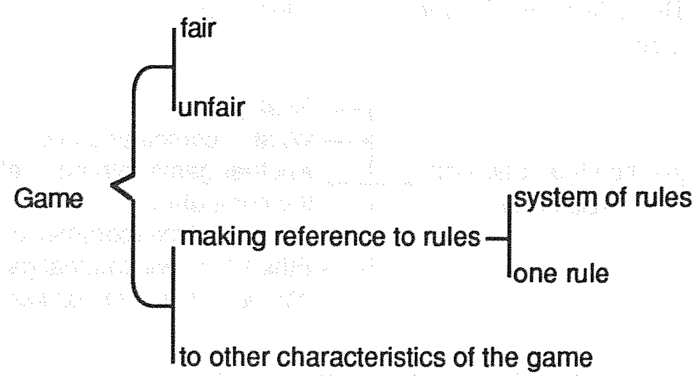
"Parents don't like sweets, so they remove them"

"Babies are eating sweets and reproduce"

In a different task children had to make a story using predefined rules coming from another model. So, after they played the 'Gardeners' paper game they had to answer questions like: 'Could a daisy be: a book, a soldier, a cake? Choose one and put it into a story'. In the cases of the book and the cake, almost all children put them in a context already known to them (e.g. two men are selling different books/cakes). But when they were dealing with the soldier it wasn't so easy to put him in any known scenario. Somebody said:

'One man is Hitler and the other one is Churchill. One likes the German soldiers and the other the British'.

In a fourth task children had to think about the global behaviour of a model, considering its local rules. In that case children could easily think about specific local rules controlling the global behaviour of a model, when these rules didn't interact with each other. But it was difficult for them to decide about the global behaviour where it was controlled by interacting rules. So, when children had to talk for instance about the size of the population of rabbits, they couldn't see that this depends not only on the rabbits (do they give birth to new rabbits?) but also on the farmers (do they kill the rabbits?). In the last task of this kind children were discussing about the 'fairness' of a game, which is a global property. Then, as the network shows, they 'judged' a game as 'fair' or 'unfair', making reference to local rules or most often, to other characteristics of the game (e.g. there is enough space where you can move).



4. Modification and creation of a rule

Children worked on the modification of a rule in two different kinds of tasks. Firstly they had to modify the graphical representation of a rule when its wording was modified, and the other way around. Then, they had to modify a rule in order for a specific behaviour to take place. In both cases, it was not easy for children to go from a global or local behaviour to a local rule, when they had to change a rule which already existed.

When children tried to create a new rule, they always defined rules already presented to them, but with different protagonists. For instance:

"The owner of a toy shop has too many toys, so he is selling them to buy clothes"

"He is feeling tired, he sleeps and put some stuff"

"He invites the clothes' shop owner to have a party together"

If children defined more than one rule, then these rules represented two successive actions, or different snap-shots.

At the end let's see how children decided whether a rule can or can not be written in the computer. Most of the time they took that decision with reference to reality. It was clear that children had some expectations about the rules regarding the nature of the objects. So, according to them you can not see in the computer people flying, because 'People don't fly. Only angels'. The other justifications that children provide are given in the following network:

Children justified their decision referred to

- Reality
- What a computer can do
- Another game (already defined in the computer)
- Another game (commercial)
- Ethics (*"an educational game shouldn't teach things like that"*)

This has been my initial research. For the rest of the PhD I want to change my point of view about modelling to some extent, but I am not at the moment sure what this change will be.

The effectiveness of using a microcomputer-based laboratory in teaching selected concepts in mechanics: an intervention study

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1. Statement of the problem

Traditional teaching methods in science have tended to consider learners as passive recipients of knowledge. During the past two decades, however, numerous researchers have claimed that, prior to entering formal schooling, children have developed conceptions, constructed through interaction with their surroundings, about natural phenomena. In some cases, children's conceptions differ from those which scientists use to make sense of the same events and these, in turn, can affect their subsequent learning (Champagne et al, 1985).

The question of how to provide instruction which could change learners' ideas from 'alternative' status toward canonical ones has become one of the main concerns in the field of science education. Several strategies used to bring about conceptual change have been developed and reported. These include discrepant events (Nussbaum & Novick, 1982) bridging analogies (Brown & Clement, 1989), socratic-dialogue (Champagne et al, 1985) computer-simulation (White, 1984), This study contributes to this field. It focuses on conceptual change in the domain of mechanics and investigates the effectiveness of a teaching intervention using a microcomputer-based laboratory.

2. The purpose and the research questions of this study

In traditional laboratory work, students are generally required to follow specified procedures and to do time-consuming work involving data collection and calculations in order to confirm existing theories. With the introduction of computers into laboratories, however, this situation has changed dramatically due to the fact that in some cases data can be collected and transmitted into electrical signals using probes and this input can then be processed immediately by computers (Thornton & Sokoloff, 1990). This kind of laboratory activity has been called a microcomputer-based laboratory (MBL for short). MBL is a setting which can enable learners to act more like scientists with opportunities to design their experiments, hypothesise, observe and explore events using easily understandable digital and graphical outputs to test hypotheses. This in turn may lead them to construct the knowledge underlying the experiments being conducted. Evidence indicates that MBL is a useful strategy to teach some domains in science such as interpreting graphs (Mokros & Tinker, 1987) or teaching conceptions of motion (Thornton, 1987; Thornton & Sokoloff, 1990).

This study investigates the use of probes in mechanics instruction, especially looking at the relationship between force and motion. Motion detectors and force probes have been developed (the ones used in this study were developed by the Tufts University of USA) to help instruction in science courses. The motion detector probe is a sonar range finding device which is capable of emitting ultrasonic pulses and recording the time taken while receiving the reflection pulses. Distance-time, velocity-time and acceleration-time graphs can be displayed on the monitor screen in real-time form. The force probe is an instrument used to measure the size of force applied by indirectly calculating the variation of current produced in the 'Hall Effect Sensor' built into the probe. The force-time graph can also be shown in real-time form. The combined use of these two probes within practical tasks can provide learners with a kinesthetic experience for the physical events under study. Furthermore, since the magnitudes of force and motion can be displayed simultaneously, these two probes used together may provide very important input to challenge learner's current conceptions of force and motion and help them restructure the relationship between them. Since a common alternative conception is that a constant force is associated with constant speed, the real-time graphing of force and motion, together may promote conflict in learners and lead to the need for them to restructure the relationship between force and motion. This study investigates the effects of using these two probes together in an intervention study of conceptual change in the teaching of mechanics. The main questions under study are as follows:

1. Is a teaching intervention incorporating force and motion probes effective in promoting learners understanding of selected mechanics concepts (here called target ideas).
2. What are the conceptual pathways learners take in their reasoning about these target ideas during the intervention?

3. What features in the intervention contribute to promoting conceptual change?

3. Target ideas for this study

The study focuses on teaching the following ideas in the context of linear motion:

1. Target idea 1: the force needed to get an object going is bigger than that required to keep it moving at a constant speed.
2. Target idea 2: an object will keep moving at a constant speed in a straight line unless acted on by a non-zero nett force.
3. Target idea 3: an object will acquire a constant acceleration if acted on by a non-zero nett force.
4. Target idea 4: objects with different masses will accelerate at different rates for the same applied force.

4. Method of investigation

Sample

There were two sample groups involved in this study. One (n=19) included students who were taking 'A' level science courses, including biology, chemistry and physics subjects (called AL group) in the Leeds area, England. The other (n=43) included students who were being trained to be primary school teachers (called ST group) in the University of Leeds, England. Both groups took part in this study in 1992.

Written materials used

Two written materials were used in this study: a 'diagnostic test' and a 'workbook'. These are briefly described below.

Diagnostic test: A set of questions for studying learners' alternative conceptions in mechanics, developed by the Children's Learning in Science Research Group at Leeds, was used as a diagnostic test (DT). The test includes questions which require qualitative reasoning in mechanics. Items from the test which related to the target ideas mentioned above, were selected for this study.

Workbook: In order to guide the students through an instructional sequence using the probes, a workbook which addressed the target ideas was prepared and piloted. The tasks in the workbook incorporated a number of features designed to promote conceptual change. These included (1) providing kinesthetic experiences, (2) exposing the mismatch between the students' existing ideas and the accepted ones and (3) providing opportunities for qualitative reasoning through discussion. The activities took between five and six hours to complete and included practical activities such as: (1) The student pushes a block by hand so as to get it going from rest on a horizontal surface and keep it going at a constant speed. (2) A force is applied to a trolley by weights over a pulley. The magnitude of the weights can be changed and the load on the trolley can also be changed.

Conduct of the study

After piloting the workbook, the administration of the study was divided into three stages: pre-test and sample selection, intervention and post-test.
Pre-test and sample selection stage: Of the 62 students who took the diagnostic test, a sub-sample of 14 followed the intervention phase in pairs.
Intervention stage: The strategy of prediction, explanation, observation and discussion (PEOD) was adopted throughout the activity. Firstly, the students were asked to predict what will happen in a given situation and to explain their reasoning. Secondly, they manipulated practical tasks in person and observed the event being investigated.

Discussion followed immediately after the observation activity. In some cases, some probing questions were used to explore their thinking further. The whole intervention stage was divided into sessions. Each session lasted for about 3 hours.

Post-test stage: About 7-10 days after the teaching intervention, the students were asked to answer the problems on the 'Diagnostic Test' again in order to identify any change in their reasoning as a result of the intervention.

Data collection and data analysis

The intervention was video-taped and transcribed. The students' written answers in the workbook and on the pre- and post-tests were also used in the analysis. In order to answer the first research question mentioned above, the students' responses on the pre- and post-tests were quantified and the difference in scores before and after instruction were compared (a t-test was applied). Based on the responses on the pre- and post-tests, the written answers in the workbook and the transcript of the intervention, the students' reasoning about the target ideas is being analysed so as to answer the second research question. In order to answer the third research question, the students' responses during the intervention will be scrutinised. The places where the students' reasoning changes will be selected and the features which are responsible for the changes will be drawn.

5. Preliminary result

The statistical test showed that there is a significant difference in mean scores between the pre- and post-tests if the results related to all target ideas were considered together. If each target idea was tested separately, only the result of the target idea 1 showed that there is a significant difference between the pre- and post-tests. It must be noted, however, that it is impossible to attribute this difference unequivocally to the teaching intervention as the students may have been exposed to other teaching or the media which may have contributed to their reasoning.

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An investigation into the effect of I.T. on pupils' understanding of some science concepts and processes

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1. Introduction

The use of microcomputers in schools is a relatively recent innovation. Although there are many studies that examine issues related to their use in schools (Chartier e.a., 1991; Swan, 1991; Cochran-Smith, 1991), and studies that examine learning in science, there is little work about how students learn science through the use of computers (Watson, 1993; Barton & Rogers, 1991; Rivers & Vockell, 1987). There are a few studies which report specific evidence about pupils' learning actual concepts or skills, compared with the number of studies which report claims about the effectiveness of computer use.

This study was undertaken in order to investigate the effect of I.T. on pupils' understanding of some science concepts and processes. In particular it investigates:

(i) whether using I.T.-based data analysis software effects students' data analysis skills, and

(ii) any measurable effects of the use of I.T. simulations on students' understanding of some science concepts and relationships between concepts, relating to the topics of 'chemical bonding' and 'electric circuits'.

2. Methodology

In the first part of the study (i), 130 students participated aged 13-15. In the second part (ii), 206 students participated aged 14-15. Each of the ministudies consisted of an experimental and a control group of the same age and ability, who were studying the same topic in their science lessons; the experimental group used computers whereas the control group was studying the same topic without computer use. The collection of data was mainly done through administration of paper and pencil pre- and post-tests, but also classroom observations of computer and non-computer sessions, examples of pupils' work, and informal discussion were used.

A pilot study was undertaken in order to investigate any measurable effect of the use of I.T. and also to test the methodology. The pilot study which is described below, formed a part of the Impact Project (Watson, 1993) work in science, and used the assessment methodology of the Project. The main study follows similar methodology.

3. Pilot study (methodology and results)

The pilot study consisted of two ministudies, on 'data analysis of chemical properties', and on 'chemical bonding'. These ministudies had as learning objectives knowledge of certain facts and understanding of concepts.

1. Ministudy on 'data analysis of chemical properties'

The purpose of this ministudy was to investigate the effect of I.T. on pupils' data analysis skills in recognising similarities in data from a selected set of chemical data values, and choosing priorities in relationships between data which included 'conflicting' evidence (Watson, 1993). Both experimental (n=11) and control groups(n=24) were studying the same topic (chemical elements and their properties) in their chemistry lessons. The experimental group worked on a database (written by their teacher) for about 45 minutes, whereas the control group had similar chemistry lessons but did not use data analysis methods, and did not use computers.

In the tests the students were asked to group the elements according to their similar properties, and also to explain what is common in each group. As they gave two kinds of explanations, the marking scheme distinguished grouping based on the 'choice of common values in the properties shown in the chemical test table', and grouping based on 'traditional chemistry reasons' and therefore results were considered in: (a) results based on data analysis skills, and (b) results based on chemistry knowledge.

The results indicated a substantial gain for the experimental group. These students grouped the elements by choosing mostly 'common values in the properties' and their approach in the post-test was similar to the way they had worked during the computer based data analysis session. The control group did better than the experimental group on grouping the elements according to their chemistry knowledge, but when they were presented with the new post-test task they did not change their approach. From this ministudy it was concluded that the use of data analysis software had an impact on students' data analysis skills.

2. Ministudy on 'chemical bonding'

The purpose of this study was to investigate students' understanding of concepts of chemical bonding and of relationships between the concepts involved. The experimental (n=7) and the control (n=14) groups were taken from a single class which was studying the topic bonding; the experimental group used the simulation package 'BONDING' (for about an hour) as a part of their work of the topic, whereas the control group did not use the simulation.

The students were assessed by a test and a repertory grid, and the results obtained from both instruments showed little change between pre- and post-tests. In one case (post-test results of the experimental group) there was mismatch in the results obtained from the two instruments. The results of this study were inconclusive, and did not provide evidence about the effect of the use of the simulation on students' understanding of chemical bonding.

The main limitations of the pilot study were found to be related to: (a) the construction of the tests (pre-test was not the same as post-test in the data analysis ministudy; in the bonding ministudy the test was easy for the students to start with and it could not therefore detect any substantial changes) (b) the marking scheme for assessing the data analysis skills (as not all variations in the way students looked for patterns in data could be assessed accurately).

3. Main study

Its purpose is to investigate: (i) to what extent the use of I.T.-based data analysis software effects students' data analysis skills in recognising patterns in data from a selected set of chemical data values, and in choosing priorities in relationships between data with 'conflicting' evidence of links between variables; (ii) any measurable effect of the use of I.T. simulations on students' understanding of concepts and also relationship between concepts relating to 'electric circuits', such as current, voltage, resistance.

The method used is similar to the pilot study, consisting of pairs of same age and ability experimental and control classes which were studying the same topic, with and without computer use respectively. In the first part of the study (i) 95 students aged 13-14 participated; they constitute an average and a high ability pairs of classes taken from the same school, and studying the topic 'metals'. In the second part of the study (ii) 185 students aged 14-15 participated; they constitute six pairs of classes taken from five schools, and studying the topic 'electric circuits'.

The limitations observed in the pilot study contributed to the design of the main study. For example, in the 'data analysis of chemical properties' study both experimental and control groups followed the same data analysis activities, with and without computers respectively. The experimental groups used the 'key' database on metals (developed by their teachers) following the same data analysis activities as the control groups (which were searching through books); these activities formed a part of the teaching of the topic and all students were exposed to them for about an hour.

In the electric circuits study, one experimental class used the simulation 'D.C', whereas all the other experimental classes used the simulation 'CIRDES'; both programs were provided to the classes from the Educational Computing Unit of King's College. Whatever the programs used, all experimental and control classes followed the same objectives for the teaching of the topic.

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Design of a 'just in time' learning situation around a computational tool in a professional cooperation framework

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1. Context of the thesis

This research takes place in the 'Unité BioInformatique' (Biology and Computer Science Unit, managed by Philippe Sabatier) of the Lyon Veterinary School. In this laboratory, the research themes on knowledge communication, in the discipline of animal quality and health, are: biological systems modelling; conception of educational and decision making tools; study of communication activities in social practices.

Thirsty years ago, in breeding, veterinary practitioners used the Koch postulate: a specific germ infects the animal as the only cause of the disease. The treatment consisted in identifying the germ and giving the appropriate medecine (or eventually preventing the disease by a vaccination). This was so successful that nowadays, most of the traditional diseases have been mastered. This evolution, in addition to a relative frailty of the animals, due to their high level of productivity, has thrown a new light on the importance of what we call *breeding diseases*. Above all, their consequences are a decrease of the production, and their mastery depends on the control of numerous risk factors: presence of multiple more or less commensal and timeserving germs, feeding, reproduction, hygiene, and so on. The health of the herd is no longer only a problem of the vet, but also of the breeder and of the pathology laboratory biologist.

Two questions emerged from a preliminary investigation, based on information collection during breedings and laboratory visits, participation in meetings, teaching practices, and informal discussions:

- some cooperations between vets, breeders and biologists are satisfactory, and other are not: *why*?
- those three kinds of workers formulate a real demand for an increase in skills: *how*?

2. First results and aims of the research

Data have been collected by means of a questionnaire and semi-directive interviews. The vets regret that biologists do not come on the field, and ask for regular meetings about new diseases. The biologists protest against vets who ask them to do their diagnostics, and many of them are ready to put in place cooperation protocols. Another study in our laboratory has shown that dialog between breeders and vets allows a socialisation of practices and concepts. The use of a computational tool 'breaks' the too usual hierachy between those partners, because it emphasizes the knowledge of each potential user.

The issues are clear: cooperation between vets, breeders and biologists is benificial if the basis of communication is not only practical considerations, but the knowledge itself in use, in a shared approach to the problems considered.

So we decided to design a 'just in time' learning situation, around a computational tool, in a professional cooperation framework. The computer is essential, though not sufficient. Its use must take place in a constructed problem situation, where *the machine is a medium between humans* (socio-cognitive paradigm), rather than the pole of a human-computer relation (psycho-cognitive paradigm).

3. Knowledge engineering

To be computerised, and to be accessible to the three kinds of users, the knowdge on animal pathology has to be adjusted:

- the first step is the collection of elementary units: monographs, pictures, etc. This is quite easy, because this knowledge is already prepared and available.
- the second step is more difficult. It consists of the construction of 'scenarios', to reflect real problem situations, by descibing all the links between each unit of information. This knowledge is not available in books or in school courses. The experts we consulted were not able to speak about it while sitting around a table, but needed to be in a breeding situation, with their boots to their feet and holding a scalpel in their hand!

Finally, we may say that it is not only a mere adjustment of knowledge, but the construction, or formulation of *new knowledge*. Its validation, in the professionnal sense, comes from the recognition of the ability of the consulted experts.

An example of knowledge in use: the necropsic diagnostic
Necropsic diagnostic, as a subject of collaboration between vets and biologists, is the recognition, on post mortem animals, of anomalies on organs. It does not take place in a theorical but in a pragmatical frame, using precausality mechanisms (indices matching to known schemas, instead of formal causalities). It can be expressed in natural language only, for it is not independent of a particular perception, and of an action-situation. In veterinary schools, necropsic diagnostic is taught during 'clinical tutorials': the teacher realises a diagnostic, speaking aloud in front of students, who are supposed to assimilate this knowledge by imitation. Because it is not generalisable, not decontextualisable, not expressible in a formal language, not recognised by the whole scientific community but only by different groups of experts, we can say that this kind of knowledge is *pre-scientific*.

4. The legend between verbal and visual codes

The main support of 'necropsic diagnostic knowledge' is visual: shape, size, color, texture of the organs. The visual language has two components: figures (geometrical figures, colors, brightness, etc.) and signs (elementary units of images having a sense, like vein, nerve, alveoli of the plung, etc.). A black spot on a heart is a figure, but if you call it a hematoma, it becomes a sign. When figures are almost universal (as a part of common knowledge), signs have to be explicited. To be understood correctly, images of real objects require a 'visual literacy'. Biogical functions, conceptualised by verbal language, are identifiable within the images through hidden structures, which indices have to be sought.

The legend is a footbridge between visual and verbal codes. If it is absent, the learner may be not able to see what he is supposed to see. If it is permanently shown, the learner may not realize the difficulty to identify what is pointed out. A solution is *the new concept of 'furtive' legend:* it appears on the image while a word of the commentary text is pointed at with the mouse cursor, and disappears when the cursor goes away. This device allows the learner to realize what he wasn't able to see, while he must act to get a response. In this way, the question may exist and precede the answer.

5. The SHERPA prototype

A prototype of the tool was built quite early in this study. SHERPA (Hypermedia System for Explanation and Recognition in Animal Pathology) has two modules. The first works like an Intelligent Tutoring System. It asks many questions in order to identify the context, and then selects a relevant subset of informations. The second module is a data base, containing information on about ten diseases, in a transversal approach to animal pathology, from cowshed cleanness to microscope slides examination. This data base is multimedial (using texts, pictures and sounds), and hypertext (description of links between each unit of information), so it is called 'hypermedia'. In this module, the user has to 'navigate' freely, looking for relevant informations about his problem. Sometimes, the system may provide help when the user is lost, by offering some indices for the choice of a particular pathway.

The other characteristics of this tool are :
- multiple windowing (the same reality is shown from different points of view);
- self data recording;
- instantaneous communication of images at a distance (for instance, a vet from Lyon has a problem he can't explain, so he takes a photo, scans it in the computer, phones to his colleague in Utrecht who may see the same photo on his own computer, and they can discuss together: '*do you think this black spot is an hematoma ?*');
- required hardware: IBM compatible micro-computer, with a minimum configuration: micro-processor i386, SVGA monitor, CD-ROM unit, MicroSoft Windows 3.x (in two years, this configuration will be portable and will cost less than $ 2,000).

6. Provisional conclusion

This research focuses on a-priori reflexions about how to design a learning situation around a computational tool. The first reactions we recorded from many potential users were always very positive. But no scientific study of its use has already been done (it could be another thesis subject). Anyway, the main interest of this research is to specify the *particularities* of veterinary knowledge, and to propose some solutions to its communication. It was possible because of our *critical distance* from our professional partners: we were sufficiently close to finely and deeply understand their problems, but sufficiently far to keep our independence of mind, and to cast a new glance on a too ossified education system.

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Designing a computer-based course on basic electricity for prospective primary school teachers

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1. Introduction

This research is about the design of a course on basic electricity organized around lectures, desktop experiments and exercises with software tools, that we are developing in HyperCard for prospective primary school teachers. By basic electricity we mean: Coulombs Law, Kirchoff's rules, simple D.C. electric circuits which include batteries, bulbs, resistors connected in series and/ or in parallel. The main aims of the course are to:

1. Enhance our students' understanding of basic electricity and promote their qualitative, rather than quantitative, reasoning.
2. Inform our students about intuitive ideas and reasoning of their future pupils, in the same phenomenological field, and offer them ways to manipulate and change these ideas and ways of reasoning.

Our students have some formal knowledge and a superficial understanding of basic electricity from courses on electricity, static and dynamic, at upper secondary school, 4-5 years ago. Our basic assumptions are:

1. Science courses in primary teacher education should be designed to facilitate:
   a. a change of student teachers' conceptions of natural phenomena,
   b. a change of student teachers' conceptions of teaching and the acquisition of appropriate conceptions to implement conceptual change teaching strategies.
2. Primary school teachers should possess qualitative understanding and reasoning in the field of basic electricity. These qualities can be obtained through qualitative courses on basic electricity, based on a minimal set of concepts and procedures which describe a microscopic mechanism underlying phenomenological and macroscopic behavior.
3. Computer software tools are approriate for expressing, visualizing and manipulating models of the above microscopic mechanisms.

Our work has three phases: in the first phase we designed and conducted two pilot investigations of student teachers' conceptions and reasoning about electrical phenomena at the phenomenological, macroscopic and microscopic levels.

In the second we are formulating criteria, taking into account results of the above investigations, in order to

1. locate appropriate characteristics of several proposed instructional models of the microscopic mechanism, underlying electrical phenomena,
2. select, structure and sequence the tasks of the course and
3. determine the appropriate characteristics of the software tools we are designing for our course. Our basic software tool will be used mainly as a work environment by our students to develop a microscopic view of electrical phenomena, based on specifically proposed assumptions and mechanisms. In the third phase, the course will be tried out in our department. Student teachers will work in groups of three. We are designing the evaluation of our course by pre- and post-tests, as well as by continuously monitoring students' progress during the course.

2. Basic assumptions

The knowledge, offered through the course, will not be used by primary school teachers as a base for the study of other more advanced subjects, nor as a basic element of their science background. They are going to use this knowledge in the near future in the classroom, while teaching their pupils. Because this knowledge becomes meaningful only in the context of its use, we must offer it as knowledge to be used in teaching. By this term we mean the transformed scientific knowledge teachers have to possess (teachers knowledge) in close relation to the transformed teachers' knowledge, they have to teach to their pupils (pupils knowledge). This relation is established through the various teaching strategies they may follow in the classroom, the difficulties they may encounter and the ways they may use to overcome these difficulties.

Pupils knowledge is not merely a simplified subset of teachers knowledge, it is a theory in itself with its limitations and range of validity; the same is true with teachers knowledge with reference to physicists knowledge. Teachers must be aware of the differences between the knowledge they possess and the knowledge they have to teach, of the limitations and the validity range of these two systems of knowledge, of the ways they may use their knowledge to facilitate their pupils' learning processes without going beyond the framework of pupils knowledge. Well articulated links between these two systems of knowledge require i) meaningful understanding of the subject matter and qualitative reasoning and ii) understanding pupils' concepts and reasoning, in the particular field, and ways to change them.

The first characteristic imposes a qualitative, rather than a quantitative, character on teachers knowledge. In the literature, it is argued that these qualities can not be acquired through traditional electricity courses, which emphasize the quantitative aspects of electrical phenomena. Courses which include qualitative treatments are often based on a minimal set of concepts and procedures which describe a microscopic mechanism underlying the macroscopic behavior (Sherwood & Chabay, 1991; Frederiksen & White, 1991) and refer to local interactions among microscopic entities, usually examined under electrostatics. Such qualitative treatments of basic electricity offer the links between electrostatics and electrodynamics which Eylon & Ganiel (1990) have pointed out that students miss. Usually treatments of basic electricity, based on models of microscopic mechanisms, use computer simulations for visualizing and manipulating these models. These computer simulations seem to offer the visual mental models (Wiser, 1992) which are necessary for the solution of problems.

The second characteristic calls for informing student teachers about and training them i) to detect pupils' conceptions and ways of reasoning and ii) to implement conceptual change teaching strategies. Since student teachers also hold alternative conceptions about electrical phenomena, very much alike their future pupils' conceptions, the first of the above processes involves directly or indirectly student teachers' own conceptions and reasoning. Our strategy to change their conceptions must be transparent to them, so that they are aware of the implementation of conceptual change teaching strategies. This experience may facilitate changes of their own conceptions about teaching, which may be in conflict with those considered appropriate to implement conceptual change teaching strategies.

In the literature, we find science courses, in primary teachers' education, designed to facilitate the change of conceptions about natural phenomena held by teachers and student teachers (Borghi e.a., 1991; Webb, 1992), or courses, in science education, designed to facilitate the change of conceptions about teaching held by student science teachers or in-service science teachers (Hewson & Hewson, 1987). Our course aims equally at changes of conceptions held by primary student teachers in both fields of science and instruction.

3. Two pilot investigations

The content of basic electricity and the teaching of this content may be seen at three levels of abstraction: the phenomenological, the macroscopic, and the microscopic. The phenomenological level has to do mainly with objects (batteries, wires, bulbs etc.) and events (brightness of bulbs, heating of resistors etc.); the macroscopic with concepts (I, V, R, E) and their relations; the microscopic with microscopic entities and mechanisms. The two characteristics of well articulated links between teachers knowledge and pupils knowledge are associated with the articulation of these levels, with the way the coupling of these levels is conceived by pupils and teachers: Meaningful understanding and qualitative reasoning is associated with the coupling of the macroscopic and the microscopic levels, understanding pupils' conceptions and reasoning is associated with the coupling of the phenomenological and the macroscopic levels. In these two areas of associations, which are very crucial for the structure of knowledge to be used in teaching, we have designed and conducted two pilot investigations: the first into the differences between pupils' and student teachers' conceptions and reasoning about electrical phenomena, the second into student teachers' conceptions and reasoning about microscopic mechanisms underlying electrical phenomena.

A pilot investigation into the coupling of phenomenological and macroscopic levels

Research suggests that little difference exists between conceptions of electric current held by primary student teachers, in service primary teachers and children (Webb, 1992)) and that more mature students express their conceptions with more clarity (Sjoberg & Lie, 1981). This clarity may come from greater ability to express themselves, better understanding of their views, higher meta-cognitive ability. Our hypothesis is that student teachers may detect contradictions in their reasoning more easily than pupils. If this is true then awareness of and dissatisfaction with their own ideas will be facilitated. In order to test this hypothesis and to investigate the ways pupils and student teachers are reasoning we have designed three questionnaires. They were answered by 153 pupils of the lower secondary school (14-15 yrs), who had been taught some aspects of electricity at primary school and by 146 student teachers of the last (8th) semester in our department. Four of the questions refer to three simple electric circuits (C, CS, CP) with identical batteries and bulbs: In circuit C one bulb (Bl 1) is connected to one battery (Bt 1); in circuit CS two bulbs in series (Bl 2, Bl 3) are connected to one battery (Bt 2); in circuit CP two bulbs in parallel (Bl 4, Bl 5) are connected to one battery (Bt 3). In the first question (QBS), pupils and students are asked to compare the brightness of bulbs Bl 1 and Bl 2; in the second (QDS) the duration of batteries Bt 1 and Bt 2; in the third (QBP) the brightness of bulbs Bl 1 and Bl 4; in the fourth question (QDP) the duration of batteries Bt 1 and Bt 3. In all cases, they are asked to justify their answer. In the three questionnaires the same questions are differently arranged to give different opportunities of comparison and reflection.

Each one of the above four questions has three possible answers: One is associated with causal action (c.a.) Give, the other with c.a. Take, while the third does not fit into the framework of the two causal actions. These everyday causal actions have active agents, passive patients and a mediator of the causal action. In case of simple d.c. circuits, usually an undifferentiated quantity, like electric current or energy, serves as mediator (Psillos et al., 1991). In c.a. Give the active agent (the baterry) gives an undifferentiated mediator to the patient (the bulb). In the case of c.a. Take, the bulb is the active agent which takes an undifferentiated mediator from the battery (now the patient). In every case each active agent of the causal action gives to or takes from the patient(s) a constant amount of the undifferentiated mediator. In other words more cause (active agents) results in more undifferentiated stuff given to or taken from the passive recipients. Preliminary results from these questions suggest that:

1. The great majority of pupils and student teachers (more than 90%) give answers corresponding to causal actions Give or Take: They reason in terms of these causal actions; so we can focus on these two modes of answering and their combinations.
2. The great majority of pupils adopt c.a. Give when answering questions about brightness, and c.a. Take when answering questions about duration. However, there is a shift from c.a. Give to c.a. Take when the bulbs are connected in parallel.
3. Student teachers, when answering questions about brightness or duration, are divided between causal actions Give and Take, with a small preference to c.a. Take. This preference becomes stronger when the bulbs are connected in parallel.

It seems that pupils are bound to a way of reasoning which favors c.a. Give when asked about brightness, and c.a. Take when asked about duration. It seems also that the parallel connection of bulbs is a factor favoring c.a. Take, in both pupils and student teachers groups. We could consider that their reasoning evolves in two steps: First they determine which object, battery or bulb, is the active agent and which is the passive patient. Next the causal action takes place: c.a. Give, if battery is the active agent, and c.a. Take, if bulb is the active agent.

In the case of pupils, it seems that in steady state electrical events, like brightness of bulbs, batteries are privileged active agents, while in evolutionary electrical events, like duration of batteries, bulbs are privileged active agents. This preference may be explained as the result of the function of a causal constraint: When the value of a characteristic (brightness of bulb / duration of battery) is in question, then this characteristic is considered as the result of a causal action on the object on which this characteristic is observed (bulb/battery). This object (bulb/battery). takes the role, in the causal action, of the passive patient and the other one (battery/bulb). takes the role of the active agent. In this framework we may consider that pupils are very strongly influenced, while student teachers are less strongly influenced, by this causal constraint.

If we search for patterns of answers to all four questions (QBS, QDS, QBP, QDP) we see that the big majority of pupils (88%) and student teachers (84%) fall into the 16 possible combinations of answers (two possible answers, each following c.a. Give or c.a. Take, in four questions). The distribution of percentages among the 16 possible patterns of answers show some distinct characteristics:

1. In the case of pupils, pattern of answers GTGT (four answers following c.a. Give in QBS, c.a. Take in QDS, c.a. Give in QBP, and c.a. Give in QDP) takes 39.4% of all answers, in agreement with our speculation that pupils are bound to a single pattern of reasoning, c.a. Give in questions about brightness and c.a. Take in questions about duration. Pattern GTTT takes the second highest percentage 9.8%, the shift from c.a. Give to c.a. Take in question QBP indicating the influence of the parallel connection of bulbs. All other patterns show frequencies which do not differ significantly from the expected value (87.9%/16=5.5%).
2. In the case of student teachers, pattern TTTT takes 12.6%, in accord with our speculation about their preference to c.a. Take; pattern GGTT takes 10.37%, indicating the influence of the parallel connection of bulbs, more patterns, than in the case of pupils, show high percentage, in accord with our speculation that student teacher are less bound to a single pattern of reasoning.

From the preliminary analysis, three general factors have been identified, which influence, in different ways, the reasoning of pupils and student teachers: The first refers to causal actions Give and Take, the second to serial or parallel connections of bulbs, and the third to consistency conflicts of answers to successive questions. Pupils very consistently follow c.a. Give in the case of steady state electrical events, like brightness, and c.a. Take, in the case of evolutionary events, like duration (Psillos e.a., 1991), while their answers on successive questions show contradictions. On the other hand students are less bound to the pattern of reasoning, which pupils seem to follow, while their answers on successive questions are less contradictory. At present we are analysing in terms of the elements corresponding to the phenomenological and macroscopic levels of abstraction, i.e. objects, concepts etc. the structure of the justifications given. Next we will explore the associations between patterns arising from the above analysis and factors influencing reasoning.

A pilot investigation into the coupling of macroscopic and microscopic levels

Research in this area is very limited, but recently interest has been renewed (Koumaras, 1989; Eylon & Ganiel, 1990; Licht, 1990; Sherwood & Chabay, 1991; Frederiksen & White, 1991). Our work focuses on two aspects of the macro-micro coupling: 1) The development of a comprehensive, functional and efficient, for the students, model of microscopic mechanisms which will establish clear and simple associations: i) between steady state distributions of micro-entities, and macro-concepts and their relations, and ii) between transient states and directions of change of macro-concepts in their interrelations. 2) The investigation of student teachers' conceptions about micro-entities, how do they perceive their interactions, what kind of mechanisms do they generate by these interactions and how. Our hypothesis is that: our students teachers, because of their background, do not have any prior structured microscopic view about what is happening in the circuits. They only have some vague ideas about electrons moving around and so they are building up a microscopic view when asked to do so. This process should depend heavily on some basic characteristics of the learning environment such as the elements of the conceptual models we propose and the tools we offer to students to manipulate the proposed models and their mental models.

We have designed a set of tasks in which students are asked to show how they think electric charges are moving in simple electric circuits and to state their assumptions, without bothering whether they are right or wrong from the physics point of view. These tasks were given to groups of two students as work assignments in an introductory course on Educational Technology. Preliminary results (from what our student teachers designed, wrote and said in interviews) show that they construct microscopic mechanisms during their work by giving characteristics to micro-entities and assigning roles to devices, in which very often we recognize characteristics of their perceived macroscopic behavior. For example, a switch controls the movement of charges; charges can not move at all under their mutual attractions, if the switch is open. Usually they are not aware of inconsistencies existing in their micro-mechanisms, but they recognize them as soon as a relevant question is asked. For example, in most cases charges move in groups of similar polarity inside an empty conductor, although they state that 'dissimilar charges attract and similar charges repel each other' is the basic rule which governs their movement. When asked how come that the charges move in groups, then they recognize that there is a problem in their visualization. During their work, they always try to resolve any inconsistency they detect and they usually succeed, of course in their own way. For example, in the above case they state that the repulsion is negligible compared to the attraction of dissimilar charges.

4. Some characteristics of our basic software tool

As mentioned before, qualitative treatments of basic electricity, based on models of microscopic mechanisms, use computer simulations for visualizing and manipulating these models. These simulations are very useful but they can not be used as expressive tools. On the other hand model building tools lack visual representation capabilities, because of their generic character.
Our basic software tool will be the work environment for our student teachers to develop their microscopic view. This environment combines properties of simulation and model building tools and will allow the students to express their microscopic view as they construct it, to look for relevant pieces of information when they need them, to write down their assumptions at each stage of their work, to challenge their assumptions by comparing them to the proposed ones, to have a history record of their development from the beginning to the point they have reached. It has three modules: the expressive module, the theory module, and the worksheet module.

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Introducing explanations in a chemistry learning environment with a computer

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1. Introduction

My study is part of various didactic investigations concerning explanations given to students by an expert. When speaking of explanations, one may have in mind explanations produced by pupils or students and aimed at a teacher or other student, or explanations given by teachers - and any kind of 'experts' - to students. My interest is focused on the last kind of explanations: those given by teachers or experts to students. That means not only scientific explanations of a fact or a concept, but also any verbalization aimed at a better comprehension of these facts, concepts, relations or any pedagogical situation.

The main objective of this study is to build a body of data (corpus) concerning explanations, in order to implement different kinds of help (explanations, advices, guidance or more technical helps) in a computer learning environment. Such an environment, (without any explanation) is in the process of being developed in collaboration with a team of the French National Institute for Pedagogical Research (Institut National de Recherche Pedagogique, INRP). The domain of this study is 'the chemical reaction' and problem solving of quantitative chemistry at the secondary level.

2. Methodology

a. The situations studied

For my work I have considered three different situations of explanations:

- Academic textbooks: those are mainly intended to teach an individual student in a tutorial way. They are based on a highly structured description of the knowledge to convey. In a way they may be considered as a data base used by teachers and/or pupils. Even when textbooks try to evoke pedagogical environments (descriptions of experiments, differentiations according to levels, sets of questions and answers,...), the lack of adaptability and interactivity due to the written text, only allows standard explanations aimed at standard students. They contain a well defined and highly structured scientific content. Therefore, their study may be considered as a 'reference situation' which allows to analyse the content of explanations, whoever the students are.

- Classroom situations: in these situations, the teacher produces an explanation directed toward a whole group, which can be considered as a sample of different individuals or as a set of average students. Consequently, the teacher spontaneously carries out adaptations both for the content and the methodology. The observation of teachers in the classroom allows to focus both on the process which activates the explanation and the explanation itself. The comparison with textbooks will set off differences between the two situations. It will permit to distinguish scientific explanations from other kind of verbalizations having yet some characteristics of explanation (or guidance, help, comments). This situation is characterised by the interactivity and adaptability of the teacher to the class context or to the situation of the student himself.
- Learning environments with a computer: those are meant for individual purposes. The student is in an active learning or problem solving position and the mastery of the strategy is in his hand. Moreover, modern techniques allow a reasonable interactivity between environment and student. Learning environments allow to follow more closely all steps of the solving process and to elicit every question and answer in the dialogue between student, computer and teacher or expert.

b. The different stages of the work

After having made a few bibliographical researches about explanations and problem solving, the first step of my work has consisted in gathering experimental data. First I studied different *textbooks* of chemistry and developed a grid of analysis. I chose five textbooks most commonly used in French classes.

The main points of the grid are:

- global content: general structure of the text book; main concepts: inventory of main concepts and 'subconcepts', and organization of these different concepts,
- the 'style': illustrations; vocabulary; grammatical forms, ...
- the explanation itself: level of explanation (qualitative versus quantitative, microscopic versus macroscopic, ...); function of experiments in the process of explanation; objectives (goals) of the explanation (from the point of view of the one who explains: inform, illustrate, convince, give tools, demonstrate, ...),

- the form and medium of explanation (deduction, induction, analogy, generalization, ...).

The second step has consisted in recording three *teachers in their class* during problem solving activities. This step is at present in the process of being analyzed. Part of the above grid can be used, but it has to be adapted because, as already said, the situations are not the same and teachers deliver much more in their speech than scientific explanations. So we focus on the dialog between students and teachers and the way they interact with each other without forgetting the forms and contents of explanations.

When this material wil be analysed, we shall probably have to do some more recording because, even though the situations can be very 'rich', there are not many explanations in each. We think that it could be interesting after every recording to interview the teacher in front of the videotape in order to make him clarify what he intended to do in every situation.

The third part, simultaneous with the second, has consisted in letting students experiment with the *computer environment* already mentioned. During these experiments, we record all actions made by the student on the computer, which gives us a 'trace'. At the same time, we audiorecord all oral questions expressed by the student and the answers proposed by the teacher, while an observer focuses upon the relations between student and teacher. So, the situation is very well observed and mastered, and we know exactly what has been going on. Explicit and implicit questions are relatively easy to analyse. Spontaneous interventions of the teacher are a little more difficult to describe, but we can always find a reason for these interventions, either technical or because of the supposed strategy of the student. The explanations can be classified quite easily into 'help', 'guidance' and scientific explanations and they can be described. Due to the 'game rule' we gave to the teachers, there are not many real scientific explanations, which will probably lead us to some more experiments of that kind with more activity of the teacher. The questions and answers are of two kinds: need of help about the software (how it works, what is expected, ...) and real explanations about chemical knowledge (mainly declarative and seldom procedural). In a second round, I am analysing all empirical data so as to specify and differentiate the explanation processes at work in those various situations. As I explained before, I distinguish several levels:

- the process which activates or provokes the explanation (explicitly, implicitly or supposed by the teacher);
- the process of the explanation itself: form, kind of argument, ...;
- the content of the explanation: facts, concepts, knowledge structure, ...which will surely be different in each situation.

3. Discussion

The main difficulty raised by the general objective of this work is to get a clear view of what may be considered as an explanation. What sort of criterion do we have to select explanations? One of the first distinction to be made is the distinction between the action and the content of the explanation. This distinction, which seems to be quite elementary, is not always so easy to capture. In the first meaning (explanation as an action) the explanation is part of a dialog between two partners. The questions to answer in order to lead this study are multiple and complex: can there be an explanation without any need manifested by the student? When does an explanation begin? What triggers an explanation? Is the explanation adequate in view of the need (real or supposed) expressed by the student? What about the effectiveness of the explanation ? Who can tell about its efficiency?

In the second meaning, the questions could be: what counts as an explanation, more or less independently of a person's need? What is explanatory in the sense of the knowledge object?

These two meanings may provide a tool for analysis. Quite evidently, they are very different, but it is necessary to have both of them in mind for any study about explanation. In natural situations they join in a global 'process of explanation'. Probably, elements of each approach will be present in the final corpus, the contents of explanations being completed with some kind of 'parameters' or conditions for application, issued from the analysis of the actions of explanation. In doing so, we position ourselves a little differently from the common literature on computing science or artificial intelligence. Most of the A.I. literature deals more with the content of explanations than with the interactive aspect. At every step of the software, the computer researcher wants to know what kind of explanation he has to implement, without always having to address the question: 'what is needed to explain to this person in this precise context?'.

Assessment in physics as a tool for learning

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1. Introduction

At present an important transformation of the teaching-learning paradigm in science is taking place. Researchers are becoming aware of the importance of developments in assessment in order to complete this transformation. At the Conference for Research and Science Education celebrated in Berkeley (1986), one of the conclusions was that 'recent innovations in the curriculum fail to persist unless they are reflected in similar innovations in testing' (Linn, 1987).

However, from the literature on science education we notice a great difference between the abundance of work carried out on many aspects of the teaching-learning process (i.e., laboratory work, introduction of concepts or problem solving) and the very few publications that we could find about assessment. In our opinion, this is in part due to a view of the role of assessment still coherent with the previous paradigm of science teaching, that is to say, a view in which assessment is seen as a 'measure of pupils' performances'. But, of course, we consider this 'traditional' view of the purpose of assessment to be completely inadequate for constructivist science teaching. On the contrary, for us the main aim of assessment should be to improve meaningful learning rather than to measure it. Accordingly, our contribution consists of the development of a new physics assessment proposal, in which it is **conceived and designed** as a tool for learning (Alonso, Gil y Martínez Torregrosa, 1992). To this aim, we have tackled the following three questions:

1. Which role and what characteristics should assessment in physics have to be coherent with a constructivist view of science teaching?.
2. To what extent does the ordinary assessment practice in Physics correspond to these characteristics?, Which are the main obstacles to overcome in order to implement the new assessment proposal?.

3. To what extent will the new assessment contribute to the improvement of meaningful learning by encouraging a conceptual, methodological and attitudinal change in pupils *and teachers*?.

Some of the main results that we have obtained in relation to these three questions are summarized very briefly below.

2. The role of assessment in a constructivist paradigm

In order to establish the role of assessment coherent with a constructivist view, it has been very useful for us to take advantatge of the analogy between the situation in a science classroom and the situation in a guided investigation. To make this analogy we only have to take into account that in a constructivist paradigm the teacher role is not to transmit the contents in a final state, but to let pupils be involved in activities in which they will construct those contents. Therefore, the classroom atmosphere in this context is very similar to the one we can find in a guided investigation: small groups of pupils act as groups of novel scientists and the teacher acts as the director of their investigation (Gil y Carrascosa, 1992). And, in an investigation, assessment is performed in order to push the investigation itself. After clarifying the purpose of the new assessment we have developed our assessment proposal, about which we will only show here the following 5 points that summarize very briefly its main features:

1. Students should perceive assessment as a help to learn. Therefore, it must pay special attention to provide them useful feedback in their learning.
2. Assessment must be fully integrated into the learning process, since the essential question is not to know who has done and who hasn't done things well, but to encourage everyone to improve.
3. Assessment must indicate clearly to students their advances, difficulties and needs. For this aim it is necessary to establish general objectives, and foresee possible obstacles in the learning process.
4. In order to promote meaningful learning, assessment activities must deal with all aspects (conceptual, methodological and attitudinal) that meaningful learning of physics includes.
5. Assessment must include the teacher task, the classroom atmosphere and, in general, all aspects that influence the learning process.

3. Analysis of ordinary assessment in physics

After having developed the main characteristics of our assessment proposal, we have proceeded to analyse the ordinary assessment practice in physics. Since we expected ordinary assessment to be still coherent with the previous paradigm of science teaching, the interest of this analysis has been to identify some of its predicted deficiences, to characterize it precisely and, mainly, to determine the transformations that should take place to make it useful for meaningful physics learning. In this analysis we have studied three general aspects of the ordinary assessment practice (teachers, exams and learners) and obtained, in short, the following conclusions:

a. Physics teachers do not conceive and do not use assessment to improve the learning process, but only to measure pupils' final performances.
b. Ordinary physics exams cannot contribute to pupils' meaningful learning because they only deal with the most 'objective activities', necessarily poor and repetitive.
c. As a consequence, the ordinary assessment practice has a negative influence on students' attitudes towards physics learning and towards the assessment practice itself.

These results put in evidence that the ordinary assessment practice is very far from what is needed in the present physics teaching paradigm. In particular, the results we have obtained for physics' teachers show very clearly that, regarding assessment, their ideas and behaviour are deeply interrelated and conform to an overall 'spontaneous conception' of this teaching element. This implies that, in order to implement a new way of assessment, it will be absolutely necessary to modify this 'spontaneous teachers' thinking and behaviour'.

4. Some achievements of the new assessment

In the third part of our work we try to show some of the main achievements of the new assessment proposal. For this aim we have tackled again the same aspects that we considered before. We obtained, among others, the following results:

a. It is possible (and not too difficult) to transform ordinary assessment activities in physics by designing alternatives in coherence with our proposal. In order to show clearly the distance between ordinary and new assessment, we have designed a whole lot of examples of transformations of ordinary into alternative assessment activities. Whith these examples we have tried to point out that: the new activities include many conceptual, methodological and attitudinal meaningful contents that are completely ignored by the ordinary ones. Besides, the new assessment activities are much more useful than the ordinary ones, not only to indicate meaningful learning, but mainly to promote pupils' improvement. This is because they have been designed by paying special attention to students' self-regulation processes, either by helping them to overcome possible difficulties or by highlighting their advances, etc.

b. It is possible to (re)elaborate curricular physics materials by including the most important aspects of our assessment proposal. We have developed a new physics curriculum project for secondary school pupils (age 12-16), in which the main aspects of the new assessment proposal are included. These materials are being used now in Spanish physics classroom with promising results.

c. The new assessment proposal is suitable to promote changes in teachers' thinking and behaviour, in order to make them conceive and use assessment as a tool for learning. In order to promote necessary changes in physics teachers' thinking and behaviour, we have designed a seminar of about 20 hours, in which they can (re)elaborate the main aspects of our assessment proposal and make themselves aware of the most important deficiences of ordinary assessment. After the seminar most teachers evaluate the new assessment proposal very positively and the ordinary assessment practice very negatively.

d. The new assessment practice fosters better attitudes of pupils towards learning and towards evaluation itself. In order to prove this, a comparative analysis between the influence of ordinary and new assessment on pupils' attitudes has been carried out. This analysis involved two samples of students: a random group assessed in the ordinary way (150 students) and an experimental group assessed alternatively (282 students). The results show that: 1) Pupils who are asked about the new assessment say that it contributes to make the subject interesting. Pupils of the random group (asked about the ordinary assessment) say just the contrary; 2) Pupils consider the new assessment activities very useful to make them appreciate progress and difficulties. This question divides the random group in two halves (50% agree and 50% disagree); 3) Students who are asked about the new assessment say that it encourages them to study reflectively. Students of the random group are hesitant about this question; 4) As a consequence, students who are asked about the new assessment believe that 'pupils who pass know the essential things of the unit assessed'. Those who are asked about the ordinary assessment do not believe this statement to be true.

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Effectiveness of practical work in the remediation of alternative conceptions of force with students in Botswana

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1. Introduction

Aims of practical work in science education are (Kempa, 1988) *affective* aims (enhancement of appreciation of science), *practical* aims (the development of skills) or *cognitive* aims (appreciation of the scientific method and conceptual development). This study focuses on practicals, that aim specifically at the development of conceptual understanding in elementary mechanics. According to the literature, such a practical can be effective only, if it is *aim-specific*: it may aim for skills or conceptual development, but not both. In a practical aimed at conceptual development ('concept lab', Van den Berg and Giddings, 1992)), students must already master the skills used in it. Furthermore, the practical must stimulate the process of constructing new understanding by the students. Hence it will contain the following elements:

- *Prediction.* Students predict the experimental outcomes, to become more aware of and committed to their existing ideas.
- *Creating 'dissonance'.* Then, observations are performed. Students are to become aware that observations disagree with intuitive ideas ('dissonance'). A student experiencing 'dissonance' (Clement, 1987) may search for scientifically more correct explanations.
- *Resolving 'dissonance'.* A 'way out' of dissonance may be offered through direct interpretation of the results, reasoning about analogous situations, or conducting further experiments. Resolving 'dissonance' involves formulating a tentative conclusion, that makes sense to the student and explains the observations.
- *Test of the tentative conclusion.* The tentative conclusion is compared with the original ideas in view of the experimental evidence, in further experiments or in paper exercises. Testing of the conclusion may lead to its establishment as a new 'rule'.
- *Application and generalisation.* The new rule is to provide a useful instrument in reasoning about situations not studied experimentally. Students

should obtain at least a partial notion of the range of applicability and possible generalisations of the new rule.

In this study three practicals were researched, using different models for the elements of 'creating and resolving dissonance', whereas the other elements were structured similarly. These 'concept labs' were taught both as teacher demonstration practicals (TDP) and as small group practicals (SGP). This paper reports on how the effectiveness of these teaching modes depends on the model used in the practicals.

2. Models and teaching modes for practical work

In the literature, at least two models for 'concept labs' can be found. In the *'cognitive conflict'* model (Nussbaum and Novick, 1982), the practical contains experiments that aim to show unequivocally and immediately the incorrectness of students' intuitive ideas. It is attempted to modify or replace the incorrect ideas by attacking them frontally. The *'anchor-bridges'* model (Clement, 1987) aims to build understanding from intuitively correctly described 'anchor'-situations, towards 'target'-situations that are initially incorrectly described. The 'target' is, for the physicist, analogous to the 'anchor'. Students' reasoning is guided towards the 'anchor-target' analogy through a study of 'bridging'-situations, that are more obviously analogous to both 'anchor' and 'target'.

We used a third model, since the two above cannot always be applied. In this case, students' predictions are too vague and undifferentiated to create an immediate conflict with observations. But since the aim of the practical is to show that two quantities are *not* analogous, it is difficult to conceive of conceptual 'bridges'. In this practical, creating dissonance involves analogous reasoning, as in the 'anchor-bridges' model. Resolving dissonance is attempted through new observations of the same phenomena used in creating dissonance. Students are guided to describe these new observations in more detail, differentiating aspects that were not previously deemed relevant (by the students). The more detailed description of the observations should enable the students to distinguish the quantities that were initially muddled. We tentatively suggest to call this an *'enhancing of detail'* model.

Ideally, a teacher will provide stimulus and proper guidance to each individual student at the right time. In large classes this is no longer feasible. In SGP's, the teacher can only attend to one group at a time, and will be unable to follow the whole process of meaning-construction of each student. In demonstrations however, provided that the teacher is able to involve all students in the process and is able to keep the right pace, (s)he has more opportunity to provide accurate and timely guidance. In as far as the process of constructing meaning can be controlled, the teacher has more control in TDP's.

3. Background of research

Between O-levels and Science Year 1, students in Botswana follow the compulsory, 6-month Pre-Entry Science Course (PESC) at the University of Botswana (Cantrell et al., 1993). In PESC-physics conceptual understanding of 'force and motion' is considered important. At entry, many students show incorrect intuitive ideas (Halloun and Hestenes, 1985) in that area. Both at the VUA and at PESC, research and development activities have taken place since 1986 (Thijs et al., 1993; Smith, 1989). From 1988-1991 the section on mechanics in PESC-physics was thoroughly modified, based on results from yearly pre- and post-course questionnaires. The changes prior to 1992 were insufficiently effective in addressing the following problems:

1. Many students remain with 'impetus'-ideas about force. An object that moves *has* a force in the direction of its motion. This force is larger if the speed of the object is larger. In case there is a force along with the motion and one opposite to it, the forward force is larger.
2. Induced forces, in particular friction in rest-situations, are often not understood. If an object is being pushed but remains at rest, the force preventing motion exceeds the force that would cause motion.
3. A lack of qualitative understanding of acceleration. Many students do not distinguish the acceleration of an object from its velocity; if the speed increases or decreases, so does the acceleration.

Practicals to address each of these problems were introduced in 1991. In 1992, a pilot study into the effectiveness of these labs was executed. This paper reports on research in 1993. The practical on 'impetus' ideas 1.) uses the 'conflict' model, that on induced forces 2.) the 'anchor-bridges' model. The practical on acceleration uses the 'enhancing of detail' model.

4. Aims of research

The following are the most important questions in my research, but are not necessarily addressed here.

a. Design of the practicals
   The three practicals have a similar structure, that arose from following the conditions set out for 'concept labs' in the literature. How do the various elements of the practical contribute to its effectiveness?
b. What is the quality of the understanding, that students gain through these practicals?
   The practicals will affect students in different ways. The effectiveness of the lab can be measured in terms of changes in answer-patterns in tests written by all students, but also in terms of changes in ways of reasoning or thinking, that may be revealed in interviews.
c. Feasibility of the labs
   The labs aim to use a constructivist approach to teaching, which is demanding on both student and teacher, especially in the educational setting of Botswana (Cantrell et al., 1993). Can the teaching materials reinforce, or perhaps even enforce, the approach assumed to be essential in realising conceptual change in students?
d. Comparison of teaching modes
   A balanced comparison of TDP and SGP is not possible in this paper, but the following is relevant. SGP's have disadvantages: they require large amounts of equipment and special laboratory classrooms. TDP's may have advantages. The main disadvantage of demonstrations is that students do not get hands on experience or train practical skills, which has a high priority at (courses like) PESC. Clear information about the merits and disadvantages of the teaching modes is important, especially for developing countries.
e. Comparison of practical models
   The models described in the literature cannot address all intuitive student ideas in elementary mechanics. It is however not an aim of research to develop models, or to give an exhaustive overview of possible models. This research will at least attempt to compare the three given models on aspects such as student and teacher appreciation and long term effectiveness.

This paper will give results of research only regarding the following consideration. The content and structure of a practical may determine the need for teacher guidance. If the discrepancy between observations and expectations is immediately obvious, while the new rule follows directly from the data, students will need the teacher less. On the other hand, if the practical follows a coherent sequence requiring logical reasoning, the importance of guidance will increase. We therefore expect, that a TDP is more effective than an SGP in the *'anchor-bridges'* and *'enhancing of detail'* models. We expect no difference in effectiveness between TDP and SGP in the *'cognitive conflict'* model. (In practicals that aim to develop *process skills*, this may *not* be true, as it may be essential then, that students handle the equipment themselves.)

5. Methodology

Sample and research method

Research in 1993 was carried out in 6 PESC groups of around 30 students each (from a total of around 430). 3 experienced teachers took part, one taught 2 groups, two others 1 group each, while the researcher taught 2 groups as well. Each practical was taught as TDP in 3 groups and as SGP in the remaining groups, using the same worksheets, set-ups and amount of time. On the basis of O-level marks in maths and the sciences, PESC groups were constructed to have equal amounts of 'weak' and 'strong' students. Pre/post course tests were administered eliciting the use of a number of student ideas, including those mentioned. The tests occurred 3-7 weeks before and 18-22 weeks after the practicals. After each lab, shorter intermediate tests were written, addressing specifically the ideas dealt with in the lab. Student predictions and answers to worksheet questions were collected. To acquire information about individual student thinking, 1 hour student interviews were audio-recorded, in which students were asked to motivate the answers they gave in the tests. Per practical, about 4 students were interviewed. The try-outs of each lab by 2 students were also recorded. After each lab, 10 students per group wrote an 'appreciation' questionnaire. Teachers were interviewed regarding their appreciation of the lab, and asked to estimate how many students would use intuitive ideas before and after each lab.

Example: content of the practical on 'impetus'-ideas, using the 'conflict' model

A trolley is placed on a horizontal runway (See figure 1). A hanging mass is attached to it, that is big enough to make friction negligible. At the front, a string is attached by which the trolley can be pulled forward. Forces are

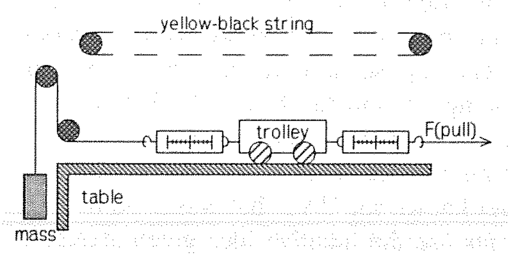


figure 1

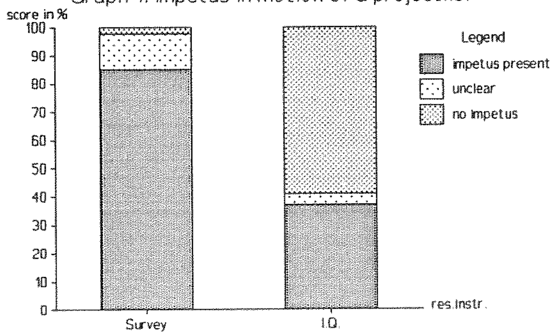
measured by spring-balances. The string above the set-up is propelled at constant velocity by an electromotor and gearbox. By pulling the trolley along with the string, it is given that same velocity (chosen between 0.5 and 2.0 m/s). In large majority students conclude from their observations, quite contrary to their expectations, that the forward and backward force are equal in each case, and are independent of the velocity. Students answer and discuss a series of questions, in which they apply the conclusion. The conclusion is generalised, in small steps, to the following rules:

- On an object that moves horizontally without friction, the forward force is zero newton.
- On an object that moves but is not at that time pushed or pulled by another object, there is no force in the direction of its motion.

6. Some preliminary results

Some results of the practical on 'impetus' ideas

Graph 1. Impetus in motion of a projectile.



A study of the effect of the teaching mode makes sense only if the practicals are effective in the first place. As an indication that student answers do become 'better' after the practicals, the effect is given of the 'conflict' lab on the following student idea: *On an object moving after being launched, there is a forward force in the direction of the motion.*

This idea was used by on average 74% (σ_{n-1}=17%) of the students entering PESC in the period 1988-1992. At the end of the '88 and '89 course, virtually the same percentage of students used this idea. About 30% less students used it at the end of the '90 - '92 courses. For 1993, graph 1 shows student predictions just before, and answers to test questions a day after the lab. The top section of each bar shows the percentage of students not indicating an impetus force, the bottom section shows those that do. The central section shows students that drew an arrow when asked for all forces, but gave it no name or an alternative name (e.g. 'momentum'). Retention is not yet known for 1993, but was good in 1992. After the practical, 48% less students use the intuitive idea given above.

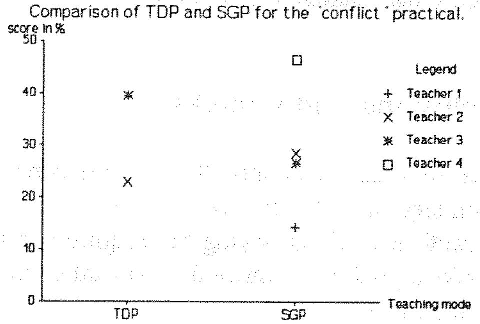
Comparison of TDP and SGP

For each of the practicals, scores on the intermediate tests (IT) for TDP and SGP groups were compared in two ways. One comparison is based on the use of the targeted intuitive ideas, the other on physically correct scores on all test items.

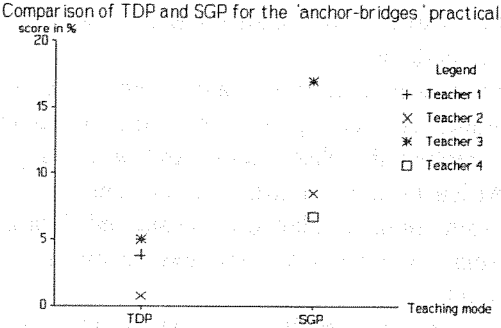
Graphs 2, 3 and 4 show group percentages of students using the intuitive ideas. Each teacher is represented by a separate symbol (the researcher is 'Teacher 2'). The graphs suggest, that TDP works better in the 'anchor-bridge' and 'enhancing of detail' models, and that TDP and SGP are equally effective in the 'conflict' lab. Graphs for correct scores (not shown) look similar.

With ANOVA the significance of these differences was determined. The resulting F-values and their significance are given in table 1. The item-scales obtained from the ITs had modest alpha reliability coefficients of around 0.6. The results need to be interpreted carefully.

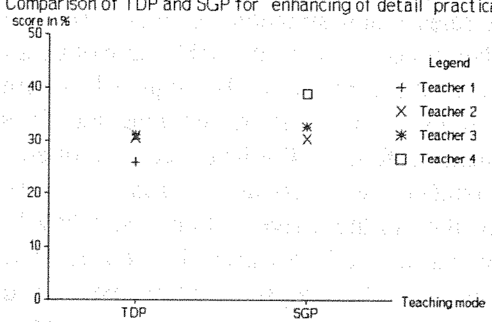
Graph 2. Group percentage scores on 'impetus' ideas in IT. Comparison of TDP and SGP for the 'conflict' practical.



Graph 3. Group percentage scores on ideas re. induced forces in IT. Comparison of TDP and SGP for the 'anchor-bridges' practical.



Graph 4. Group percentage score on 'acceleration as speed' in IT. Comparison of TDP and SGP for 'enhancing of detail' practical.



Results from interviews

The quantitative data do not provide sufficient information about the quality of understanding of students. Further information is obtained from student interviews, held at least one week after the lab. We give some preliminary conclusions based on those. All students remembered what they did in the experiments, and recalled the conclusions, but not all of them recalled the generalisations. In situations similar to those in the experiments students were able to apply the new rules. Transfer to other situations did occur to some extent, but rapidly decreased for more 'remote' situations. Students would abandon the 'new' rules quite easily when provoked. Finally it was hard to find back traces of the 'construction process': students were unclear about *why* they had changed their mind.

7. Conclusions and remarks

The above results can only illustrate the conclusions presented here. They are preliminary, as retention was not yet studied.

1. Practical work satisfying the requirements set out in the introduction can make a positive contribution to student understanding of elementary concepts in mechanics.
2. Demonstrations are more effective than small group practicals if creating and resolving dissonance depends strongly on (ana)logical reasoning by the students.
3. There is no evidence of a difference in effectiveness between the teaching modes if creating and resolving dissonance requires little more than accepting the observations and perceiving the regularity in the data.
4. At least one week after the lab, students can apply the 'new' knowledge in situations similar to those studied. Transfer of that knowledge to other situations occurs to some extend but decreases rapidly for more remote situations.

The quantitative results do not show why students use the 'new' rules, how these rules fit in with other ideas they use, whether they are able to generalise these rules to new situations, etcetera. The question 'Has this student acquired another concept due to this lab?' cannot be answered. There are many levels at which the concept can be acquired, varying from ability to formulate it, via ability to apply it in concrete situations, to ability to generalise and rationally defend it. The level acquired often depends on the context in which the concept is to be applied, and is often unstable. Developing a satisfactory description of these levels of understanding I see as the most challenging task at this stage of this research. It is hoped that, at least for the particular case of these labs, the analysis of interviews will supply guidance. At a later stage, the interviews may render a more meaningful description of the effectiveness of the labs than the tests alone can.

Table 1 Results of ANOVA for the comparison of TDP with SGP for the three practical models.

Practical Model	Compared effectiveness (expected)	Preliminary results	ANOVA based on intuitive ideas		ANOVA based on correct physics	
			F-ratio	sig. of F	F-ratio	sig. of F
'conflict'	TDP = SGP	NOT DISCON FIRMED	0.68	0.41	0.06	0.81
'bridging'	TDP > SGP	CONFIRMED	8.15	0.005**	4.43	0.037*
'detail'	TDP > SGP	PARTLY CONFIRMED	2.81	0.10	6.18	0.014*

**: significant beyond 0.01 level *: significant beyond 0.05 level

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A constructivistic approach to assessing pupils' process skills in science education

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1. Introduction

In my doctorate study I wish to deal with practical assessment in science education. My research is divided into three parts. Firstly, I will describe some features of how *science processes* have got importance in science education in Anglo-American countries during the last 20-30 years. I think there are reasons to describe this as a paradigm, and I will try to illuminate some typical aspects. Secondly, I will study pupils' performance of some investigative tasks. Thirdly, I will take part in a practical component of IEA's third international science and mathematic study (TIMSS). In this connection I want to look at the competence in practical science of 13 year old Norwegian children.

Since the curriculum reforms in the 1960's and 1970's, science education in the Anglo-American countries has been influenced by a wish to develop pupils' scientific skills. Curriculum projects have been developed that had process skills as their main goal, like SAPA (1967) and Warwick Process Science (Screen, 1986). Categories have been developed to describe students' achievement, and items to test it (e.g., Klopfer, 1971; APU 1985). Many of these projects have stressed that the process of science should not be seen as a stepped process that leads inevitably to the successful solution of science problems. They have stressed that not just one scientific method exists but many, and that these methods can be described as rather independent processes that scientists use. Different curriculum projects have described different processes, but a common feature for many of them is that they stress processes that are cognitive in nature. The processes of science are regarded as rather general and cognitive, e.g.,: observing, comparing, classifying, hypothesizing, predicting, interpreting, inferring, generalising, explaining, communicating. For assessment, categories and items have been developed that correspond to these different aspects of science processes. This also applies to the IEA's studies. In my research, I will try to look closer at the validity of some of these items.

Lately, questions have been raised about the description of science processes as general cognitive skills and about the possibility of improving such skills through teaching (Millar & Driver, 1987; Millar 1989). To my opinion, many of these questions are motivated by current constructivist philosophy. I will try to use this philosophy as a theoretical framework for my research. An important feature in constructivistic philosophy is that each individual develops his or her own knowledge about the world, and that every new event is seen through this knowledge. From this point of view it would be natural to focus on the importance of an individuals' knowledge, rather than on one's ability to use general process skills in teaching and learning. We do not only develop knowledge about the natural world, but we also develop *knowledge about* knowledge and how to use it. In that way constructivism has become important for metacognition. Paris & Byrnes (1989) stress that children build up knowledge about how to learn, alongside their development of what we usually see as knowledge in school. This is in many ways important for science education. Regarding the development of students' scientific process skills, it is important to bear in mind that what they learn and do is a result of their knowledge about the situation, and not only a result of some content-independent skills. In research and achievement tests on students' scientific process skills, I think it has been taken for granted that the items did measure such skills. Students' responses have not been regarded as a result of their knowledge about the topic, of their knowledge about how the teacher or the researcher wants them to respond, or of other types of knowledge about the test-situation. This may be important for how we interpret students' responses to items.

2. Research questions and methods

As mentioned above, my doctorate study will be divided into three parts. I will describe briefly the research questions and methods for each:

Part 1: Description of a paradigm in teaching and assessing science processes

What are typical features in the teaching and assessment of science process skills in science education during the last 20-30 years? It will be a theoretical study of literature in this field. Both research literature, assessment projects and curriculum projects will be of interest.

Part 2: Children's performance of investigative tasks

This will be an empirical study of five small groups of pupils. The description of pupils' performance on investigative tasks will be the main problem of the study. I will focus both on their perception of the test situation and the tasks, and on the cognitive and practical abilities they use when they solve the tasks. I will also try to focus on the relationship between what are intuitive 'prior ideas', and what they learn from school science investigations. The empirical study will be related to a model developed by the PACKS-group (Millar, 1993) in England. I will also use some of the tasks used by this group.

The different questions/problems I want to work on in the empirical study are:

1. How do pupils' performance of investigative tasks relate to the PACKS model?
   How does the model fit with what pupils really do?
   How do the different components in the model relate to each other (what do the different arrays in the model mean; what factors affect their performance and how do these factors affect their performance)?
2. What are pupils' conception of investigative tasks and how do these conceptions develop through repeated testing.
3. Which 'prior ideas' have pupils developed that are important for their performance of investigative tasks?
   What ideas are intuitive and what ideas are learned through school science investigations?
4. Which coding system can be used to describe pupils' performance on investigative work?

I will use the following methods to explore these questions:

1. The pupils conduct an investigative task in pairs. 1 pair in each group is recorded on video tape. The rest of the pupils make a report on a 'cued' report sheet.
2. Interviews of 'video taped' pupils after they have conducted the investigation.
3. View the videotape together with the pupils. Record their comments on an audio tape.
4. All pupils answer written questions about the topic of investigation.

Part 3: Practical assessment through IEA's Third International Mathematics and Science Study

This will be an empirical study following the guidelines from TIMSS. This test will also focus on pupils' performance of investigative tasks. I hope to use some of the experiences from part 2 in developing and interpreting this test.

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Increasing the availability of conceptual tools about colour: a teaching sequence integrating physics, technique of art and perception

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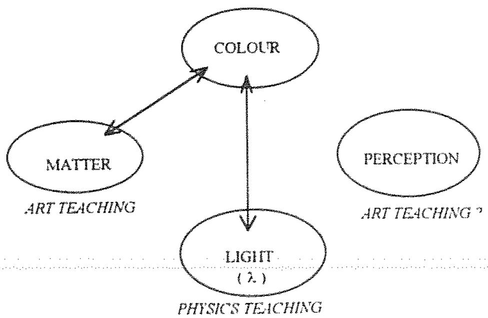
1. The hypotheses of the research

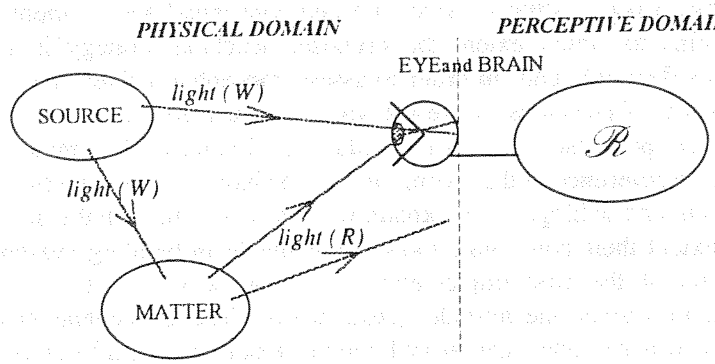
The general framework is a contructivist approach: I analyse and take into account students' ideas about colour (conceptual tools, ways of reasoning) which has implications for the teaching-learning process, in particular as regards style of working and the role of experiments. In terms of the distinction made by Philip Adey, my educational goal is 'increasing the availability of conceptual tools about colour', through a teaching sequence that integrates: physics, technique and perception. This sequence is designed for applied arts students. A-priori compatible with my educational goal, I have done research with the following hypothesis: in order to understand, analyse and make predictions about situations of colour, a necessary condition is to integrate physics (light and matter), perception (eye and brain) and technique (technical applications in art, painting, video, photo...). I performed a preliminary enquiry, using interviews and a written questionnaire, in order to get a first idea of the kind of links that students are likely to establish between different aspects of colour.



In art teaching, as in everyday life, colour is mainly associated with matter; in physics teaching, colour is only associated with the wavelength of light and no connection exists between these two domains and perception. If perception is taken into account, it can also be an obstacle; indeed perception is linked with subjectivity and can be considered as non scientific.

2. Design of the sequence

How to integrate physics, technique and perception? In comparison with traditional physics teaching, the basic concepts of the teaching sequence imply more perception ('coloured' light is the cause of perceived colour), more analysis and reasoning about technique (the experiments are directly linked with situations encountered by students in their work with colours) and simplified physics. I don't introduce wavelength but only three basic components, red, green and blue light, and special attention is given to selective absorption resulting in lack of a band. The main goal is to enable students to make predictions and analyse situations, using the idea of a **chain** in the process of information about colour. I suggest to use the following representation which emphasises two different domains, one connected with physics and one connected with perception. In the physics domain, coloured light is designated with a printed character (R). In the perceptive domain, the perceived colour is symbolised with a round script character (R). The basic ideas of physics are that light enters the eye and that matter interacts with light. The results of this interaction are the diffusion of light and a change in the composition of light.



Functional diagram : "chain"

The sequence has been implemented by the teacher within the normal constraints of the classroom. Students are invited to reason about simple but non-prototypical situations. Practical and prediction-verification activities are essential components of the proposed work. In particular, it provides opportunities for students to express their own concepts. They are constantly requested to put into play some conceptual reasoning tools in order to simply interpret, or more frequently, to predict, justify and check the results of experiments. Practical activities have the status of guided observation, implying reasoning which is far from simple contemplation: conceptual tools are 'good glasses', shown to extract information from experimental situations.

3. My question

I would like to see more precisely how to formulate what I have learned after having implemented the sequence. In particular, I would like to see whether I can use some quantitative results in a sound way, in addition to fine grained analysis of selected transcripts. Doing so, I don't think of an assessment in terms of a monolithic 'better', but I would like to try to associate quantitative results to the kind of achievement reached.

Elements of evaluation

The evaluation consists of two parts. During the sequence, some predictions made by students and written answers are analysed, in order to have some information about the following: importance of possible blockades, and steps and strategies used by students to overcome difficulties. I don't speak here about the first part, called 'logbook'. The second part, a final evaluation, implies two aspects, attitude evaluation and conceptual achievement. I want to determine to which extent the proposed teaching strategy is accepted (attitude evaluation), and, in order to assess conceptual achievement, I have built two sets of questions, a pre-test and a post-test for internal evaluation, and only the post-test for external evaluation. I want to determine ways of reasoning in reference to the chain. On the one hand, I try to assess students' involvement and willingness to explain what they see, and, on the other hand, to what extent their conceptual tools are available in building reasoning.
At the end of the first implementation of the sequence, test-group-1 is requested to answer the attitude questionnaire. The conceptual evaluation includes two parts, one internal and another external, as said before. In the internal evaluation, the second year, test-group-2 had only the conceptual questionnaire, a pre-test at the beginning and a post-test about one month after the end of the sequence. About one year after the course, in an external evaluation, the answers of test-group-1 were compared with those of two control-groups, having a-priori the same background (same school level and motivation, in another applied arts school). The two control-groups attended a traditional course on the test-group syllabus. The conceptual evaluation was postponed in order to help to discriminate simply memorised knowledge from conceptual tools available in the long term. Here my attention is also focused on students' ability to organise arguments to solve new questions. From the data, I analyse arguments and diagrams and also raw answers (predictions)

for situations that are a-priori non solvable by rote learning. To characterise the questions posed, I look at the two following non exclusive features: Is the question likely to raise an analysis in terms of the 'chain'?, or is the question rather 'classical', for instance, classically posed at the final examination ?

Examples of questions

Two examples are given of not-easily-available questions, meant to analyse reasoning in terms of the chain. In the first *'Can you see all the colours in the rainbow ?'*, it is an element of a correct answer if it mentions light. An alternative correct answer, given as he most frequent argument by students who say 'no', is: *'UV and IR can't be seen by the human eye'*. A better argument in terms of the chain is that some colours are obtained by adding light. The second example is about the definition of 'additive and subtractive colour mixing', it is a super-classical question in a technical field where correct answers can be easily memorised. These questions do not discriminate much in terms of the chain, because some right answers can be found referring to only one domain. Other questions are more appropriate to see to which extent students use elements of the chain. The following examples need more or less elements of the chain: diffusion, interaction light/matter (subtraction and transmission in case of a filter, subtraction and diffusion in case of pigment), analysis of the composition of light and perceived colour. The first example, which I characterise as 'simple' and classical, is: *'Can an observer make a difference between a red screen lit by a white light and a white screen lit by a red light, whwn entering a dark room ?'*. There are two levels of analysis, 'a red screen only diffuses red light' is a sufficient argument for a good answer. That the object subtracts green and blue from white light, can be said in addition for a more complete explanation and justification. The second question concerns the prediction of the colour obtained by using two superimposed filters on white light and two mixed paints. I have classified this question as 'non trivial', non classical and particularly in the line of the sequence. The third is a prediction of the colour seen when coloured objects are lighted with coloured light. It is classical but 'non trivial' for the students.

4. Results

In the internal evaluation, for the first question (classical and 'simple') the test-group rates of correct answers and correct elements of justifications are much higher in the post-test. In the external evaluation, control-group-1 seems

to be more explicit in justifications in terms of 'light' (55% against 20% and 30%). Surprisingly, half of the test-group does not give any argument.
For the second question ('non trivial') a low increase (30% to 45% correct answers) results in the internal assessment. The persistence of obstacles (60% to 50%) can be noticed - this shows more difficulties in learning. But, in the external evaluation, a larger difference between the test-group and the control-groups exists (40% against 10%) than for the preceding question. In this question, reasoning in terms of the chain is needed.

The third question needs reasoning for a correct answer. Internally, the high rate of correct elements of justification (50%) follows the high rate of raw correct answers (80%). Externally, the rate of raw correct answers is higher than in the control-groups (35% against 10% and 5%) and we could explain the lack of justification by lack of time. But anyhow, here, we don't need explicit arguments to know that students have to use reasoning in terms of the chain, given the complexity of the problem.

To summarise from the first type of questions - classical and 'simple' questions do not allow analysis of reasoning - it happens that one of the control-groups is better in physics related questions, while the second is better in technique related questions. The test-group answers as well as the 'physicists' group and as well as the 'technicians' group. This group thus shows an *'integrated profile'*. The other conclusion from the second type of questions is that one third is undoubtedly able to reason and answer in terms of the chain. The increased high rate of predictions and justifications shows an increase in conceptual achievement. But we can also observe the persistence of difficulties commonly shared by all the groups (filter = light, colour = object). In the external evaluation, compared to the two control-groups, the test-group shows the same rate of predictions and a lower rate of justifications for simple classical questions, higher rates of predictions and justifications for non-classical and non-trivial questions. This group gives a higher rate of good predictions when reasoning in terms of the chain is necessary for a good answer. One third of the test-group has reached a long-lasting integrated understanding.

Children's ideas about colour and light

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1. Background

Coming from a background in art, my interest in science education has grown through working with young children in this field in recent years. Their interest and enthusiasm has inspired me to look in a more structured way at the ideas they hold. The area of Light and Colour had a particular appeal because in some respects it forms a bridge from art to science. On looking at studies in the area, I found that the body of research to be reviewed dealt largely with older children. (For example, Stead and Osborne, 1980; Andersson and Karrqvist, 1981; Guesne, 1985). It is important to assess the understanding of children who may have spent 8 or 10 years in the educational system and plan their teaching programme accordingly. However it is equally valid, although methodologically more difficult, to attempt to assess the extent of young children's ability to understand these ideas. Younger children are often more receptive to new ideas - a programme planned to match their ability to understand may well be more fruitful than one aimed at older children. Current research (Driver, 1985) indicates problems arising from children's adhesion to 'alternative frameworks'. It may be possible to resolve some of these by addressing them at a young age before they become too deeply entrenched.

Another factor recently introduced (in 1989) into the educational arena in the U.K. is the National Curriculum. It enshrines a legal requirement to teach a broad science curriculum to all primary school children from the age of five. It includes statements relating to light and colour. In this study, I hope to asses some of the ideas the children hold as they approach the end of the first phase of their education - Key stage 1 - at the age of 6-7 years.

The key questions I want to address are:

1. How far do young children recognise that light is an entity which travels in space?
2. Do they have any understanding of the range of ways that light behaves when it interacts with matter?

3. Do they see a relationship between light and colour? Do they have any notion of what that relationship might be?
4. How far are their responses context-dependent?

2. Methodology

Overview. I am a working teacher and, as such am in the position to be able to undertake a very natural form of 'action research'. I have worked with groups of children in my own class of 6-7 year olds as a small scale case study. Most past research in the area has involved removing children individually or in pairs in an interview or interview about objects situation (e.g., Osborne et al., 1990). This offers the advantage of an uninterrupted concentration on the discussion in hand and the chance to map clearly a particular individual's response. The teacher conducting research in her or his own class will have to cope with the greater methodological problems imposed by the constraints of classroom management. However, studies undertaken in this manner give a clearer picture both of children's response in their normal learning environment and of what it is possible to achieve in everyday classroom interaction.
Specific Context. Many of the children are very articulate and have been encouraged to express their ideas with confidence. In the classroom situation the children will usually be working in mixed ability groups and will be accustomed to working in different groups for different tasks. Some work requires ability grouping but in science I often gender segregate both to promote confidence in the girls and to offer a variety of social groupings.
The activities. The focus activities in the initial phase of data collection included a loosely-structured opportunity for the children to play with a variety of toys dependent on light. A request for the children to draw things which give off light. An exploration of the perceptible effects of light shining a torch into a dark corner and then into light. A task requiring the children to bounce light off a mirror to hit a target. An inquiry into how far light travels. Some exploration of filters and prisms.
Data collection. The data was collected in a variety of ways. Audio taping was used to record interviews, undertaken whilst children were engaged in activities or making drawings/written recording related to the topic. Video recording was used in the activities which were much more physical in nature. Written work was collected as well as drawings that the children had completed or made.

3. Progress to date

Initial data from the pilot study has been collected and largely transcribed. Some refining of the research questions and assessment of suitable research tools has been undertaken. Preliminary results highlight the active nature of the children's response. It is obvious that young children respond better orally than in writing, in this study it became apparent that the level of response was even better when expressed physically. They might not actually state that light travels, but they acted as if they knew it did by bouncing light off a mirror onto a target.

Guesne's study ('85) suggested that children under the age of 10 seldom used the physicists concept of light as an entity propagating in space. She found that they tended to equate light with its source, with its perceptible effects or with a state (eg. brightness). At first sight there is much evidence to support this view. The children seldom refer to light, talking about shining the torch and remarking on the effects produced by strong lights. However, in the period of initial data collection their physical actions showed a deeper level of understanding. When a torch was shone in ambient light, the children did not believe that it was no longer giving out light, even though there was no longer a perceptible effect. The way that they used mirrors to reflect light onto a target indicated much about their concept of light and its properties. The second stage of data collection (now in progress) has concentrated on encouraging the children to verbalise their ideas more. Initial results indicate a confirmation of the existence of a deeper level of understanding of light as an entity, propagating in straight lines in these young children. There are some indications that the children saw some relationship between light and colour in 'everyday' phenomena, such as rainbows and prisms, but not that they understood anything of its nature.

4. Further Questions

- How far are their responses context-dependent in terms of their ability to apply their ideas to a range of activities or situations?
- What are the possible 'parallel activities' one might undertake to test this?
- What does context-dependency indicate?
- Do children's responses indicate a difficulty in recognising how light behaves, or is the root problem one of lacking the concept of the conservation of light/matter? In other words with what conceptual tools are the children working and are we making appropriate demands in relation to these?

This paper was first presented at the Ph.D. Summer school for research in science education, some of the above questions were discussed and useful suggestions were made. In particular, I was directed towards the work of Wanda Kaminski in France. She has developed teaching activities, some of which may be appropriate in probing the children's responses further.

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The concept of energy and its teaching

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1. Background

The problem I have chosen to address in the PhD research I have embarked on since January 1993, is one of great importance to science education, namely the teaching of energy. Energy is considered to be one of the most fundamental concepts of the Natural Sciences, both because it is crucial to their application in Technology and even more because treated as an abstract conceptual framework it serves to interpret complex reality in a coherent way. Moreover, in recent years energy education is expected to deliver both the specialist knowledge and enough civic understanding to guide informed decisions and effect changes in policies concerning environmental and ecological issues.

Despite, however, its suggested importance for achieving scientific literacy, there is strong evidence world-wide that the concept of energy presents significant conceptual difficulties to pupils and teachers alike, difficulties which on many occasions result in a fundamentally incorrect understanding of the concept. This misunderstanding seems to arise in part from the way the word 'energy' is usually discussed in relation to the 'energy-crisis' as something (a fuel or a kind of fuel) which is in short supply and which is used or consumed for our benefit. Furthermore, in most school science courses today when energy is used to talk about processes of change it stands in for the cause of change -an approach which besides being erroneous suggests that energy gets used up. Thus, the concept of energy is made to cover both its main aspects, that is, being a conserved quantity which limits the possibilities of change, and 'fuel' (technically a source of free energy or negative entropy) which is destroyed, needs to be saved, and is a way of thinking about the direction of a possible change.

A way to resolve these difficulties in a teaching approach for energy which would build on children's ideas, following an evolving and not an unlearning process, and be relevant to their experience of life, is by addressing the fact that processes of physical and chemical change depend on the Second Law of Thermodynamics, that is, that the direction of change is that of decreasing order. In other words the suggestion/hypothesis I adopt (Ogborn, 1990) is that we can profit from the fact that children are already thinking about processes of change and prompt them to speak of the cause of change in a Second Law language where attention will be paid to differences; differences such as those between hot and cold, concentrated and dilute, pure and impure, squashed and spread out. The term 'differences' corresponds to the scientific concept of negative entropy -or free energy-, and the key idea is that differences drive change because differences tend to decrease, entropy tends to increase.

The great advantage of this approach is that it encapsulates the Second Law thinking without needing explicit reference to entropy or other Second Law ideas, and thus is capable of providing both a simple and intuitive starting point for talking about what makes things 'go' at the beginning of work at a secondary level, and a foundation for development of a Second Law account at a more advanced level.

Where does energy fit in this approach? Energy does not drive change, but sets the limits for the possibility of change. Thus, energy is introduced when we need to quantify change, when we need to compare the amounts of energy transferred from and to various kinds of systems. In this way, the more intuitive concept ('the something that is used up') will be introduced before the more difficult one ('the something that is conserved'), in an effort to make discussion in science classrooms about important matters like food, fuels, and life, sensible and intelligible.

2. A funded research project - a phd research is born

A funded research project undertaken by the Department of Science Education (1992-1994) is developing a set of classroom activities, resources, and INSET (in service training for teachers) materials about energy and processes of change based on the ideas discussed above. Since January I have been assisting with this effort.

One of the first difficulties the research project had to tackle was how to show that a wide range of phenomena, from a hot cup of tea cooling to chemical reactions and even to processes involving life, which look so different and behave so differently, are essentially very similar in the sense that one only needs a few thermodynamic principles to make sense of them. Although the story about differences is more easily accessible than the conventional Second Law story, it still requires pupils to reason about real world situations in abstract terms. A way that has been suggested to overcome this difficulty is by using pictorial representations to illustrate the idea of differences (e.g., of concentration of energy and matter) getting evened out in spontaneous changes or maintained in steady state systems. A set of pictures illustrating mixing, diffusing, heat flow, melting, boiling, and chemical change have already been prepared and tried out in schools. There needs to be thought however, about how to represent the differences in the arrangement of energy and in the arrangement of matter, as these also constitute causes of change. The emphasis is on pupils becoming familiar with the ideas behind the representations through materials used over the long term by relating them to real world prototypical situations, so that they in turn help them to think about less familiar real world situations. So, representations are not by themselves a goal of this teaching approach, but constitute a tool which may help pupils to abstract the story about differences from a variety of processes of change. At the highest level we would want the children to be able to abstract further from the different kinds of representations and reach a broader understanding -to see how the bits fit together and are used in an energy language.

At present we are investigating the way children make sense of and use such pictures by conducting a series of interviews. The structure of these interviews reflects the ideas about teaching expressed above. We interview children in groups of four, and the interview consists of three activities. In the first activity we give them some situations, and we ask them to think about what is changing in each one of them and then to put them into groups of similar kinds of changes, and explain their reasons for grouping. In the second activity, which we call 'the teaching activity', we introduce to them the representations and give them a chance to try out whether they have understood their conventions. Finally in the third activity we give them the same situations as in the first activity, and ask them to match the situations to some representations and to explain their reasons. If a situation is matched to a representation which is already matched to another situation, the interviewer asks for similarities and differences between the two situations. What we are investigating is whether the pictorial representations succeed in drawing children's attention to the essential features of the processes of change, and furthermore whether they help them see similarities between different processes based on these essential features. Given some encouraging evidence that children which are exposed to this novel teaching material actually develop a sensible way of talking about changes, my research next year will be to follow the integration of the above teaching material in the science curriculum of a secondary school and to monitor in a systematic way how children's thinking changes in the course of a year, in relation to the above objectives.

The target age groups of my research will be 11-13 year olds, i.e., pupils in their first or second year of secondary school. I expect to use a lot of the material developed in the project but also to develop new material appropriate to the research requirements. The analysis of my data, which will be of various kinds, both written and verbal, as a result of the application of different research methods (observation, written activities, interviews), will be qualitative with the aid of few case studies. There is however a long way to go and many questions to be asked on the way. Some very general questions could be:

- What features of children's reasoning should we focus on, and how are we to monitor the change?
- Can energy play the role of the 'overarching concept' to help students towards a unified interpretation of nature? In other words, is it realistic to say that energy ideas can be treated uniformly in the different school science disciplines?
- How do you deal with the issues of reversibility and irreversibility?
- How do you get around the problem of steady state systems, e.g., living organisms, where 'nothing is happening' -they appear to stay unchanging far from equilibrium- because 'something is happening' -they do it by continually consuming differences, that is, by destroying order?
- To what extent is energy useful in a qualitative account if there is no quantitative treatment?

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Educating primary teachers in science: the case of energy

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1. Introduction

Pre-service science teacher education is a complex task, especially when viewed from recent research in science education. On the one hand, it is well known that not only pupils, but also student teachers themselves do hold alternative conceptions about physics concepts and phenomena to teach, which may be at odds with the scientific reference knowledge. This makes it necessary to design teaching approaches, which provide them with opportunities to actively construct new concepts, closer to the scientific ones. On the other hand, student teachers have difficulties to adopt innovative instructional models. Therefore, development of teaching strategies which help them overcome traditional instructional models is needed.

In this context, we hypothesize that through a constructivist approach, student teachers might improve their knowledge of both science and constructivist teaching models. A pertinent question that arises in the design of such a constructivist approach for science teachers is the following : Which topic(s) could facilitate development of a balanced approach between content and methodology for educating primary teachers in science?

The search for a suitable physics topic led, for two reasons, initially to the selection of energy: it has a trans-phenomenological character and it is included in all physics curricula. The research plan has three main phases:

I. An analytical phase which includes:
   a. Analysis of the concept of energy as used in physics and study of the problems related to the selection of a suitable modelling and experimental field for primary science teachers education.
   b. Identification of similarities and differences between students' and student-teachers' reasoning with regard to the topic under investigation.
   c. Analysis of constructivist approaches to teaching science and educating science teachers.

II. A developmental phase which includes:
   a. The design of a course on energy which will be based on results from phase 1.
   b. A pilot trial of this course in selected small groups, in order to investigate in depth student teachers' reactions and to make necessary adaptations.

III. An experimental and evaluation phase which includes:
   a. Extendent field application of the course.
   b. Evaluation of results related to both students' learning of content and appropriation of teaching model(s).

This paper describes the first phase of the research.

2. The energy concept

The choice of energy to be used in teaching, led to the study of the particular way physics deals with the concept of energy, in order to make clear what possible transpositions and selection of features of the concept are to be taught. A comparative analysis of energy in three physics textbooks (Feynman 1966, Halliday-Resnick 1966, Yavorsky-Pinsky, 1975) was carried out. Guiding questions of the analysis were:

a. Is energy introduced in the same way? For example, using the same formula, definitions, physical phenomena?
b. Among the variety of its forms, are some dominating over others?
c. In what order are energy forms presented? How are they related?

In the meantime, we looked for critics on energy content in the literature. Specifically, we searched for problems that are related with the content of energy, such as inconsistencies, misconceptions, misleading terms. The answers to the previous questions underline basic features of the energy concept:

1. Energy is a physical concept that can be approached in many different ways.
   a. In some cases, energy is presented as an existing, objective reality or as an abstract nummerical quantity.
   b. In other cases, energy is introduced as a primary concept or as a derived one, for example through the concept of work.
   c. Although a large number of energy forms have been listed, three are dominant: kinetic, potential, internal. Also, work and heat appear frequently. These five concepts of energy are even approached in many different ways, in the fields of mechanics, thermodynamics and electricity. We found that:

- In each textbook the five dominant concepts are introduced in different order.
- Some of them are not presented at all in some topics, such as potential energy in thermodynamics. Others are introduced gradually, for example, internal energy and heat in Feynman's and Halliday-Resnick's textbooks. Others are dominant all through a textbook unit, such as in Yavorsky-Pinsky's where work is a keyword in electricity. Feynman, on the contrary, does not use work so often in his lectures concerning electricity.
- Energy concepts are related to a large number of other physical concepts, (length, velocity, force, voltage, charge, intensity, etc.) These concepts belong to different physical areas and some are more abstract than others, for example length and voltage.

2. A large number of concepts, terms and definitions are used with unclear meanings. M.K.Summers (1983), in his paper 'Teaching heat - an analysis of misconceptions', underlines a number of statements from well known textbooks, where the concepts of internal energy and heat are not clearly discriminated. Also J. Beynon (1990) in his paper 'Some myths surrounding energy', discusses energy as an abstract quantity and considers the effect of using inappropriate language in the teaching of energy. He wonders: 'How is the energy stored in the object and where is it stored? Where does the thing being stored come from? How did it get there? Is energy stored in fuel?'

In the context of constructivist education of student teachers many crucial questions emerge. We point at the following:

1. What are the general features in the nature of energy, that will be helpful for construction of the concept of energy for primary student teachers?
2. What energy concepts (potential, kinetic, work, heat, etc.) and energy terms (transforming, storage, etc.) have to be included in the teaching content?

3. Learning difficulties

The learning difficulties of pupils and student teachers are also related to their intuitive ideas about the concept of energy. Most of the research done focused on pupils in secondary education. During tasks performed, in order to investigate students' alternative frameworks about energy, it was found that:

1. The majority of pupils do not use the word energy in their explanations.
2. A very small number of pupils use the energy conservation principle in their answers. It is difficult for pupils to understand that something that is dissipated, can be conserved at the same time.
3. In the answers of pupils who use the word energy, seven frameworks can be recognized: anthropocentric, depository, ingredient, activity, product, functional, flow-transfer. (Watts, 1983). When replying to tasks all pupils use more than one alternative framework; the anthropocentric, depository and product frameworks are used frequently. (Trumber, 1990).

Research outlines the alternative frameworks about energy and deals, from a didactical point of view, furthermore with specific topics concerning energy. A study (Koliopoulos, Tiberghien, Psillos, 1989) that aims at determining a suitable application field for the teaching of the energy, indicates that electrical and thermal phenomena may be privileged for introducing energy. Furthermore, a deeper analysis shows that pupils' interpretations of phenomena are frequently based on a simple casual knowledge structure. Elements of that structure are active agents and passive patients. Effected changes on the patient are causally related to the agent by an action such as the transfer of a property or an activity.

An investigation (Nicholls and Ogborn 1993) into basic dimensions of thinking which may underlie children's conceptions of energy, shows that all energy-related entities (people, animals, devices, food, fuel, physical objects) and phenomena are classified by students according to two different dimensions, which may be used simultaneously:

a. Users/consumers of energy and sources of energy;
b. Entities which are able to use their own energy in order to act and entities which are not able to use it, but are being used in order to act.

The above classification is predominant to elementary school pupils, while at the secondary level, pupils begin considering energy as something that can be exchanged between objects, in a way that permits them to be both sources and users.

Finally, research about student-teachers' alternative frameworks concerning energy (Kruger, 1990) points out that student-teachers and pupils have common anthropocentric and depository frameworks. They also deal with energy as if it wasn't a conservable entity. Nevertheless, unlike children, student-teachers recognise a lack of rigour in their understanding about energy.

4. Teachers' science knowledge

This last remark makes the improvement of teachers' science knowledge necessary. In addition, the following problems have been reported in the literature:

1. Although teachers acknowledge the advantages of an innovatory educational approach, they genarally do not feel able to engage in it due to their poor scientific education (Bonera, Borghi e.a. 1983).
2. They are dissatisfied with how they have been taught at school, but they need structured and in-depth support in order to move away from the traditional patterns of teaching which dominated their own 12 years as pupils (Thomaz and Gilbert, 1989).
3. Early in their careers, they are concerned with self interests, while later their concerns shift to focus more on their pupils (Symington, 1985).
4. Many of the reported problems on teacher education are related to teachers' views on the nature of science and the learning process (Licht, e.a. 1991) We must underline that an individual teacher's attitude to physics and to physics teaching governs pupil attainment and inclination to further study of the subject (Thomaz and Gilbert, 1989).

These facts lead to the conclusion that student-teachers' science education has to confront both teachers' ideas about phenomena and their conceptions about the teaching process. The analysis of different developmental constructivist projects revealed two main trends. The projects focus on the acquisition of scientific content or on the appropriation of constructivist teaching strategies. In the first approach, all projects insist that at a certain stage of their education, student teachers should become aware that their existing conceptions about physical concepts/phenomena may differ from the scientific ones. In the second, they may have to realise how strongly they are influenced by traditional models of teaching and learning. However, in both approaches, specific teaching strategies used for this self-awareness stage vary significantly. The balance between the above two trends seems to be one of the most important research issues in teacher education.

Research during this first year of the study brings forward a number of questions. On the one hand, primary student teacher education has a characteristic feature. The student teacher is taught in order to be able to teach his/her pupils in the future. Teacher education is essentially a transformation process of an individual from learner to teacher. This is a difficult and complicated process as student teachers need to learn new teaching strategies as well as to improve their scientific knowledge. Student teachers' ability to design constructivist innovative activities seems to depend strongly on their physics knowledge. How much emphasis should be laid on

the improvement of student teachers' knowledge of science, as compared to emphasis given to the acquisition of constructivist teaching models?
On the other hand, the analysis of energy content and students' alternative frameworks points out that:

a. The nature of the energy concept makes it approachable in many different ways.
b. Pupils have their alternative frameworks and their underlying structures of thinking about energy. Student teachers' conceptions of energy have similarities with those of pupils, however there may also be differences in their ways of thinking.

In the context of a constructivist training of student teachers, crucial questions emerge. We point at the following:
Shall we use the same energy content in teaching pupils and students-teachers? If not, what criteria will lead us to consider appropriate content for each group?
What could the structure and special features of energy content be?

Currently, our work focuses on the selection of appropriate activities which will be incorporated into a constructivist teaching sequence for pre-service teachers on the introduction of the concept of energy.

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The role of available information in learning about energy through the spontaneous use of analogy

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1. Introduction

This research is done in the context of teaching of energy for the 'literary section' of the French Lycée, at the level of the 11th grade (17 years old). These students do not specialize in science subjects; they receive one hour per week of physics teaching. Several classes were involved.

2. Research objectives

Background study
A previous study (Bissuel, 1991) focussed on students' spontaneous use of analogies. In teaching, a model about properties of energy had been introduced and we studied how students linked the material situation to the model, in constructing an energy chain. This study has shown that students directly map elements of the model onto elements of the material situation, to make sense of the latter in terms of energy. They often modify the relations of the model. This study was part of a larger research project, concerning students' modelling activities of material situations.

Broadening of the research
These previous results showed a need to broaden the study to the analysis of relations between the cognitive process 'analogy' and the task performance of students, taking the teaching situation into account. This applies in particular to the phenomenon students' modification of model-relations. Our general aim is to study the relation between students' processing of the available information and their knowledge evolution, in respect to the analogical process.

3. Theoretical framework

From a general point of view

In order to permit the determination of the evolution of students' knowledge about energy, we chose a theoretical didactical framework: 'situations theory' (Brousseau, 1986), with its concepts of 'devolution', 'didactical contract', 'breach of the didactical contract, and 'environment'. The latter is considered here as an informational environment. We distinguish two levels of devolution:

- The teacher devolves to the student the task performance and the learning of properties of energy.
- The teacher devolves to the student the choice and the treatment of information in the informational environment.

The devolution can be controlled with a ' breach of contract or not'.

From a particular point of view

- We elaborate theoretical frameworks of analogy (Rumelhart, 1981; Gentner, 1983; Brown, Vosniadou & Ortony, 1989). This is incorporated in our study of goals and sub-goals pursued by students in performing a task, in order to link the process of analogy to their task-performance.
- In order to evaluate students' learning of the properties of energy, we will use Vergnaud's (1985) theoretical didactical framework, with concepts like 'conceptual field' and 'operating invariants'.

4. Informational environment

The informational environment was constructed as a tool to teach the concept of energy, and as a research tool to study the role of available information, in order to relate the level of theory-model and objects-events. Two categories of informational sources were constructed.

'Hard core' information

This information, consisting of descriptions of the task, experiment, and energy model, should allow students to learn the properties of energy by constructing an energy chain. Figure 1 shows an example of an energy chain.

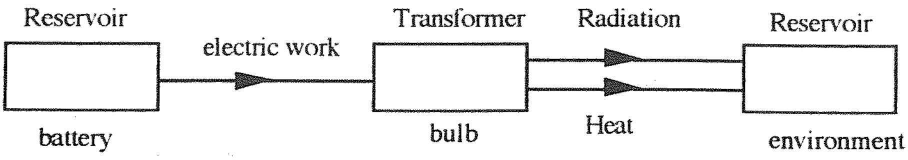


figure 1: An energy chain

'Help' information

This information respects the two levels: theory-model and objects-events, and is available during problem-solving. It may consist of suggestions presented with drawings and/or with text.

5. Method

Data of students, performing the task in groups of two, have been collected in two classes The task consisted of constructing energy chains. While solving problems, the two students had to agree on one common answer to be given to the teacher. Two groups of two students were tape-recorded during two sessions. So, 4 dialogues have been transcribed and analysed: one group in every class for two sessions of one hour.

6. Analysis of the dialogues

Procedure

In order to analyse the phenomenon students' modification of relations or properties in the model and to analyse the relation between the cognitive process of analogy and the task-performance:

- We are interested in the planning of the cognitive process that gives meaning to objects-events / theory-model. We have divided the dialogues into parts corresponding to goals and sub-goals (Table 1). For example:
  General goal : 'Draw the chain that gives the meaning of this task'
  Sub-goal 1 : 'Map the objects of the experiment and the 'objects' of the model'
  Sub-goal 5 : 'Map wires and transfer'.
- We note the parts of the dialogue where an analogy (2) is used. We note what information sources are connected (3) and what the role the analogy (7) plays in giving meaning to the task.

- We note whether there is a breach of contract or not (8).
  There is a breach of contract when students give a bad interpretation of a practical rule of chain construction, or when after several attempts to relate objects-events and theory-model, they renounce or give hasardous answers or when they call the teacher.

Table 1: **Number of occurrence of goals and sub-goals in students'dialogue**

Goal (1):

Students and content of information (2)	Connection between (3)	Start by (4)	Sub-goal pursued (5)	Analogy (6)	Role (7)	Contract (8)

- In order to put (fig. 2) the cognitive analogy process and the breach of contract in time together, we draw 3 axes: 1) information sources for analogy or for a breach of contract connected in time; 2) the goals that are pursued by the student in time, and 3) the role of analogy.

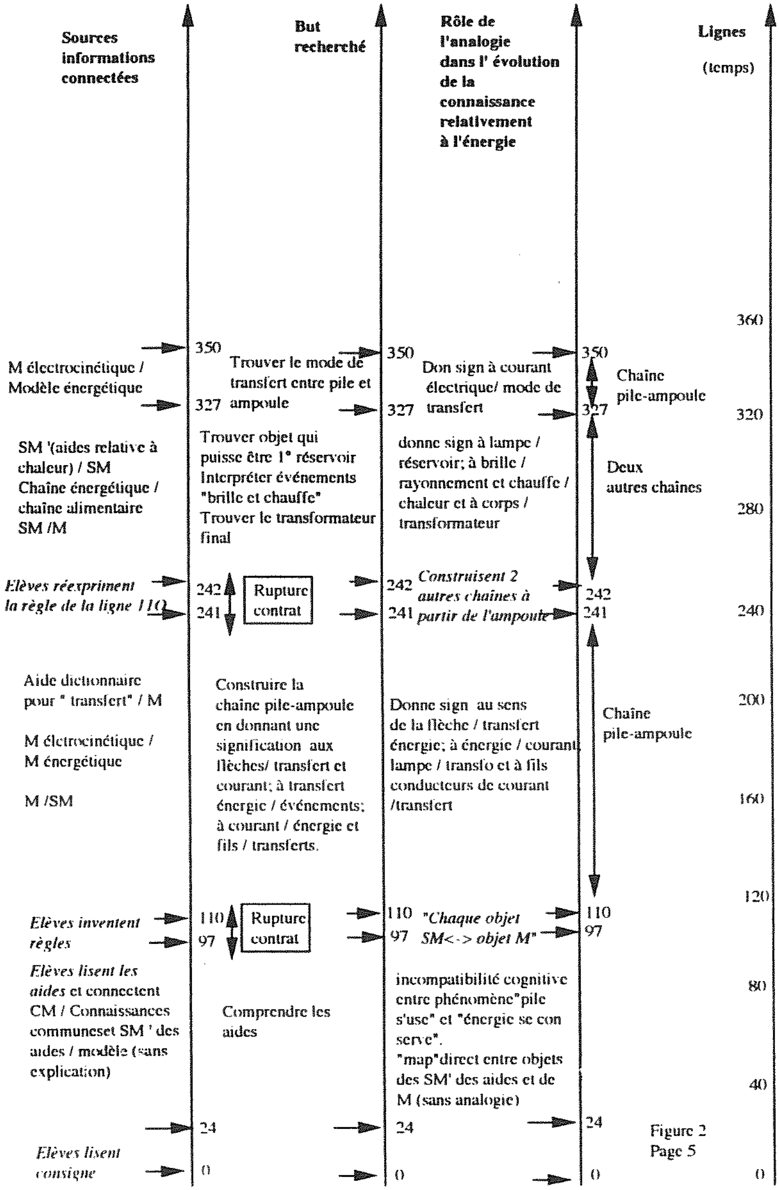
Some results

- Using analogies, students give meaning to objects in the experiment / 'objects' in the model, when they find relations or properties in their previous knowledge about the experiment that they can map on relations or properties of the model. Sometimes, when they don't map directly, they look for 'help' information, and when they fail, they renounce or give a hasardous answer, or call the teacher, then there is a breach of contract.
- Often, the relation that permits to give meaning, stays as a property of the 'object' of the model and modifies the model..
  For example: reservoir stores energy <-M-> battery produces energy => battery <-> reservoir. This match gives meaning to the battery/ reservoir in the model. A subsequent question: a motor transforms energy but it also produces energy; is it a transformer or a reservoir?
- Does the use of analogy permit to access the properties of energy?
  For example: students have to find the first reservoir of an energy chain in the experimental case in which a mass falls down and pulls a motor linked up to a lamp. 'The mass stores energy when it falls; it is like an object that you throw, a mass that falls is a reservoir'. In a later experiment, with a battery linked to a motor and a mass that goes up, they don't see after several tries that a rising mass is a final reservoir'. The analogy between events permits the students to understand 'reservoir of kinetic energy', but not 'reservoir of potential energy', which is more important for the construction of an energy chain.

Etude en fonction du temps du rôle du processus cognitif "analogie"et des ruptures de contrat au cours de l'exécution de la tâche

Fille-Garçon Pile-ampoule

SM: Situation matérielle pile-ampoule; M: Modèle énergétique; M: Modèle énergétique;
CM: complément modèle énergétique; SM': autre situation matérielle



- Students can map events and concepts of the model directly.
  'The bulb shines, mode of transfer is radiation'. 'When we make/do an effort/work, heat goes out', and 'when a mass goes up (tractor-drawn by a motor), the wires are hot. Look at that!'; 'the mode of transfer is heat'. An analogy is used between 'we make an effort' and 'the motor pulls the mass' (motor makes an effort) and transfer of 'heat' directly maps to 'hot'.

We are currently continuing our data analysis. Our next step will be to confirm the results.

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In search of a 'didactical structure' for the introduction of particles

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1. Introduction

A few years ago, when I was still studying for my Mastersdegree in physics, I did some research at the Centre for Science and Mathematics Education in Utrecht. It concerned the usual introduction of the particulate nature of matter in physics lessons at secondary school level. I studied literature on pupils' ideas, analyzed teaching materials and investigated pupils' ideas by means of a questionnaire and interviews. One result was that Dutch pupils expressed the same kinds of "alternative particle explanations" that had been found in other countries (e.g. Brook, Briggs & Driver, 1984).

As the nature of matter is usually seen as being continuous in our everyday life it seems natural for pupils to see particles as "tiny bits of substance", that is as final links in a process of division (Pfundt, 1981). At school they learn to call these particles (or tiny bits of substance) molecules. They also learn that these molecules obey certain rules: they move around, there is empty space between them and they exert attracting forces upon each other. But to them these molecules will probably still be nothing else but tiny pieces of substance.

If that is the case then it is not so surprising that pupils attribute macroscopic properties to molecules. It becomes even less surprising, given that in textbooks it remains very much unclear why pupils should not do so. They learn for instance that the dilatation of a solid during a rise in temperature is to be explained by an increase in the distances between molecules, and not by a dilatation of the molecules themselves. But it remains unclear why the latter explanation is not a proper one, while the first one is. Therefore, in a next situation, pupils will probably again tend to attribute some new macroscopic property to molecules.

Apart from the above criticism towards current Dutch textbooks, I also think that this topic is introduced much too soon. Often pupils are supposed to explain phenomena in terms of particles when they have hardly learnt anything about these phenomena on a macroscopic level. Furthermore, usually no clear reasons are given that might motivate pupils to study the topic. Why do pupils need to learn the particulate theory? Is it because scientists use it? As a pupil why should I care? Is it because it explains so many different phenomena? As a pupil I have no need for that, have I?

Also the particle models that are presented are often not consistent, the explanations given are not always sound explanations, hardly any connections between particles and macroscopic properties are made explicit, and although some textbooks use words like "model" or "representation", the particle theory is mainly presented as established facts.

Finally, many physics textbooks seem to suppose that pupils are not capable of thinking things through themselves. Usually, after the theory is presented, some phenomena are described and pupils are often told what to "see" in them. Even if they are asked to develop a particle theory on their own, then after this activity the scientific model is given and pupils are not encouraged to explore the differences between this model and their own thoughts.

2. My PhD-study

The topic

The results described above made clear that a lot could be done to improve current teaching methods concerning the particulate nature of matter. That is why, this time as a PhD student, I am currently involved in a research project that aims at the development of a didactical structure for the introduction of particle models at secondary school level. The development of this structure will be based on a constructivist view on teaching and learning, which maintains that all learning involves the interpretation of new phenomena and ideas in terms of the learner's existing knowledge. To me this implies that pupils need to be actively involved in experiments and other activities and that they should have plenty of opportunities to discuss their thoughts with other pupils and the teacher, while working within the didactical structure.

A didactical structure is not just a textbook, but a theoretical account of the expected course of the pupils' learning process. That is, a detailed but yet flexible outline of worthwhile and preferably problem-posing activities that eventually lead the pupils towards a set of goals concerning the topic.

Planning

The research activities are spread out over 5 years. In the first year a framework for the didactical structure will be set up. To this end I will analyze relevant literature and alternative teaching materials. I will also videotape and analyze an alternative teaching sequence in one class of 15 to 16-year-old pupils. This will be recorded on videotape. During the second year I hope to give such a concrete form to the didactical structure that it can be tried out and used as an instrument to investigate the process of interaction in the classroom. In the third year the didactical structure will be revised and the process of interaction will be investigated again in the next try-out. The last two years of the project will be spent on evaluating the results and writing a thesis.

In the end I hope to find out in what way this process of interaction can be made worthwhile to pupils and how it needs to be managed, in order for pupils and teacher to really understand each other and to be able to build together a common body of shared knowledge.

3. Further elaboration of the topic

I have already begun to set up a framework within which the didactical structure will be further developed. It consists of a starting point, a set of goals and the process leading from the starting point towards the goals. Each part of the framework will now be explained a little further.

The starting point

When we start teaching about the (particulate) nature of matter, we need to consider the starting point of our pupils and the teacher. Ideally, the pupils should in every respect be ready for learning about this topic. What kinds of capacities and knowledge are needed for that and how can they be developed? That is what I eventually aim to define, and what would constitute the ideal starting point.

First of all, both teacher and pupils need to have a positive attitude towards an activity based way of teaching and learning. Besides this, it might for instance be necessary that pupils are able to express their thoughts and to really listen to what other pupils or the teacher are trying to explain. I suppose that at least they would have to feel safe in their classroom environment, which means that they should not be afraid to ask questions or to make mistakes. And maybe it is helpful that they have some experience in doing experiments and writing reports, etc. Furthermore the teacher needs to be able to really listen to the pupils and encourage them to ask questions. He or she also needs to create an environment in which pupils can develop the kinds of capacities mentioned.

Apart from these (and without doubt many more) capacities, we can also ask ourselves what knowledge pupils should have gathered before they start with this new topic. If we want them to be able to make sense of what they learn about particle models, it might be necessary that they have learnt quite a lot about properties of matter, macroscopic phenomena and relations between macroscopic properties. Which properties, phenomena and relations are relevant and why? And what other knowledge is necessary? The teacher also needs some specific knowledge. The ability to understand the problems that pupils are dealing with, while they are trying to make sense of a particle theory, might be improved by some knowledge of literature on pupils' ideas and knowledge of the history of science. To prevent the teacher from presenting the school science view as established facts, it could be helpful if he or she has read some philosophy of science. And there are probably more domains of knowledge that the teacher, in this respect, could profit from.

The process

The main part of the didactical structure is the process of teaching and learning, leading pupils from the starting point towards the goals. I will try to predict and describe the process of learning and teaching the particulate nature of matter in a so called scenario. Apart from a description of the activities themselves, the scenario will also contain an account of why I think these activities will be worthwhile to pupils, how they will interpret them, in what way they will carry them out, talk about them and reflect on what they have done. Briefly an account of which intermediate goals can be reached in what way on the basis of which motives.

An account of why participating in a certain activity will be worthwhile to pupils, consists in a description of how what they have done before, could now serve as their motive. Given what they have done before, it should in some sense be challenging, not just to us but especially to them, to work on the next activity. For instance, when pupils raise questions during or after a certain activity, their desire to find answers to these questions may serve as their motive to participate in the next activity. That is why it is also necessary to try to predict what the pupils will say and do during a given activity, because it is from what they say and do that their motives for the next activity will have to emerge.

Explicit attention to pupils' motives is one aspect of what makes the scenario different from many other teaching sequences, in which activities are justified in the light of the teacher's goals. If one does not know these goals (and pupils usually do not), it remains unclear why the activity has to be done.

The goals

The goals I would like pupils to approach are the following.

1. *Being able to describe a lot of phenomena in terms of macroscopic properties of matter*

This goal is strongly related to the starting point, so parts of it could be done before explicit teaching and learning about matter starts. Still it needs to be stressed for I think it is a very important first step on our way to dealing with the particulate nature of matter.

In the process of teaching and learning, this first goal (or parts of it) could be seen as an intermediate goal. This should then function as a motive for next activities leading towards the other goals. In other words, when pupils have reached the first goal I would like them not only to be able to give macroscopic descriptions but also to feel a certain need for more profound explanations, or for explanations of a whole array of different phenomena. The question is whether this is possible. Is it possible that their reaching the first goal at the same time generates something that could serve as a motive for their learning about particle models? Is it possible to create some kind of need for particle models? Are there any activities to be found which are not only introducing to particle explanations but also worthwhile, challenging or problem-posing to pupils?

2. *Being able to explain a lot of phenomena in terms of particle models*

I divided this goal into two interrelated subgoals: "understanding how particle models function" and "being able to choose between different particle models". The first subgoal concerns things like:

- being able to give a sound explanation based on assumptions about particles given by the teacher, or
- being able to formulate assumptions that make it possible to explain a lot of phenomena in terms of particles, or
- being able to see the bounds of a certain particle model, etc.

The other subgoal concerns things like:

- knowledge of the origin and development of particle models in the history of science, or
- being able to understand why certain particle models survived while other models did not, or
- being able to explain why you prefer one particle model to another, etc.

I am aware of the fact that these goals cannot be fully reached by every pupil. That is why they serve as a guideline in developing the didactical structure.

But instead of asking whether these goals can be reached or not, I think it is more important to establish what these goals really mean. What kinds of particle models are to be introduced or developed in the process? What sorts of explanations are pupils supposed to learn to understand and give themselves? I suggest that in the process of learning to understand and give particle explanations, there should be an emphasis on the assumptions of the model and on the relations between the particles and the macroscopic properties. Otherwise the models might easily be interpreted as absolute facts that will never change. I would like pupils to understand that the assumptions of a model (that they themselves have made) can be changed or replaced when predicted events do not take place.

But what kinds of models, assumptions and explanations do we find acceptable? Are pupils allowed to attribute all kinds of properties to the particles? And if not, which properties are they allowed to attribute and why only these?

3. Having a balanced opinion about the existence of particles like molecules and atoms

This goal I might not yet have reached myself. As a pupil, and even during my first few years at university, I was convinced of the existence of particles like molecules and atoms. The particle theory was presented as a set of established facts that nobody could deny. Later on, when I read some philosophy of science I began to doubt. What actually is the relation between theory and reality? Are there not many ways to look at reality? And when do we say something really exists and what do we mean by that?

Why are so many scientists convinced of the existence of such particles while some philosophers of science are not? What characterizes their discussions? Can we take part in such discussions? On what grounds do we say that particles do or do not exist? Can we develop a balanced opinion ourselves? And what do we want pupils to learn from this?

The main point I am trying to make is that I think it is wrong to present particle theories as facts that are established once and for all. Of course nowadays science is built on these theories and therefore particles are very real. But I think pupils should know more about the history of science, the development of different models and the techniques for detecting particles. This might show them why these particles have become so real to scientists. In this way I hope they will understand that their own questions about the validity of these theories are good questions and that we have only limited answers.

4. Interpretation of the discussion during my presentation

1. Are there any activities to be found which are not only introducing to particle explanations but also worthwhile, challenging or problem-posing to pupils?

When looking back at the discussion I note two basic points on which a choice will have to be made. The first point concerns a choice between on the one hand beginning with one phenomenon, for which a more profound explanation will be devised, and on the other hand starting from a whole array of different phenomena, for which a theory will be devised that explains them all. The advantage of taking only one phenomenon at first might be that one could perhaps start with a fairly simple model. However, beginning with several phenomena seems to be more realistic in that it is, of course, the point of a model to explain more than just one single phenomenon.

Another question is whether it is possible to create a need for particle models at all. If we cannot make normal events problematic to pupils then, as Jon Ogborn argued, we need to make the pupils interested in our problems. He thought this could perhaps be done by looking at materials and their properties (e.g. stretching). Some members of the group especially liked the idea of looking at structures through a microscope and then moving on to a deeper level.

The second basic point concerns a choice between on the one hand asking pupils to invent a theory themselves and, on the other, offering such a theory at a suitable moment. Philip Scott mentioned that in the CLIS-Project it was found that asking pupils to create their own theory was very motivating for them. In that way, he argued, it is no longer necessary to first create a need for particle models.

2. What kinds of models, assumptions and explanations do we find acceptable and for which pupils (age, ability, etc.)?

Are pupils allowed to attribute all kinds of properties to the particles? And if not, which properties are they allowed to attribute and why only these? According to Robin Millar it is not possible to make this clear on logical grounds. Pupils just have to learn about this by listening to the teacher. He compared this process to the way in which young children learn a language, not by learning rules but by listening to their parents and other adults and by hearing the things they say themselves being confirmed or not. I agree with him when he quotes Lemke (1990): "learning science is learning to talk science". But I also think that learning science is more than learning your first language. As a pupil, I do not only need to learn what I can and cannot say, without knowing why.

Still, as a teacher, you need to define what models and assumptions you find acceptable. In this respect Adri Verdonk emphasized the relation between the concept of "substance" and the concept of "atoms" or "molecules". Besides asking what properties should be attributed to particles, we also have to ask ourselves what properties should be attributed to substances. By investigating these and the relations between them we might learn a lot about acceptable models and assumptions. This however, we did not discuss in further detail.

Apart from models and assumptions we also talked about explanations. Two interesting questions were raised. First, Laurence Viennot asked us about the extent to which we really explain something with a particle model. Sometimes it is clear, but also sometimes it is ambiguous. For instance when someone says "molecules need more room to move faster".

The other question raised was whether explanations in terms of particle models are explanations of a peculiar, perhaps even very strange kind. If so, we should talk about this explicitly when introducing such explanations. But perhaps they are not so strange after all. As Robin Millar argued, pupils already have ideas about what an acceptable explanation should consist in and explanations in terms of what little bits do seems like a perfectly acceptable social way to account for the behavior of a mechanism.

3. On what grounds do we say that particles do or do not exist?

Instead of discussing this question we talked about the extent to which we want pupils to think about this. Some members of the group thought that you need a very mature 14-year-old to be able to deal with the problems of constructing a model and at the same time to reflect on the status of that model. This might very well be the case, but even if pupils do not raise these questions themselves, I would still would like them to understand that a molecule is not simply a piece of substance too small to be seen through a microscope.

That is why I am reserved, like Eduardo Mortimer, about the idea to start teaching the particulate nature of matter by looking through a microscope and then moving on to a deeper level. I agree with de Vos (1990) when he says that the ability to "see" molecules in pictures produced by e.g. a electron microscope should not be the start but rather a result of a long and difficult learning process. Indeed, the development of such sophisticated and powerful apparatus was based on the assumption that atoms and molecules exist and on the constructed models concerning their properties, not the other way round.

4. Comments on the design of the scenario

Some people expressed their doubts about the necessity of a logical sequence of activities and the possibility of predicting pupils actions and statements. Looking back, I think that perhaps some of these hesitations were based on a language problem, in particular the use of the word logical. I do not expect every pupil to follow the outline step by step all the time, exactly in the way it was predicted. I am only trying to describe a sequence of activities that pupils will find the most obvious. In this way I think there will be a bigger chance that the actual interaction process will be very similar. The more the actual interaction process corresponds to the planned one, the more we can say about children's learning.

So obtaining a scenario is not the main purpose of my research project. This scenario is an instrument used to investigate the interaction process in the classroom. From these observations I hope to get more information about children's learning and about improving the process itself. In the end, as I said before, I hope to develop a didactical structure that describes in what way this process of interaction can be made worthwhile to pupils and how it needs to be managed.

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The evolution of students' explanations for physical state of matter as a change in their conceptual profile

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1. Description of the study

The aim of my work is to describe the evolution of students' atomistic explanations for physical states of matter, by comparing their performance before and after teaching and by analysing the classroom discourse during the teaching process. In order to achieve this objective I analyse pre- and post-test data and a video record of 12 lessons in a Brazilian year eight classroom (14-15 years old students).

To analyse this empirical material I develop a new model to analyse conceptual evolution in the classroom, based on a notion of a conceptual profile. This model differs from conceptual change models in suggesting that it is possible to use different ways of thinking in different domains. It also suggests that, even in scientific domains, there are epistemological and ontological differences between successive theories. We can see this when we analyse the development of important ideas in science, such as the development of the theory of matter. The new model also differs from some of the constructivist models of learning by showing that the process of construction of meaning does not always happen through an accommodation of previous conceptual frameworks in the face of new events or objects, but may sometimes happen independently of previous conceptions.

The teaching process was planned according to this notion of conceptual profile and tried to build an atomistic explanation for the physical states of matter moving from the students' extrinsic ideas, based mainly on external features of the materials, to an intrinsic one, based on a constructed, atomistic model. In this process there was no expectation that students should abandon their initial conceptions or that their ideas should be subsumed by the new atomistic explanation. The only expectation was to construct a new idea with some explanatory power, that could explain but not necessarily replace the common-sense notions. This is a consequence of using the notion of conceptual evolution in classroom as a change in the individuals' conceptual profile.

Atomism was chosen because it is a central idea in Chemistry, has a rich history of successive models increasingly suitable for experiments, and because it is also possible to discern a profile of alternative atomistic conceptions among individuals from a great number of works in the literature. Atomism is, therefore, a concept with a large and clear conceptual profile. Moreover, atomism is a model and, in that sense, a construct with no direct link with observations. The history of atomism in the nineteenth century shows that there was no definite evidence of the existence of atoms and that only someone who had taken the atomistic route could see atoms anywhere. In this respect, anomalies, conflicts and critical experiments seem to be ineffectual in keeping alternative ideas about matter in check. On the contrary, these alternative ideas seem to be coherent, plausible and fruitful, possessing high status for the students. However, these ideas present some epistemological and ontological obstacles to the development of scientific atomism, even at an elementary level. It is possible to identify these obstacles in the literature and plan the teaching taking them into account.

The other concept, physical states of matter, has a number of different features. It has strong roots in empirical experiments and even in the empirical dealings of everyday life. There are several studies in the literature showing that children are able at an early age to conceptualise solids and liquids in some way and to use these concepts to classify materials. Moreover, these primitive ideas of liquid and solid, like 'solid is rigid and hard', 'we can pour liquids, they wet and have water', are very useful in dealing with liquids and solids in everyday situations. The construction of a new, scientific idea, must explain the old one but not suppress or lower its status. If this happened, the students would have a number of problems in their everyday life, spilling liquids and colliding with solid objects. In that case, the teaching process has to show the boundaries of the primitive concept, through situations where they do not function, for example with regard to colloidal suspensions and liquid crystals.

2. The conceptual profile

The first zone

To analyse the results of the pre- ans post-test, as well as the classroom talk, I had to develop the categories that constitute the different zone of the conceptual profile of physical states of matter and of the atom. An important feature of the idea of 'conceptual profile' is that its 'pre-scientific' divisions are not constrained by philosophical schools of thoughts, as in the Bachelard's 'epistemological profile' (Bachelard, 1962), but by the epistemological and ontological commitments of individuals. As these individual characteristics are strongly influenced by culture, we may try to define a conceptual profile as a 'superindividual system of forms of thought' (Marton, 1981) that can be assigned to any individual within the same culture. Despite the differences between individual profiles, the categories by which each conceptual profile is drawn are the same. The conceptual profile is, therefore, context-dependent, since it is strongly-rooted in the individual's distinct background, and content-dependent, since it refers to a particular concept. But at the same time its categories are context-independent, as within a culture we have the same categories by which the zones of the profile are determined. In our western, industrial civilisation, the scientific divisions of the profile are clearly defined by the history of scientific ideas, as part of the Popperian 'third world' (Popper, 1972). The pre-scientific zones for many concepts are also clearly defined as a consequence of the last two decades of intensive research on students' alternative conceptions, that have identified the same sort of conceptions related to the same scientific concept in different parts of the world.

The first sector of the atomic profile is a realistic one, and it is characterised by the absence of any discontinuous notion of matter. This area is characterised by a negation of atomism and its main obstacle is a negation as well, the negation of the possibility of the existence of a vacuum. A student that only has this notion of matter represents it as continuous, without any reference to particles. Related to that concept of matter, there is a realistic notion of the physical states of matter closely linked with external appearances and sensible features of materials. Our pupils showed the same variety of realistic views that appear in the literature: solids are hard, thick; it is possible to touch and to hold solids; liquids are soft; it is not possible to hold liquids, they drain off; liquids are wet, they contain water; gases are invisible; it is not possible to touch or to feel a gas; gases spread in the atmosphere (see, for a comparison, Stavy and Stachel, 1985; Stavy, 1988).

The second zone

The second zone of the profile I call 'substancialist atomism'. Substancialism is a relevant feature because it leads to the conclusion that despite using particles in their representations, the students think of such particles as matter grains that can dilate, contract, change state and so forth. Students, thus, made an analogy between the behaviour of the drawn particles and that of the substances. They are not referring to the atom, as a scientific concept, but to grains of matter that show macroscopic properties. This analogy between the macroscopic and the microscopic worlds is the main epistemological obstacle for students whose concepts can be classified in this region.

Nevertheless, the fact that they use particles in their representations of matter is no guarantee that they believe in the existence of the vacuum between them. This is particularly important in the sense that someone in this area does not necessarily overcome the obstacle of the previous one.

There is no concept of the physical states of matter that corresponds to this substancialist atomism. The second area of the profile of such a concept is related to empirical properties that allow one to define solids, liquids and gases in a more precise way. This concept is usually taught in schools, in the early grades, and uses two empirical properties to classify materials: the shape and the volume. According to such concepts, solids have definite shape and constant volume; liquids also have constant volume, but their shape is variable; and gases have both shape and volume variable.

The third zone

The concept of the atom has no corresponding empirical area and the difficulties of accepting it in the 19th century were related to the absence of empirical evidence. Several important scientists in the 19th century were sceptics regarding its validity and some of them were in strong opposition to it. The third area of the atom's profile corresponds to a classic notion of the atom as the basic unit of matter, which conserves itself during chemical transformations. The atom is a material particle and its behaviour is governed by mechanical laws, like any other body. The substances are made up of molecules that result from the combination of atoms. Atoms of the same type have the same atomic weight.

In my study I am concerned with this third area of the atom's profile, as I am interested in finding ways of teaching the theory of matter at an elementary level. To teach this concept we have to identify its categories and use these categories to expand this section of the profile, by creating a 'fine structure' of the conceptual spectrum. One important category to be added to discontinuity and absence of substancialism is the conservation of mass in the transformation of matter. The lack of conservation seems to be easier to overcome than the idea that 'nature abhors a vacuum' and 'substancialist atomism'. I think there would be an epistemological obstacle to the construction of the concept of the atom if students did not use reasoning of conservation in any context. However, such is not the case. Students in the age 14-15 use the reasoning of conservation in several ways. The question is only concerned with the transfer of this reasoning to a new situation. The three categories (continuity/discontinuity; substancialism/non-substancialism; absence/presence of conservation of mass) were sufficient for an analysis of the atomistic ideas showed by students before teaching. As in many studies in the literature, our students did not use the other categories that characterise classical atomism: motion-energy; interaction-arrangement.

The third area of the profile of the physical states of matter is supported by a generalisation that is not an external characteristic of materials but has to be constructed as an explanatory model. In such a definition there are mutual aspects among the solid, liquid and gaseous substances, that is, they are made of particles. What makes solid substances different from the liquid and gaseous ones is no longer the external variation - an extrinsic and sensible feature - but an intrinsic one, belonging to a broader conceptual system that allows us to identify similarities between materials that seem to be so diverse. This transition from external features, linked to strong sensible aspects, to internal features, linked only to imaginary models, is a great epistemological obstacle to be overcome when teaching.

3. Use of the profile

These categories of the conceptual profile of atom and of physical state of matter were used to analyse the students' answers to the pre-test. The test, based on previous studies available in the literature, were constituted of four phenomena involving gases (compression, dilatation by heating, vacuum and diffusion), and two other involving liquids and solids (the dilation of the alcohol column in a thermometer and of the melting and boiling of naphthalene). In each phenomenon the students were asked to represent, with models, the material before and after the transformation. There also were questions about the mass and the density of each system before and after the transformation.

The post-test should be different from the pre-test since it had to evaluate if the students had constructed an atomistic model of matter, which involved some ideas not available previously, like the intrinsic movement of the particles, the interaction among them and the level of organisation giving by different levels of interaction. Beyond these categories, we aimed to verify the stability of the new idea, or in other words, whether the student achieves or not consciousness of his/her own conceptual profile. For this reason we introduced in the post-test questions: a) to verify whether the student generalised or not the new concepts to a new phenomenon (a question about the dilation, by heating, of a solid material (iron); and another about the dissolution of naphthalene in carbon tetrachloride, in which student were asked to explain why the naphthalene dissolves in the carbon tetrachloride and does not dissolve in water). b) to verify if the students recognised a potential disturber phenomenon, and, if so, whether they compensated or not

Table 1 Conceptual Evolution on theory of matter in a classroom age 14

<table>
<tr><th colspan="4">results of pre-test</th><th colspan="3">results of post-test</th></tr>
<tr><th>group 1</th><th>group 2</th><th>group 3</th><th>group 4</th><th>group I</th><th>group II</th><th>group III</th></tr>
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Characteristics of each group (pre-test)

Group 1 - Sensible-empirical definition of states of matter; continuous conception of matter; no conservation of mass

Group 2 - Sensible-empirical definition of states of matter; continuous conception of matter; conservation of mass

Group 3 - Sensible-empirical definition of states of matter; discontinuous conception of matter; substancialism; conservation of mass

Group 4 - Sensible-empirical definition of states of matter; discontinuous conception of matter; conservation of mass

Characteristics of each group (pos-test)

Group I - Incomplete atomism, with vestiges of discontinuous and substancialist ideas; conservation of mass; absence of generalisation and compensation of disturbances; absence of relationship between different concepts of states of matter

Group II - Complete atomism; conservation of mass; difficulty in generalising and compensating for disturbance; relationship between different concepts of states of matter

Group III - Complete atomism; conservation of mass; complete or almost complete capacity to generalise and compensate for disturbance; relationship between different concepts of states of matter the disturbance (a question about the three states of water, which shows an anomalous behaviour, since the solid is less dense than the liquid). c) to verify if the students made distinctions between the different concepts of states of matter, recognising the boundary of each one (a question in which the students were asked to comment about the physical states of clouds, glass and liquid crystals. All these materials are problematic for the empirical concepts of solids, liquids and gases.)

The analysis of students' answers to the pre- and post-test according to these categories allowed us to grouping them and to analyse their conceptual evolution, as showed in the table 1.

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Educational structure of chemical bonding; the use of models in descriptions of chemical bonding

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1. Introduction

The position of the topic Chemical Bonding at the end of the upper secondary school curriculum, leads to a traditionally determined content of the chapter(s) on chemical bonding based on the idea of achieving a certain level of knowledge supposedly required by the university curriculum. In practice, while struggling with the essential concepts, students as well as teachers complain about difficulties and, furthermore, universities seem not to be satisfied with the results. A specific conceptual structure can be the cause of the problems, but also the traditional content of the chapter should be brought up for discussion. In this paper preliminary results of my research project are reported and possible answers to some questions are given.

2. Position

Research in chemical education requires knowledge of chemistry and of education. Preparing lessons in whatever subject implies reflecting on specific concepts, that is even more true for doing research. As I realise how I have been influenced by my previous experiences as a chemistry teacher, I consider it relevant to define my position as a biochemist and as a teacher.

a. Reflecting on chemistry as a discipline, I percieved it as consisting of several subdisciplines, each with its own history, its own rules for using language, its own concepts with sometimes very specific meanings. I studied biochemistry in a period when this was being established as a separate branch of science. In biochemistry structure is a dominant concept, as biochemical compounds and their activities are preferably described in terms of structure-property relations, for instance in the form of lock-and-key representations. In devising new teaching material I have been influenced by this background.

b. For several years I worked as a chemistry teacher and for most of that period I was also a co-editor of a chemistry textbook. That can explain why I attach great importance to language in the written form and in the functioning of illustrations both in texts and in classes.

Reflecting on my experience as a teacher, I feel that learning and teaching both contain elements of constructivism as a personal and social activity (cf. Driver, this volume). Learning is an individual process of constructing knowledge, not only consciously but also subconsciously as the learner is going through various phases to understanding. As indications for this individual activity, two not often mentioned aspects are important, that are needed for construction: time and concentration. With regard to the need to concentrate on the task of constructing, motivation can be important. But learning has also a social aspect, as the learner is a member of a community and as such has to communicate with other persons in verifying personal constructs.

The process of understanding contains a phase in which explaining to another person can play a crucial role. One of the advantages of teaching is the opportunity to get better understanding of earlier acquired knowledge, not only by reflection on the subject matter but also during the inevitable structuring of that material and its presentation to students. Part of teaching consists of learning, on the other hand its main part is passing on of knowledge in order to enable others to learn. In that respect, I think, teaching is on the social side of constructivism. As there are dual and sometimes conflicting aspects in teaching, in my opinion (and experience), it is very advantageous to learn how to teach a certain topic while coaching students. Then you have better opportunities of a personal interchange, direct response and time to (re)structure and (re)formulate together.

3. Research topic and method

The research project, an educational structure of chemical bonding, started when the department of chemical education and the publisher of the textbook I formerly worked with, agreed to cooperate and analyse a chapter that was to be revisioned. The analysis focused on the framework and function of concepts. As a result of the cooperation the chapter has been rewritten by and under reponsiblility of the editing group. But as one part of the project, the research has been extended to other traditional textbooks on secondary school and university level. Lessons given within the traditional curriculum, some of them slightly adapted according to earlier results of the analysis, have been audiotaped. Results of the analysis showed that the conceptual structure underlying the traditional approach to teaching chemical bonding is characterized by at least one major inconsistency. Therefore, another part of the research project consists of the development and testing of new material in a cyclic procedure of research and development (cf. Van Keulen, this volume) A new unit on structure and chemical bonding has been designed using results of an educational analysis of concepts such as bonding, structure and model. The unit has been tested in the classroom. After analysing protocols and other material collected in the classroom, a revised version of the unit will be written with regard to the intended educational structure.

4. Research questions

As chemical bonding is considered to be difficult by students, and by teachers with regard to the teaching part as well as to the estimation of 'learnability', the first objective of the research project can be formulated as follows:

1. What are possible reasons for the problems connected with learning and teaching Chemical Bonding in the traditional approach?

   In most A-level textbooks, theories on chemical bonding are preceded by descriptions of a model of free atoms. This model, originally developed in a physical context with electrons and energy levels as its main concepts, is suitable for explaining spectra and ionization energies. However, our analysis showed that this model is inadequate when, in the chemical context, a structural model of molecules is to be introduced. Of course, energy remains an important issue for bonding but, in order to explain structure and shape a more spatial model is needed as well.. We conclude that there is no coherence, that there is a *gap*, between the models of free atoms and bonded atoms.

   Bonding cannot be deduced from the free atom, although this suggestion is made by the sequential presentation of free and bonded atoms in many textbooks. Support for the idea that chemical structure cannot be derived from first principles on a strictly theoretical basis can be found, for instance, in articles by Primas (1985).

   The tradition of introducing chemical bonding on a theoretical basis has its origin in the nineteen thirties. The increasing amount of chemical data to be taught called for classification according to certain criteria and the need for organizing schemes. That is reflected in textbooks showing a development from descriptive chemistry, to the periodic table as organizing scheme and then to a 'theory first' approach, especially in general chemistry courses.

The conceptual framework of the chapter(s) on chemical bonding may, in our opinion, be unsatisfactory, the traditional content of the chapter itself should also not be taken for granted.

2. What are legitimate aims of a chapter on Chemical Bonding and what content is suitable for pursuing these aims?
   In order to answer this question we have to ask: legitimate from whose point of view? Should it be the chemical researcher's point of view? Or rather, what does society want the student to know as a scientifically literate citizen? As the subject is taught at pre-university level to prepare students for advanced studies, it is legitimate to ask what does the university curriculum expect students to know? In the opinion of several university professors, some experience in handling theories and models regarding this subject is more important than the actual content of what is being taught. Taking this into account, together with results of the previous analysis, the choice has been to start the experimental course with chemistry, i.e., with substances and reactions of substances. Students are invited to ask questions which require formulas, molecular formulas and/or structural formulas, and to give some meaning to the structural formula in the form of structure-property relationships. Meanwhile, conflicting data have to be dealt with and have to be brought in line with previous acquired knowledge, causing uncertainty about the 'factuality' of models.
   It is commonly known that students are inclined to learn models as facts and that they are unwilling to accept the possibility of other models. They often ask to tell how things 'really' are, even when a teacher argues that a model can be provisional or of relative applicability. Students are not used to ask questions about models. They are not used to reject a model, they are told that models are (or have been) rejected.
3. Can students experience the relativity of models and of theories when they struggle to bring experimental data into line with a theory which may be wrong or inappropriate for the experiment?
   We want to draw attention to three possible ways of handling models in teaching and learning. Sometimes only one model is presented, and as is the case with chemical bonding, this model may be very sophisticated and difficult to cope with: the *one-model* model. Another practice is the presentation of a simple model to start with because learning is just beginning. Later, when this model is considered not so good anymore, another, more refined, model is put in its place. This leads to a row of succesive *provisional* models, each one better than the previous one and causing the students to ask how long the last model will last. However, in our experimental unit the students are confronted with the simultaneous

use of various models in a *multi-model* model. Depending on their usefulness, a choice has to be made for answering specific questions in relation to chemical data. The relativity of models is to be seen in the ability of using models.

5. 'Kennis maken'

The experimental unit designed as an alternative for the traditional approach has two main characteristics in addition to its multi-model approach.
First, structure is introduced in a chemical context, initially without mentioning energy aspects. The intention is to raise questions regarding structures of substances by means of appropriate chemical reactions, and also to let structure function as a tool to predict reactions. As the school laboratory is not equipped with sophisticated apparatus, it is not possible to carry out advanced chemical experiments. But the old-fashioned methods, including an acid-base titration, are an appropriate alternative for two reasons. We want to experiment in a chemical context, while most modern methods are based on physical principles. And secondly, the practice of chemistry of the past allows for a shorter distance between subject and object and can therefore stand closer to students.

The second characteristic of the unit is the 'making of knowledge'. This is the rather literally translation of the title 'Kennis Maken'. There is a double meaning in the title, as 'Kennis Maken' in Dutch also means 'to get acquainted with'. The emphasis is on the process of *making* knowledge as a human activity including the acceptance of new facts and rejection of others. In the unit a story is told of a pair of substances and of the men and women who during the past and present have contributed to our knowledge about these substances, their place in chemical theories and in daily life. The students are learning new concepts but also relations between concepts earlier acquired.

As an example, in the second paragraph of the unit, the results of the titration will suggest that there are two isomeric compounds, maleic acid and fumaric acid, and the question is asked which structural formula can be assigned to which compound. Two models are offered, both representing the rigidity of the double bond. One is the figures of Van't Hoff (1874) and the other pieces of paper folded following instructions of Fu-cheng He et al. (1990). Although the two models look alike students confronted with them had to ask themselves the meaning of these models in relation to the question of structure, but also the meaning of, for instance, the stick-and-ball models they are used to.

The following example is from another paragraph where the dashes of the structural formula are under attack with diagrams of electron density contour plots and EDD plots. Various representations may look alike but X-ray data will point to other distances and different angles when related compounds as hydrogen salts of maleic acid are compared. From an EDD figure one could even conclude that there is a conjugated system in maleic acid, though that is not in agreement with distance data. (See, for instance: James and Williams, 1974.)

Early results from classroom tests of the unit seem to indicate that the appeal on students to discuss the applicability of models seems to function.

6. Discussion

Questions brought forward for discussion in the workshop, are:

1. Is it possible to experience the relativity of a model, for example, the relativity of the dashes in a structural formula?
2. As it takes some effort to develop a model, how can the model be prevented from becoming a goal in itself instead of a tool?
   (The problem raised in the second question does not only apply to handling models but also more generally to the use of teaching aids, for instance computers.)

The discussion went along two lines: the educational aspect of models and the model concept itself. According to Vanessa Barker, it is good for students to experience lots of models and to realise that each model has its limitations. In order to see such limitations, questions must be asked at the same time when the models are presented. Wolter Kaper mentioned that even if both 'things' are representations of the same model, for children they could be different models. Anna Spirtou pointed out the possible different interpretation of models by children depending on their age. The limititations of a model should be researched in this regard. For Dimitri Psillos it is important how students work with the models, either by comparing two models or by comparing model and experiment. Jerome Viard brought forward the relation of models to theoretical frameworks. Is there a problem of two models or of two representations of one model? Hanno van Keulen asked about the model character of molecules. In his opinion it is very difficult to escape from the view that molecules are real and that a material thing is a model of a molecule.

At this point of the discussion the argument was, if molecules are models or real. Van Keulen's feeling is that molecules are real, wheras Viard stated that molecules are models in a theoretical framework. As Adri Verdonk remarked: in chemistry you have to describe, to predict reactions and substances, then/therefore a new, changed model is needed. And that change can be represented by a material model. Another remark of Verdonk was on the model being a tool: a tool for what? What is the function of different material models? There is the possibility of an interpretation of what is represented in a (material) model in the chemical context. But Vanessa Barker has the idea that from the teacher's point of view a model can help to achieve an educational goal regardless of the arguments about models not being real or not representing reality. Two important topics can be concluded from this discussion:

1. the coherence of the model concept in science and education;
2. the functioning of a model in (constructing) one's knowledge.

These topics require further attention in my research project.

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The educational structure of organic synthesis

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1. Introduction

This study aims at establishing an *educational structure of organic synthesis* at university level, especially with respect to the first year laboratory course. 'Educational structure' stands for a detailed description of educational material that satisfies two criteria. First, the chemistry in this educational context should be a sound representation of the chemistry in the professional context. Second, learning should be related to teaching, i.e., learning outcomes should be a result of teaching efforts. In this study, research is carried out to specify these criteria in order to develop an educational structure.

Heuristics used in this study

In my view, learning is *domain specific*, because knowledge is domain specific. The meaning of words and activities depends on the context in which they occur. Hence, learning depends at least in part on a successful representation of this context in the educational process. The characteristics of this representation, and hence the content and structure of the organic chemistry curriculum, cannot easily be derived from a general educational theory on learning or instruction. Rather, they have to be generalized from empirical studies. This project aims at establishing such *context specific concepts* for teaching organic chemistry.

I adhere to the paradigm of *learning through experience*. This implies that the educational material should provide students with experiences in the field of organic chemistry. The aim of this project is to establish crucial experiences, to sequence them, and to create an appropriate educational context to provide these experiences. Experience itself is not the only important thing for learning to take place. Experiences should be *articulated* and conceptualized in words. Education should provide students with opportunities to discuss their experiences with one another and with a teacher.

I adhere to an *instrumentalist epistemology* with regard to learning chemistry. That is, students have acquired an understanding of organic chemistry when they are able to solve organic chemical problems within a relevant context. In general, education aims at creating knowledgeable students. Students can show their learning by applying their knowledge in suitable contexts. However, chemical knowledge is typically used in out-of-school contexts, such as research laboratories and industry. Therefore, these contexts are often reconstructed in such a way that educational institutions can handle them. The consequence of this choice is that there is no guarantee that students really have acquired applicable chemical knowledge. Alternatively, education restricts itself to talking about chemistry, instead of doing chemistry. This often results in emphasizing 'understanding'. Chemistry, in all its diversity and complexity, is reduced to a value-free system (or knowledge base) of facts, procedures, concepts, and theories. Students failing to correctly reproduce this system lack understanding, or worse, have misconceptions. Whether or not students can use their understanding in a realistic context remains unknown. The advantage is that it is fairly easy to assess students, because the knowledge system can be defined precisely. However, educational studies focusing on this kind of educational processes run the risk of equating correct reproductions with chemical competence. The 'meaningful knowledge movement' is a reaction to this problem, but not a fundamental one. Whether or not students 'really' understand is one thing, but what counts is what they do with this understanding in their future lives, as citizens or chemists.

Hermeneutical philosophy provides a framework in which understanding and application are related. Confronted with something unknown, it is natural to start an interpretative process to make sense of it. In this process, certain phenomena are recognized and verbalized, relations are discovered, and a tentative understanding of the situation develops. An essential part of this process is the enduring attempt to apply these tentative relations and concepts to the situation, to check their validity and usefulness. In this way, *interpretation, understanding, and application* are inseparable. The concepts, definitions and formulae which are used to understand cannot be taught in a context-free manner without losing contact with the original questions and goals.

2. Method

To establish a relation between the chemistry in an educational context and the chemistry in a professional context, an analysis is made of the *professional context* of organic chemists. This is done through interviews with organic chemists (both inside and outside education), through an analysis of textbooks, laboratory manuals, documents on objectives of curricula, and educational literature on chemistry teaching. In this way, a description is being produced of the current situation in teaching organic chemistry. Much attention is paid to an analysis of the first year organic chemistry laboratory course at Utrecht University. The analysis of this course establishes relations between chemistry in the current *educational context* and the chemistry in the professional context. This analysis also aims at illuminating relations between current teaching and learning.

Both relations are investigated and further developed using a *cyclical method* of constructing and executing new educational material. This method is represented in figure 1.

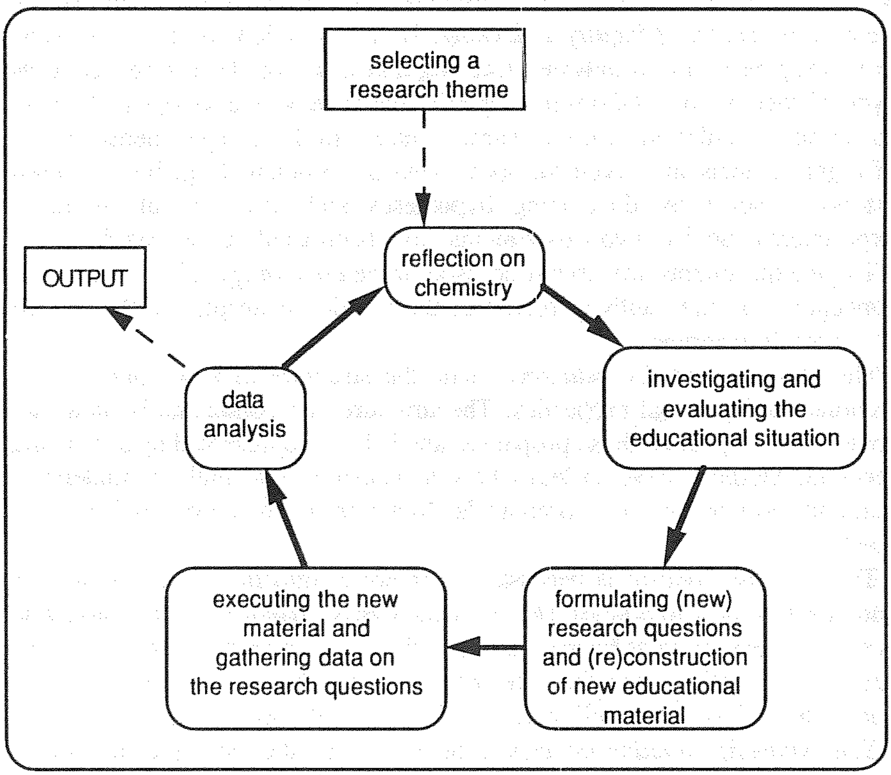

figure 1: The cyclical method

In this way, educational material is being created which satisfies specified criteria on relations between teaching and learning, and on chemistry in the professional context and in the educational context. Data are gathered by observation of the educational process and by audio taping the discourse taking place between students and between students and teacher. The data are analysed using *interpretative methods*.

3. Results

The analysis of current educational contexts in organic chemistry has shown that *chemistry has been split* in areas called theory, practice, and problem solving, which are dealt with in different parts of the curriculum, i.e., lecture courses, laboratory courses, and problem solving classes. Integration does not take place sufficiently. The professional context is misrepresented, largely because *a context of inquiry is lacking*. In this situation, it is of little value to investigate relations between teaching and learning. Therefore, using the cyclical method, *new laboratory experiments* have been developed which are based on a simulation of the research context. In these experiments, groups of eight students are given an open synthesis problem (e.g. how to make esters) to solve by developing hypotheses and carrying out laboratory experiments. So far, two experiments have been tried out successfully.

These experiments are structured using three *domain specific concepts*: the concept of structure-activity relations, the reaction concept, and the concept of synthesis planning.

The *structure-activity relations* relate the structure of a compound to its chemical and physical properties. The structure of a compound is, in a way, contrived to represent these properties and is itself represented by a structural formula. Students have to learn how to interpret a formula to understand reaction possibilities of compounds, reaction phenomena, and reaction mechanisms.

The *reaction concept* is necessary to interpret information on the amount and identity of compounds (the so called mass balance) before and after synthesis steps, such as formation or purification. Using this information, the nature of reactions can be inferred, i.e., whether a reaction comes to completion, forms an equilibrium, splits off a side product, and so on.

The *synthesis planning concept* is necessary to take the right measures in each synthesis step, and to gather relevant information to evaluate each measure. For example, the formation step should be constructed in such a way that purification problems in the next step are minimized. These concepts are being taught in the newly developed laboratory experiments. In the first experiment, for example, students experience the shortcomings of the Brønsted-Lowry theory on acids and bases to describe the reaction possibilities of organic compounds, and they develop parts of the Lewis acid-base theory. They start using a reaction concept which has the general form $A + B \rightarrow C$ (i.e. the reaction comes to completion), and they expand this to include the concept of equilibrium reactions: $A + B \rightleftarrows C + D$. With regard to synthesis planning, they learn to evaluate and reconstruct the formation step with regard to purification problems using characterization techniques.

The second experiment elaborates on these conceptual developments. It aims at expanding the reaction concept to include side reactions. The starting point for synthesis planning is the end point of the previous experiment: students should have acquired the ability to plan their formation procedure with regard to purification before they start the reaction. If they have understood they will be able to apply their understanding in this second experiment. With regard to the concept of structure-activity relations, the experiment starts with the Lewis concept of molecular structure and lets students develop new concepts on the energetic interpretation of structural formulae.

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A productive group as a means for structuring learning; a didactical research in biochemistry education

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1. Introduction

In january 1988 our group started a project in which the relation between secondary and tertiary education is the central focus. In this project the way in which secondary education can be preparatory for tertiary education is elaborated. Its main question might be formulated as: In what ways does or does not secondary education prepare students for tertiary education? The project concentrates on chemical education in the first two years of the chemistry study at the university of Amsterdam. Problems students encounter in concept development are interpreted in connection with the preparatory function of secondary education.

Didactical background
The idea of preparation of earlier education for further education is central in our work. It means that we see learning as an ongoing process: each educational activity is preparatory for further activities and is prepared for by earlier activities. For parts of chemical education the so-called van Hiele level scheme has proved to be successful in describing this process (Ten Voorde, 1977; Kaper, these proceedings). In this paper we want to elaborate on the idea of learning seen as a continuing activity, a cooperative activity and as development of language.

On a large scale, the first feature means that tertiary education is not only prepared for by secondary education, but also that tertiary education should be preparatory for work as a professional scientist. This means that we see no fundamental difference between learning in education and learning in research, although a difference is that learning in education is a guided process whereas in research it is not. On a smaller scale it means that, for example, working out a problem in a tutorial session[1] or in a laboratory course should be made possible by results of earlier problems, while further problems should be made possible by this specific problem. In learning as a cooperative activity, we want to express that in our view learning should not be seen as a one-way road, but rather as an interactive process. In fact this lies very close to learning as a continuing activity since interaction with another person or persons might very well lead to something new. We owe the following beautiful analogy to one of the outstanding members of the Dutch didactical community of researchers: Hans de Miranda[2].

We've got two eyes to see the world around us. Each eye sees another world than the other eye, each eye has a different image of the world than the other eye. When, in our head, these two images become connected, we see something that neither one of the eyes sees by itself: we see depth. Here something new appears. Something similar can happen when two people (or more) speak with each other. When I tell you something, it might happen that you recognize it as something that is part of your experience. You might tell me about it, and I might recognize what you are talking about. But the words you choose to tell me about it can change my angle of looking at what we are discussing and I see something new, something which didn't exist for me. This might happen to you too, and then we share something new.

An example: when compact discs were relatively new there were some people who rather fanaticly preferred records over compact discs. They said the sound of a record had more warmth. Then one day someone succeeded to prove (or so it was reported by newspapers) that the sound quality of compact discs was indeed less than that of old fashioned records. A friend of mine and I both are rather fond of music and we were puzzled by this report. We had come to know the compact disc as superior to the record. So how could this report be true? I told my friend of my puzzlement, which he recognized. To make sense out of this report my friend came to discern between recording technique and recording medium. Indeed, a compact disc is a better medium than a record with respect to vulnerability, but that has nothing to do with recording technique. We decided that the 'quality' of which was spoken about, referred to recording technique. At that moment I saw an unexpected consequence: I remember vividly that rather surprisingly

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1. "Tutorial session" is used here as a translation of the Dutch word "werkcollege". By "werkcollege" is meant a sessions in which 10 to 20 students work on problems in small groups. It was suggested to me that "workshop" is perhaps a better translation.
2. I take this analogy from a lecture de Miranda gave for our group on 19-04-93. The original quote was of course in Dutch, I therefore give out of necessity a paraphrase in English.

we had to conclude that if this report about the sound quality of compact discs were true, it had to be true for digitally recorded records as well. This conclusion resulted because I told my friend of my puzzlement, which he recognized, and in the exchange that followed something new resulted, that was neither part of me nor him, but is now part of us. I still believe it is true, until perhaps some of you can tell me something we haven't considered at that time. Our learning at the time was a result of a cooperative activity and it may continue to be so. When I would talk with some of you about record media, my and our learning could be continuing. Perhaps I could even gain an interesting view on the matter to continue the discussion with my friend. The distinction between technique and medium which we perhaps knew in words gained meaning in that we could use it to answer a question. And in the proces we reached a new expression concerning digitally recorded records. When viewed in this way this example also shows the third feature: learning as a development of language. Perhaps it is better to formulate this as: the agreement my friend and I reached expressed itself in the common use of expressions.

This view on learning (a process in which a new view on a matter can continually lead to new meanings in the language used to talk about this matter, which is stimulated in the most potent way in a cooperative exchange with others to reach a shared view on matters we share an interest in, and in which an agreement we reach expresses itself in the common use of expressions) we take as a starting point for our research.

Because these three features turn out to be so closely intertwined I want to take them together in one expression. And I am indebted to the aforementioned Hans de Miranda for having found exactly the words. Learning can be seen as a 'lasting discourse', that is, a continuing cooperative development of language to express joint experiences. I want to call a group of learners who is engaged in such a process a 'productive group'.

The main didactical question for my research then becomes: in what ways can a lasting discourse be organized in an educational situation? Since my research field is biochemistry education, the question transforms to: can this be achieved in biochemistry education? Can biochemistry education be structured as a continuing cooperative activity in which biochemical concepts are developed? Can biochemistry education be structured as a lasting discourse in a productive group?

2. Reflection on biochemistry in relation to education

If we want students to learn biochemistry, what is it that we want them to learn? If we want them to develop a biochemical language, what does this language describe? What does it talk about? What kind of questions can this learning answer?

In an attempt to formulate answers, I will use the idea of 'context'. A context can be seen as a coherent part of the language we use to describe a matter and which derives its meaning with reference to that matter, or, perhaps better, to our joint experiences with it. I want to illustrate two contexts with the aid of the next fragment from a book by J.S.Frutton 'Molecules and Life':

> 'All the chemists from Kossel to Levine who laid the groundwork for the double-helical model of DNA either were indifferent to its biological function or were skeptikal about its role in heredity. Moreover, the mechanism of inheritance was defined by cytologists and geneticists, many of whom, like Boveri and Morgan, either refrained from conjectures about the chemical nature of the genetic material or affirmed that chemistry could contribute little to the understanding of the mechanism. If, before 1940, some biologists and physicists speculated about the chemistry of the gene, or some chemists guessed at the biological role of the nucleic acids, most of their surmises could not be tested experimentally.'

This fragment illustrates two contexts: one in which one can talk about substances, their reactions, their constitution, and a context in which one can talk about organisms, their constituent parts and the constituent parts of their constituent parts. Somehow we want these contexts to become related to form biochemistry in such a way as to make biochemical research possible.

If I say that somehow in biochemistry teaching we want the chemical and the biological context to become related, it is in view of what I said earlier about learning. It means that we productively 'connect' those parts of our language, and by productively I mean that in it we derive new meanings and expressions capable of answering the question or puzzlement that formed the reason to engage in such a process.

When one discusses a role or function of something, for example the biological role or function of metabolism, it is hard to avoid teleological reasoning. In biology and biochemistry contexts alike we encounter teleological reasoning. We can discern three kinds of teleological reasoning (Soontiens, 1990) although I still have some difficulty in telling them apart. First there is what we might call the function-ascription: we discuss the role of a part in a whole. For example, in the body the heart pumps the blood.

The function-ascription discusses the role of a part in the maintenance or the development of a whole. Second there is what we might call the goal-ascription. For example, the heart beats in order to pump the blood. The last one might be called the intention-ascription. An example of the latter is: the heart beats because it wants to pump the blood.

In a biochemistry context the role of a chemical substance in a cell is the matter which is discussed. The main question for a biochemist is which chemical properties are of importance herein. The primary educational problem I have found thus far is that those chemical properties are discussed in terms of molecules. When it comes to discussing the role of those molecules in a living cell, a large fraction of the students tends to use anthropomorphous reasoning. They seem to consider molecules as real existing entities with some form of a free will. They use intention ascriptions. This blocks them from posing questions which could lead to an attempt to chemically account for what happens in a cell. Yet this is at the heart of biochemical research, as might be shown in the following excerpt from the article in which D.E.Koshland, a well-known biochemist introduces his induced-fit theory:

> 'The deficiency of any template model is simply that it is only a mechanical analogy and, since we are making chemicals and not automobiles, that it has to be translated into chemical terms. For example in the model of Dalgleish it is assumed that the completed peptide peels off the template; but why individual amino acids which were previously tightly absorbed should suddenly prefer to be desorbed must await chemical reasoning'.

In the 'what happens' part of the story I suggest we can recognize the function-ascription I mentioned above. Then part of the biochemical language can be seen as a model to discuss the role of a part in a whole. The question of how a 'chemistry' context and a 'biology' context can become related to form a biochemistry context transforms to the question: in what way do we have to organize education to offer students the opportunity to perceive the (bio)molecule as a spatial particle as a model in order for them to be able to discuss function-ascriptions as inferred from experiments.

3. Educational experiment

Last autumn on the basis of the foregoing considerations I carried out an educational experiment. I devised a set of new problems for tutorial sessions with the intention that students would be able to discuss an enzyme-particle as a spatial entity, not as an existing reality but as a model to describe regulation of metabolism. From this experiment I give two fragments of students discussions[3]:

Fragment 1:

The first fragment belongs to the second newly devised problem, in which the scheme of Michaelis and Menten for enzyme kinetics is being introduced. The students were subsequently asked to give a description of the dehydrogenation of ethanediol.

S1: Well, ethanediol plus enzyme, is that what they mean? What is dial anyway?
S2: Diol?
S1: Dial. Let me look it up.
S2: Isn't it eh, o no, yes, isn't it with double O?
S1: Just double O, he?
S2: So, there are just two little H removed.
S1: O yes, it is being dehydrogenized. Where do they remain those little H?
S2: Ehm, on the ehm,
S1: Just H two?
S2: Yes,
S1: Shall we write that down? We just don't know what happens with it, I bet something special is going on.

This fragment shows the attitude of these students at the beginning of the tutorial sessions. They don't discuss a lot, they even expect not to be able to give the right answer. This kind of behaviour may be representative for education in which the reproduction of facts is being stressed.

Fragment 2:

The next fragment comes from student discussions while they were working on the eighth problem. In the problem that preceded this one, students were being asked whether or not ATP could be named an inhibitor of the enzyme phosphofructokinase. On the basis of experimental data they were given about reaction velocities, they concluded that 'ATP is needed for the reaction' but also 'eventually an inhibitor'. During the set of problems the students gave 'inhibitor' the meaning 'to bind with enzyme'. Then they had the difficulty of discussing a substance which can be an inhibitor as well as a stimulant for the same reaction.

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3. Again I want to stress that the original is in Dutch. Translating student discussions from Dutch into English has the disadvantage that the translation in itself is already an interpretation. I have tried to translate the original as literally as possible, resulting in Dutch expressions in English words, to minimize this disadvantage.

S2: Here "Explain how a substance can be an inhibitor as well as a stimulant for an enzyme".
S1: Hm?
S3: Yes, that is,
S2: Hey, this is, yes, an inhibitor as well as a substrate.
S3: Yes, this is, ehm,
S2: It is an equilibrium.
S1: It is on another site.
S2: If there is little of it,
S1: It is not binding the reactive site ((?))
S2: Sorry, what did you say?
S1: It is not binding the reactive site, that is why it is a substrate but not an inhibitor. Isn't that a solution?
S2: Yes, but eventually it becomes an inhibitor. So then it suddenly binds the reactive site?
S1: Well, maybe if there is an overconcentration.
S2: Yes, it may an be equilibrium reaction, and the more ATP there is,
S1: Yes?
S2: then the equilibrium is being pushed back. Sort of.
S1: Then ATP would form or something.
S2: Ehm, o no, it wouldn't form,
S1: If it forms, and you add to it, then it goes back
[silence for a short moment]
S3: I think that eh, the enzyme in a high concentration of ATP loses its activity.
S2: Loses, yes, but why?
S3: Yes,
S2: And why not in a low ATP concentration?
S3: Because it eh, probably gets distorted.
S1: But you can maybe depict that an enzyme has two sites, here binds ATP, there it binds to work, and if the concentration gets higher, it not only binds here but also here, and than it functions as an inhibitor. So before concentration one it binds here, and after that it binds here too.
S2: Yes, so how do we write that down?
S1: Ehm, yes,
S2: An enzyme has two binding sites, one for ATP to activate the enzyme,
S1: You can say, by a high concentration ehm, ATP binds to the reactive site, not by a low. Maybe it is a bit funny solution...

In this fragment we can see that these students work out a solution to their problem. Specifically the interaction between S1 and S2 is important, but S3 also has a part in it. The first hint of their final answer appears in the beginning of this fragment but later on their description becomes more refined. I want to stress that their result is not an individual result but a common achievement. In the last lines of the fragment S1 and S2 supplement each other.

The result these students achieve was not the result I had in mind when writing these problems, nor had they heard it in the lectures. They don't reproduce facts, but produce their own expressions.

I have tried to show you their reproductive attitude at the beginning of the tutorial sessions. But engaging in a process of listening to each other, reacting to utterances of the two others, checking the correctness of what one was saying, these three students more and more became a group that was building on their earlier utterances. One can speak to some extent of the formation of a productive group and to some extent of the formation of a lasting discourse. 'To some extent' because the group is building on its earlier utterances. The students cooperate (react to each others remarks and questions) and in the process they are changing their use of words. They try to build a coherent use of the words that are passed on to them in lectures or the textbook. However, the main impression I get when I read fragments of their discourse, like the one I have given here, is that their discourse is 'inward centred'. What is missing in the process that is realized are:

- a central question to start from, and
- the opportunity to check the use of expressions against concrete experience.

This means that in my next educational experiments I should incorporate practical work by students, not just for the sake of learning biochemical techniques, but to make learning as (or in) a productive group possible. I hope that this experiment allows me to give some answers to questions like:

- What kind of starting questions can be used to initiate a process of biochemistry context formation.
- Which earlier experience can be built on?
- Which experiments can be used to give students the opportunity to build on concrete experiences?

4. Concluding remarks

In working on the questions I have sketched above, I frequently talk with my co-supervisor, supervisor, my fellow Ph D students, etc. In our discussions we will try to form a productive group, engaged in a lasting discourse about learning. In that discourse we will use words to talk about learning, we will try to check the use of those words against our experiences in educational situations, and so form a didactical context - a coherent use of words to describe learning.

When we devise an educational experiment in order to check the use of our words and expressions to talk about learning against concrete educational experience I want to call that a didactical experiment. This is what I mean when I call my research a didactical research. I hope to be able to extend our didactical context on the basis of concrete experience. In other words I hope to be able to devise a didactical experiment the results of which (besides hopefully a biochemistry context in a group of students) enable me to coherently talk about learning in a productive group.

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The Van Hiele level scheme and a historic text as sources of inspiration for designing concept-development leading to entropy

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1. Introduction

The research-question of the project I work on can be formulated as follows: If languages cannot be sharply distinguished (which we suspect), how can Van Hiele levels, together with other means of characterising language (as used in a *lasting discourse* and in relation to *experiences*) be used in a consistent way which is useful in designing education.

A way to work on this question seems to me: try using these levels and try using other means in designing and evaluating a piece of education, and then later reflect on their usability. The question of usability will have to be decided by trying out in solving an educational problem.

This paper will be about the 'Van Hiele levels' as a means of characterising language used in a lasting objective discourse, and as a means of designing such a discourse for educational purposes.

Auke Jongbloed (1993) already clarified the term 'lasting discourse' and Hanno van Keulen (1993) stressed that a discourse must be *about* something, which means it must be related to experiences. He stressed this by distinguishing 'objective discourse' from other kinds of talk.

The problem I chose to test my ideas is the teaching and learning of *entropy* in a second-year university course for chemistry students at Amsterdam University. An evaluation of current practice leads to the conclusion that there's too little connection between calculations on the one hand, and reasoning in words on the other. This problem of combining physical reasoning (in words) with algebraic reasoning may be akin to Auke Jongbloed's problem of combining chemical and biological reasoning.

2. Carnots *Reflexions sur le puissance motrice du feu*, as seen through the Van Hiele level scheme

To get ideas for the course I started to read Sadi Carnots *Reflexions*, and this reading made me look with fresh interest at an educational scheme which is sketched in the figure below: the Van Hiele level scheme.

Ground level	-	Use of words is based on immediate recognition
		↓ Problem
Descriptive level	-	Use of words is based on properties used for recognising the named 'thing'
	-	The list of these properties is open *
	-	Meaning of words becomes sufficiently precise to express experienced regularities *
	-	Exclusions not possible; Predictions uncertain *
		↓ Problem
Theoretical level	-	Use of words is based on definitions: some properties are chosen as sufficient *
	-	Axioms are chosen that make possible the exclusion of possibilities *
	-	Predictions possible
	-	Expressions of empirical generalisations are checked for consistency in the light of the chosen axioms and definitions *

figure 1. Sketch of a Van Hiele level scheme

This scheme describes experiences with teaching-learning situations. For instance: Van Hiele found that the axioms and definitions of Euclidian geometry could not get meaning for his pupils until words like 'line' and 'triangle' first had got some meaning in another way, which he characterised as 'descriptive'. Now I would like to pose the question: can this structure, as found in mathematics and in chemistry education, also be found in the development of the science we call thermodynamics? It struck me that the sciences of chemistry and thermodynamics both came into existence at the moment when something was chosen to be considered impossible. The choice to consider the making of (for instance) gold out of lead as impossible turned alchemy into chemistry. For thermodynamics it was Carnot's choice to regard the impossibility of a perpetual motion machine as fundamental. Maybe this only shows us how the historians of science have a tendency to locate the birth of a science at the moment when a *theoretical level* is first reached. Can we, however, find in Carnot's writings signs of a descriptive level that he had shared with his contemporaries?

In Carnot's text we can see signs of an empirical generalisation that could have been formulated like this: The higher the pressure on the piston, the better the performance per unit of coal. The existence of such a generalisation among Carnot's contemporaries can be seen from the following citations:[1]

- 'Now it is easy to see the reasons for the advantages of the so called high-pressure engines over the ones with lower pressure. This advantage lies principally in the possibility of using a larger fall of the heat substance.' (p.56)
- 'The principle that has been formulated here is so little known or little valued that recently Mr. Perkins, a famous mechanic in London, made a machine in which the vapour, formed under the until recently unusual high pressure of 35 atmospheres, undergoes almost no expansion at all (...). Also Mr. Perkins' machine seems not to have fulfilled the high hopes that it had originally stimulated. It's been said that the savings on coal would be 9/10 of Watt's good machines, (...). These claims have not been confirmed.' (p.57)
- 'Some have proposed to use the vapour of alcohol, and they have even made machines that were meant to make this possible, by avoiding the mixing of the vapour with the cooling water (...). They believed they would find a considerable advantage in the fact that alcohol vapour has a larger vapour pressure than water vapour, at the same temperature. To us, this can mean only another hindrance.' (p.64)

In the first citation the advantage of the high-pressure engine is referred to as a well known fact. For Carnot however, this fact is in need of an explanation. The next citation shows how Carnot suspects this generalisation not to be without exceptions. In the third citation we see alcohol having a higher vapour pressure than water being considered as an advantage. However, like mr. Perkins, the builders of the ethanol-machines may have been disappointed. So, the problem that could have been driving Carnot could have been this one:

> A high pressure on the piston is an advantage in some cases, not in others. Why? How can we be sure when it is good?

This question as such is not in his book. By the time he gave the solution to this problem, the question was no longer posed. The questions he does pose are broader or deeper than this one. But I was looking for a problem of a particular type, namely one that could function as a driving force for the transition from descriptive to theoretical level, and I thought this would be a plausible one. This problem seems of the right type, as I will now try to show.

1. Pagenumbers refer to: S. Carnot (1824). Provisory translation from the German by WK.

With certain machines, under certain circumstances people have had experiences and they've formulated generalisations. To be able to do this, they had to create concepts like 'pressure', that is, they had to give words like 'pressure' a meaning precise enough to make this kind of generalisations possible. With pressure the efficiency seemed to increase. When such a generalisation has been formulated, it starts to direct further action. However this means the generali-sation will be tried out under circumstances other than the ones that gave rise to its formulation. In such circumstances it can fail. This is characteristic of the openness of a descriptive level. It's always possible that new properties of a situation will have to be taken into account. This means expectations are unsure. They have to be tried out, because the unknown variables can interfere.

So the problem I proposed is of the right kind. If one wants to be sure on a question like this, one has to choose a point of view that makes possible the exclusion of variables or properties. As we know, this is what Carnot did. Carnot's axioms are, I think, captured in these citations:

- 'Everywhere, where there is a difference in temperature, the power to move can be won.' (p.11)
- '(..) it is always possible, if one can use this power [to move, WK], to produce new temperature differences.' (p.11)
- '(...) a creation [of power to move, WK] is in total contradiction to the currently accepted ideas, to the laws of mechanics and to a healthy physics. It is therefore unacceptable.' (p.14)

The third axiom is excluding certain possibilities in an explicit way. From this axiom his well known conclusion has inherited its 'exclusive' nature: it excludes the possibility that other variables besides temperature can determine performance.

- 'The maximum motive power of heat is independent of the agent that is used to win this power, and its quantity is only determined by the temperatures of the objects, that ultimately exchange the heat substance.' (p.23)

This conclusion does not mean that other properties have no influence. It means that their influence can be deduced from their influence on temperature. That's what Carnot does when he explains the advantage of high pressure for some cases, and why it's not an advantage in the case of Perkins' machine nor in the case of the ethanol-machines. He checks to what extent the empirical rule that had guided the work of his contemporaries is consistent with his chosen point of view.

We can therefore conclude that Carnot's work shows several of the properties of a transition from a descriptive level, which he may have shared with his contemporaries, to a theoretical level[2].

2. An idea for teaching entropy

According to this interpretation of the work of Carnot I should devise a problem which in the discourse of students would function like the problem with the doubtful advantage of high pressure. The following problem is a first attempt.

When two situations can be reversibly interchanged...

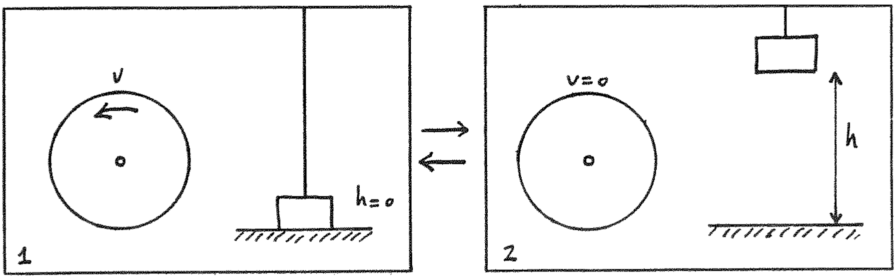

figure 2

...it seems reasonable to say that the 'usefulness' of situation 1 is equal to the usefulness of situation 2. A goal that can be reached when we have situation 1, can also be reached when we have situation 2, just because we can change situation 2 into situation 1 (and vice versa).
When we ask ourselves how we can compute this 'usefulness', the next proposal I think should be reasonable for people who know some mechanics:

$$\text{usefulness} = \text{kinetic energy} + \text{potential energy}$$

This proposal suits the requirement I just formulated. The sum of kinetic and potential energy remains constant in the reversible case, while it does *not* remain constant in cases where we cannot get the original situation back (friction). In that case this sum diminishes, which is also reasonable because,

2. In the figure on page 4 the properties that have been mentioned in this analysis of Carnot's text are marked with an *

when we cannot get the original situation back, we have lost possibilities that we originally had.

When we start taking temperature changes into account...

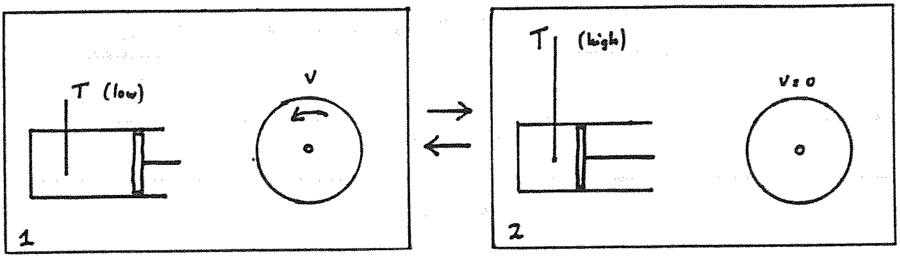

figure 3

...the fact that we can reversibly interchange situations 1 and 2 again implies that their 'usefulness' should be the same. A correct generalisation from the previous formula seems to be:

$$\text{usefulness} = \text{kinetic} + \text{potential} + \text{internal energy}$$

where the third term is related to temperature. However, this 'usefulness' remains constant not only when we can get the original situation back. It also remains constant with processes that cannot be reversed. So, this definition of 'usefulness' is not correct, it does not suit the requirement imposed by intuition. 'Energy' is not the complete answer. Something different is needed.

That's the problem I would like my students to encounter. I will not tell them the problem directly, like I'm doing now. Instead I will be giving them assignments that are designed to let them encounter the problem. I think this problem will arise sooner or later for people who know mechanical energy (which can simply be equated to usefulness) but who don't know internal energy. The assignments are designed to *let them* need internal energy, and to make them encounter the problem as quickly as possible. After that, some assignments follow that give them a chance of finding a solution to the problem.

'Usefulness', the thing we are searching for, is something that stays constant for situations that can be reversibly interchanged. To get an idea what this constancy can mean, we can look at two reservoirs which can interchange portions of water, and in doing this, can do work to set a flywheel running or use work and diminish the velocity of the flywheel.

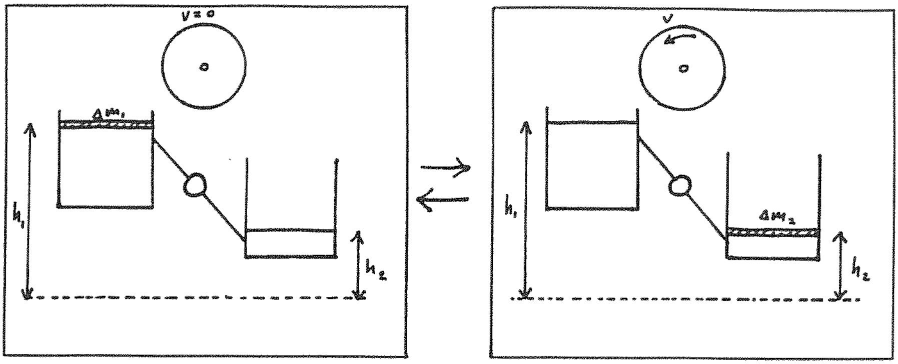

figure 4

Instead of 'usefulness' we now look at the amount of water which, like usefulness, is also constant. What consequences does this have?

$\Delta E_{pot,1} = \Delta m_1 g.h_1 \quad \Rightarrow \quad \Delta m_1 g = \Delta E_{pot,1}/h_1$

$\Delta E_{pot,2} = \Delta m_2 g.h_2 \quad \Rightarrow \quad \Delta m_2 g = \Delta E_{pot,2}/h_2$

From $\Delta m_{tot} = \Delta m_1 + \Delta m_2 = 0$ it follows that $\Delta m_1 = - \Delta m_2$

The change in the amount of water, left, is equal in magnitude but opposite to the change in the amount of water, right, and as a consequence we find:

$$\frac{\Delta E_{pot,1}}{h_1} = \frac{- \Delta E_{pot,2}}{h_2}$$

When we do the same kind of reasoning on heat and temperature, we find that the something we're looking for, something which stays constant (in total) only in the reversible case, could be something that obeys

$\Delta X = \Delta E$ (by heating) / T

for non-isolated parts of the total (isolated) situation.

The usefulness of the situation can then in a 1 to 1 way be related to the sum of the 'entropies' X of the diverse parts. In fact, we can now choose to define 'usefulness' as the negative of this 'total entropy', just because it satisfies our requirement.

In the process I just sketched students are led first to a problem and then to a solution of the problem, in agreement with the Van Hiele level scheme. This process also suits the requirement formulated by Fani Stylianidou (1993), that the more intuitive concept, 'the something that is used up', should precede the less intuitive one, 'the something that is conserved'.

This use of 'intuition' is also implicit in the Van Hiele level scheme, because according to this scheme, all disciplined discourse rests on discourse which is less disciplined (and thus more open or creative) and which deserves more respect than it usually gets in education.

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Constructivist approaches to teaching and learning science.

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1. Introduction

Classrooms are manifestly social places. They provide the setting for a great deal of talk involving countless interactions between students and between students and their teachers; they are subject to socially generated norms which govern what is regarded as being acceptable behaviour in the classroom for both teacher and students. At the same time, the principal aim of most classroom activity is to promote learning in the individual, an observation with which few would disagree, and one which raises the question of how individual understandings develop in the social context of the classroom.

In the science education literature, a large number of teaching and learning studies have been reported which focus upon changes in students' conceptual understandings in response to particular instructional approaches (examples of such studies would include Nussbaum and Novick, 1982; Rowell and Dawson, 1985; Clement et al, 1987). These studies characteristically set out the details and underlying rationale of an instructional strategy and report its effectiveness in terms of pre-to-post test learning gains. Other teaching and learning studies (Edwards and Mercer, 1987; Lemke, 1991; Newman, Griffin and Cole, 1989) have adopted a different approach in analysing the processes by which understandings develop in the classroom and in doing so have focussed principally upon the social interactions and discourse of the classroom. These differences in approach reflect more than methodological preferences. Put briefly, the latter studies are based upon social constructivist perspectives which see learning in terms of the appropriation of the values and knowledge structures of a particular culture, a process which involves transformations from social to psychological planes. From this perspective any analysis of learning must involve analysis of the social context in which that learning takes place. In contrast, the first studies cited are based upon a view of learning which offers prime focus to the ways in which individual understandings develop or change in response to external events such as items of discrepant evidence or a particular analogy. As such these studies may, or may not, include a consideration of social processes in any analysis of learning.

This thesis focusses upon how students develop understandings of particular science concepts in classroom context. As such, it will draw upon, in its analysis, perspective which acknowledge the social interactions and discourse of the classroom. At the same time, it is recognised that learning science concepts must involve personal sense making by the individual and so the development of personal understandings provides a complementary and necessary further focus for investigation. To this extent the thesis offers a socio-psychological perspective on learning science in classroom settings. The principal research aims to be addressed in the thesis are as follows:

1. To identify and document the socio-psychological processes involved in learning science concepts in classroom settings.
2. To explore how the development of students' understanding of science concepts is effected by learning in difference science concept areas which give rise to differing learning demands.
3. To identify ways in which insights into the nature of the processes by which students develop understanding of science concepts might inform planning and implementation of science instruction.

2. Methodology

Overview: The research aims locate this study in the context of the day-to-day practices of the classroom and the intention is that the aims should be addressed through detailed analyses of case studies of relatively short segments of teaching and learning in selected concept areas. The study is thus based upon qualitative multiple case study methods.

In carrying out the study, the researcher is working collaboratively with a group of six experienced high school science teachers, all of whom have been involved in previous research work with the Children's Learning in Science Research Group and are familiar with constructivist views of learning. Instructional strategies for teaching in each of three concept areas have been developed in detail with the teachers and pairs of teachers have taught each topic, as part of their school's normal science curriculum for the 11-14 age range. Two case studies are thus being prepared for each concept area. Although the teachers have worked closely with the researcher in developing learning goals for each topic and instructional approaches to address those goals, the ways in which teachers operationalise the approaches in the classroom has been left to the judgement and discretion of individual teachers.

The three concept areas which have been selected for the study are 'rusting' 'air pressure' and 'interdependency of organisms'. These topics have been selected to include elements of both the physical and biological sciences and also to present different kinds of 'learning demand' for students. For example, the main focus of the teaching on rusting is to isolate the factors essential for rusting to occur whilst the goal of the air pressure teaching is to establish a generalisable pattern of explanation for a range of phenomena. At least one of the topics, air pressure, is widely acknowledged to be highly conceptually demanding of learners. In all cases, the topics require conceptual change or development by the students.

Data Collection: For each study, data relating both to the social interaction of the lessons and to the developing personal understandings of two or three target students is being collected. Where appropriate, diagnostic questions are being set prior to and at the end of the teaching, in some cases these questions form part of the instructional approach. Data from the diagnostic questions allow some insight into students' understandings of the subject topic at the start and end of the teaching.

During the lessons audio tape recordings are made of: all teacher talk; all teacher-student dialogue; all student-student talk from the target groups; any further student-student talk that can be captured. A record is also being made of all student written work completed during the lessons.

Two researchers attend the lessons, each one following the progress of two or three target students by means of informal questioning during the class (as far as circumstances allow) and through individual scripted interviews between lessons (again, as far as circumstances allow). All researcher talk with students is being recorded and the researchers also keep general field-notes of the lessons. During the lessons the researchers do not attempt to maintain a neutral observer's role. It is recognised that any talk between students and a knowledgeable adult is likely to influence the developing understandings of the student. Researchers-student talk is therefore being reported as simply one other form of discourse in the classrooms studied.

Data analysis: The first phase of data analysis involves writing case studies which document in detail the teaching and learning events of each sequence of lessons. In preparing these case studies, attention is being given to:

a. the ways in which language and activities are used by the teacher to create 'shared understandings' in the classroom (Edwards and Mercer, 1987, use the term 'common knowledge').
b. the ways in which the understandings of the target students develop.
c. the ways in which the understandings of the whole class develop (as evidenced by responses to class activities and to written work).

A second phase of analysis will focus upon issues emerging from all three concept areas and will address the issue of identifying and documenting the nature of the socio-psychological processes involved in learning science concepts. It is anticipated that an important part of this analysis will follow from identifying any mismatches of expectations which become apparent during the lessons. Such mismatches would include: differences in student and teacher thinking about the purpose of a particular activity; unexpected (by researcher and/or teacher) student responses to a specific question; situations where events are contrary to student expectations.

3. Progress to date (up to the time of the Seminar)

1. Instructional sequences have been prepared, with the teacher group, for each concept area.
2. Teaching has been carried out by pairs of teachers in each of the three areas and all data has been collected.
3. Most of the audio-tapes have been transcribed.
4. One case study is near to completion.

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Knowledge acquisition as interpersonal understanding

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1. Introduction

This paper is a summary of draft versions of three chapters of my forthcoming PhD-thesis. In section 2, the theoretical background of my PhD-study is outlined. The problem of interpretation and its solution mentioned there were the main topics of my presentation at the Summer School. By critically analyzing a typical study on pupils' ideas, I then tried to substantiate my claim, repeated in section 3, that in such studies pupils' ideas are often not properly identified, due to a lack to recognize the problem of interpretation. In section 3 I am also critical of didactic teaching and some constructivist teaching sequences. This criticizing is not an end in itself but part of my attempt to get a better grip on the notion of *conceptual change*, which so predominantly figures in the constructivist literature and largely seems to be taken for granted -as if we all know what is meant by it and all mean the same by it.[1] In response to a request put forward after my presentation, I also address the question how to structure an educational process such that it leads to conceptual change. In section 4, I sketch a global outline of such a didactical structure; in section 5, I briefly discuss its status as an empiric theory. These two sections are put in rather general terms. In my thesis, however, I will report on the construction, evaluation, reconstruction, etc of a *concrete* didactical structure: concerning the topic of radioactivity and aimed at middle ability pupils of about 15 years of age. It is only because of lack of space that in this paper I hardly examine the teacher's role. In my thesis I will go in to it, and also report on my close cooperation with a teacher.

1. The point that the notion of conceptual change or, indeed, the notion of concept itself, does in fact stand in need for further clarification, has also been made by some others during the Summer School.

2. Theoretical considerations

Let me begin with drawing attention to the *problem of interpretation* that follows from the next two observations. In order to fathom someone's thoughts, meanings and actions, we have nothing else to go on but publicly observable behaviour, roughly: the other's motions, made noises and place in the world. On the other hand, the other's motions and made noises do not carry or contain meaning and do not convey beliefs, desires, intentions, etc. The problem of interpretation is how we are able to understand one another, given the nature of the evidence we have to go on. Davidson (e.g. 1990) has both put the problem sharper and shown some steps towards its solution. He argues that the smallest unit in which the problem of interpretation can be solved is a *triangle*, two of whose vertices are communicators that are aware (and are aware that the other is aware, etc) of the triangle, and whose third vertex is the communicators' shared world of objects and events, the properties and existence of which are independent of the communicators' thoughts. The process in which they come to fathom each other's thoughts, meanings and actions is one in which they render each other's behaviour, verbal and otherwise, intelligible in the way that intentional actions are intelligible -in which they come to see each other as rational creatures, who consider, test, reject and accept hypotheses, act on reasons, achieve goals and realize intentions, are subject to moral evaluation, etc.

A further investigation into the nature of interpersonal understanding, and of linguistic communication as the indispensable instrument for fine-grained interpersonal understanding, brings forward some unavoidable requirements that as interpreters we have to meet. For in order to make the interpreted person's behaviour intelligible to us, we must describe her actions and what she believes and wants in such a way that, as described, we can see for ourselves that what she did was the reasonable thing to do for her. So one requirement is that we impose conditions of coherence and consistency on the pattern of beliefs, desires, intentions, actions, etc that we attribute to her. This requirement comes down to the presumption that she shares our own basic *standards of rationality*: reason-explanations make her intelligible to us only to the extent that we can recognize our own standards realized in her behaviour. In order to give content to particular thoughts, there is another obvious requirement that we have to meet. It is based on the pedestrian idea that in the most basic cases thoughts, or sentences used to express them, are about the sorts of objects and events that cause them. If, for instance, we have good reasons to suppose that the interpreted is selectively caused to hold true a sentence by the presence of rain, we cannot do better than so interpret the sentence that it *is* true (by our own lights), i.e. as meaning that it is raining. The *causal relations* between the world and her speech and thought play an essential role in interpreting what she says and thinks. These two requirements, the complex interplay of which enables us to understand one another, may be summarized as follows: in order to make someone make sense, we must interpret her (and adjust our interpretation of her) such that she comes out as largely consistent, a believer of truths, and a lover of the good (all by our own lights). This constitutes, in summary form, Davidson's *principle of charity*. It formulates, however crudely, essential aspects of the common concepts of thought, affect, reasoning and action as we use them to understand, describe and explain human behaviour. Our ways to interpret human thought and action are thus essential to all knowledge and knowledge acquisition. Furthermore, all interpretation depends on our ability to find common ground. Finding the common ground is not subsequent to understanding, but a condition of it. Everything rests on sharing, and knowing that one shares, a world, many reactions to its major features and a way of thinking with someone else.

3. Some consequences for science education

With regard to education, the above suggests that we think of the educational task as one of creating optimum conditions for mutual understanding. Furthermore, since our ways to understand human thought and action do not only involve cognitive attitudes like holding true or degree of belief, but also evaluative attitudes like preference or strength of desire, the evaluative attitudes must also be explicitly taken into account. On a global level this means that aspects like motivation, interest and enjoyment are of considerable importance for the interpersonal process of knowledge acquisition. On a more local level this means, for example, that pupils should not only perform experiments but also devise and evaluate those experiments. That will considerably increase the chances of teacher, pupils themselves and researchers to find out the intentions and purposes with which the experiments are performed (to understand the experiments as intentional actions) and the meaning of what is said. Linguistic communication will have to play an important role in the process as well, and it should take place in the context of frank discussion. Furthermore, given that mutual understanding depends on a largely shared and correct view of the natural world and that an interpersonal process of scientific knowledge acquisition aims at an addition to that view, we get a picture of science learning in which acting and interacting pupils come to add to their linguistic and conceptual resources by using their existing conceptual resources and thinking strategies to further and further characterize and explain more and more aspects of the natural world. The task of planning and guiding science education is to adequately structure this process.

The process can only be successful, however, if it is continuously governed by the principle of charity. I see didactic teaching as an example of an educational process that, because of the way it is organized, cannot be continuously so governed. I think it is for this reason that didactic teaching leads to poor results: pupils' being unable to apply what they have learned or to solve non-standard problems, verbalism, compartmentalization, formalism, etc. An attempt to improve matters that has been proposed in recent years is 'the' constructivist approach to teaching. In the 'constructivist literature' the failure of didactic teaching is often analyzed as being due to a lack to take pupils' existing ideas into account. It is therefore argued that science education should not proceed as if pupils know nothing (as if they are empty vessels), but that the process of conceptual change that a constructivist approach aims at should rather start from what pupils already know. I do agree with this, but only on the conditions that what pupils already know is properly identified, and that we think of conceptual change as a process in which pupils build on and extend what they already know -as a process that may add mightily to their linguistic and conceptual resources, but cannot subtract much. Much that has been written on constructivist approaches does not satisfy these conditions. First of all I think that what pupils already know is often not properly identified. Indeed, instead of interpreting pupils in such a way that the existing ideas we thus come to attribute to them are generally correct, pupils are often 'interpreted' (I would rather say: misunderstood) as having views that are at variance with the scientific view. As a result, 'taking existing ideas into account' then transforms into 'taking alternative ideas into account', and 'conceptual change' then stands for 'change of alternative ideas'. The dominant metaphor in the constructivist literature is that of 'overcoming'. What pupils already know should be challenged; their alternative ideas should be directly addressed in order to encourage them to reject those ideas; they should become dissatisfied with their existing views; the status of their existing schemes should be lowered, etc. I conclude that, like didactic teaching, such constructivist teaching sequences lead to educational processes that, because of the way they are organized, cannot be continuously governed by the principle of charity. One cannot but expect poor results of them.

Conceptual change is thus not a process of absorbing a new stock of beliefs, nor a process of replacing the stock of existing beliefs with another one. Moreover, to try to describe it in terms of just one 'parameter' (belief), is principally too narrow. In line with the above one might try the following: it is a combined process of replacing existing uses of language with other uses of language (*change of meaning*) and adding to the stock of existing beliefs (*addition of belief*). But also this description, containing two 'parameters' instead of one (belief *and* meaning), is still too limited. It leaves out evaluative attitudes such as *desire*. I suggest to think of conceptual change as a process that involves desires (and thus intentions, expectations, intentional actions, etc) and changes therein, all of which are irreducibly and intimately related to beliefs, meanings, and the additions of belief and changes of meaning. In this process pupils' being rational will serve as a kind of driving force. It drives them to constantly make their present system of thoughts as coherent as possible, adjusting it as rationally as possible as new thoughts are thrust on them. The outcome of an experiment they performed for reasons that made good sense to them may e.g. cause them to add to their stock of beliefs. *Rational accommodation* of that belief may lead to new questions they want to find an answer to, to the formation of an intention to focus their attention on some aspect of an event, to the formation of expectations, to the intentional performance of an experiment, the outcome of which ... etc.

4. Global outline of a didactical structure

An account of the expected route that a process of conceptual change concerning some topic will follow (guided, of course, by teaching materials and teacher), I call a *didactical structure* for that topic. It contains predictions of the following kind: how pupils will interpret a task, given what has preceded; which kinds of experiments they will think of given what they believe and want to achieve; which conclusions and questions they will formulate as a result of their experimentation; how their intentions will change accordingly, etc. A didactical structure does thus not simply consist of a series of tasks for pupils, but rather consists in the design of a good educational process in the light of which such tasks are justifiable. The predictions a didactical structure makes are to be understood like the teleological (or: reason-) explanations we give of human thought and action. The latter render someone's behaviour intelligible to us, precisely because they describe her behaviour as being governed by the basic standards of rationality she shares with us. They are, because of their appeal to rationality, description and explanation (rationalization) *in one*. Likewise, when predicting what will happen, it is in justifying those predictions that an appeal to pupils' rationality comes in. For it will then be assumed that when devising experiments pupils will think of ones that can reasonably be expected to give answers (to questions they preferably posed themselves); that they will base their hypotheses in a sound way on the relevant evidence and will collect appropriate new evidence in order to choose between various hypotheses; that they will, by applying the principle of charity, be able to find out how each of them uses his or her words, etc.

I will now sketch a global outline of a didactical structure for some scientific topic that supports a learning process in which pupils come to add to their linguistic and conceptual resources in order to further and further characterize and explain more and more events of the type that the topic covers. Much of the point of the general outline is that the pupils are brought in such a position that they themselves come to frame the main problems they are going to work on. For this reason I call the approach *problem-posing*[2]. Having framed some problem themselves will secure that it has a clear meaning for them and that they will be more involved in finding a solution. Moreover, reflection on the very process that lead to their framing their problem is likely to be of great help for their later solving it and for realizing that solving it may involve them in a process of rational accommodation. My ideas about the global outline are inspired by the work of van Hiele and ten Voorde.[3] They articulate the process in three successive periods that presuppose one another: (1) a period of attention selection, in which a *ground level* for the following descriptive level originates; (2) a level transition from ground level to a *descriptive level*; (3) a level transition from descriptive level to a *theoretical level*. Below I focus on the first two periods, partly because of lack of space and partly because my ideas about the third period are too immature.

The descriptive level can be thought of as a *way of describing* and a *set of generalizations* such that, if appropriately described, the occurrence of a range of events can be predicted and explained by means of the generalizations. The descriptive level can thus be seen as a systematic answer to problems of the following general kinds: how can an event of some kind be made to happen?; or: what will happen if something of this kind is done? Specific examples may be: how can an object be made radioactive?; if two objects are brought into contact, then what will happen to their respective temperatures? The point of a problem-posing approach now is to bring the pupils in such a position, by challenging them to perform actions (e.g. do experiments) and think about those actions, that they themselves eventually in-

2. I intend problem-posing here to be understood as more or less opposed to problem-solving. The latter appears to me to be the main or even exclusive concern of many educational studies.
3. See the references. I think it fair to say that I may have distorted van Hiele's and ten Voorde's ideas beyond their recognition. For a more faithful representation of their ideas I refer to Kaper's contribution to this volume.

tend to somewhat systematically work on such problems. This intention can thus be seen as one to bring order (structure) in the causal relations between some events, e.g. in the causal relations between their actions and the outcomes of their actions. Making the pupils arrive at such an intention requires careful preparation. For not only must they come to see some problem as a real problem that is worth a further investigation, but they must also come to understand it in a particular way, and come to get a fair idea about how to tackle it and about when they have solved it, in order that through a further investigation they can reach the descriptive level.

The first period, that of *attention selection*, is in several ways preparatory. In it pupils get a global outlook on what sort of events will be studied and, starting from everyday uses and for reasons that at the time make good sense to them, come to *agree on specific uses of some terms* (e.g. of the term 'is radioactive' alongside the term 'has got to do with radioactivity,' or of the term 'has a higher temperature than' alongside the term 'feels, when touched, warmer than'). Since it is in such terms that the pupils will later frame (and find a solution to) the problem they intend to solve, it can be said that the foundation (ground level) for the descriptive level emerges in the first period. It is the aim of the early stages of the second period that the pupils come to recognize and understand in a particular way the problem, in a process in which they more and more consistently stick to the previously agreed uses of terms in order to characterize events (e.g. events they themselves bring about in experiments) while their reasons for performing actions qualitatively shift. The shift may e.g. be one from doing something simply because they think that thus they will meet a task's call to bring about some effect, to wanting to prove that some particular action will have an outcome they themselves want to bring about, to open-mindedly and systematically wanting to do experiments in order to e.g. find out under what conditions an event of some kind will occur.

In the process that has lead to framing their problem, the pupils must also have got some idea about how to solve it. This idea has to derive from their recognition of regularities, e.g. that actions of a certain kind always seem to be followed by outcomes of some kind. Their intention to bring order in the causal relations between events can then take the form of trying to *find more* such *connections between properties of events*. It is because they are prepared for in the first period and because pupils have more and more used them to characterize events in the early stages of the second period, that plausible such properties can be summoned up by the pupils. The connections, i.e. the generalizations of the descriptive level, that are thus established will be law-like in the sense that someone who knows what their instances are and how they cohere with those instances, will have good reason to expect other instances to cohere as well, and will be able to project them to unobserved cases and to invoke them to advance counterfactual claims. They will not be lawlike in the sense of being strict, exceptionless, and indefinitely refinable within the same vocabulary. The explanations and predictions that can be produced on the descriptive level, finally, are more or less elaborate stories that relate cause and effect. They involve an appropriate generalization and a redescription or further description of e.g. the cause, such that the generalization conjoined with a statement that says the cause (described appropriately) occurred, entails a statement that asserts the existence of the effect (appropriately described).

5. A didactical structure as an empiric theory

As a prediction of what will happen in a series of lessons, a didactical structure goes empiric by comparing it with what actually does happen[4]. As any empiric theory, it is thus open for revisions to cope with new data; and as for any empiric theory, there are no strict rules that tell where (and which) revisions are to be made. Moreover, because a didactical structure is a highly interrelated complex, changes in one area are likely to be accompanied by changes in several other areas. So when researchers, preferably in close cooperation with teachers, in this way study the outcomes of their efforts to bring about educational phenomena of the desired type, they will, like pupils in *their* study of physical phenomena, have to engage in a process of rational accommodation. If they are forced to adjust the didactical structure, they must do so as rationally as possible and stand ready to tinker where tinkering does the most good.

Let me close with stressing that a didactical structure is an empiric theory of a different kind than a developing physics strives for. The main reason is that a didactical structure essentially deals in concepts such as belief, desire, meaning, intention, etc, which, precisely because they only have application against a background of rationality, resist incorporation into the closed system of strict laws that physics aims at (cf Davidson, 1980, 207-27). Moreover,

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4. Of course what actually does happen will have to be interpreted before it can be compared with the didactical structure. Having available a didactical structure will be of great help for that interpretation. The main reason for devising a detailed as possible didactical structure is that it will later serve as an important research tool. A further worked out version of Davidson's foundational approach to understanding promises to provide a means to somewhat systematize both the (re)construction of a didactical structure and the interpretation of what actually does happen.

a didactical structure does not predict or explain by recourse to a system of strict laws, but by an appeal to rationality. In explaining phenomena as physicists we are not aiming to discover rationality in the phenomena; but in explaining action we are identifying the phenomena to be explained, and the phenomena that do the explaining, as directly answering to our own standards of rationality. So there is no hope, but also no need, for a didactical structure that will for sure lead to the desired result in exactly the predicted way. What matters is whether a didactical structure is '*good enough*': whether it serves as a valuable guideline in series of lessons that are as well as possible governed by the principle of charity. Each of these series, however, will without doubt meander in a somewhat different way around the main path. So the aim is a didactical structure that is 'good enough', augmented with some rules of thumb for what to do when things do not work out as predicted. Several revisions will be needed before the didactical structure can be judged as 'good enough' and the first revisions will surely lead to considerable improvements. But no matter how many revisions have been made, without the creativity of a good teacher no education could ever be successful.

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How do individual pupils learn within small groups? Empirical investigations considered from a constructivist point of view

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1. The topic of research

At the 'Institut für Didaktik der Physik' from the university of Bremen empirical investigations with 15-17 year-old pupils are carried out within the framework of the research programme 'Individual learning processes in physics instruction'. We are looking at learning processes from the assumption that each cognitive system can only refer to itself and constructs its individual actuality. Therefore pupils construct their own meaning of scientific concepts and facts, depending on their experiences and the particular environment.

Constructivism puts the individuality of pupils at the centre of attention. Consequently, individual learning processes are of primary interest at Bremen university. We are mainly interested in the processes by which pupils produce knowledge, not in this knowledge itself.

In my own project the influence of the social sorroundings on the individual processes will be of particular consideration. The interactions among pupils and between pupils and teacher and their influence on the processes by which knowledge is produced will be a main topic. The proposal is to investigate individual learning processes in small groups of about four pupils and to compare the learning processes which take place in this small groups with regard to their different social surroundings.

2. The starting point of the investigations

In recent work, the Bremen group has developed an useful description of the cognitive system. In this description it is assumed that the cognitive system consists of separate domains, called 'domains of subjective experience' (DSE, see also Bauersfeld, 1983). The seperate domains were built up in former situations and in new situations the cognitive system refers to these experiences. In principle the DSE are modelled seperately, but they can be connected to each other. For example a DSE can contain experiences in which 'work' in a commonsense as strenuos deed is important. The concept of work taught in physics usually differs from these experiences.

Basis of our description of learning is the essential ability of living beings to categorize expectations and perceptions, which is taught by gestalt-psychologists (for example see Roth, 1985). Modifying a model from Powers, we assume that the perception of an individual is organized in successive levels:

1. *Objects* emerge from sensory impressions.
2. *Properties* are assigned to the objects. Objects are ordered in certain classes regarding color, charge, etc.
3. *Events* occur when objects with their properties are related in space and time.
4. *Programmes* are sequences of single actions. They are performed to establish events.
5. *Principles* are fixed abstract rules which lead actions.
6. *Systems* are networks of many principles.

These levels are also levels of action control. For example, pupils in their first lesson on electrostatics are usually not familiar with objects like electroscopes, glow lamps, or chargeable synthetic fibers. So before they are able to plan programmes they must get familiar with the objects and their properties. But after some time they will recognize events rather than single objects and then new objects are promptly arranged with regard to the experiences made so far.

In this model, learning is the development of DSE. Learning is the development of tools to consistently organize actuality. The cognitive system can master difficult tasks progressively by increasing its complexity.

The development of the cognitive system, respectively of parts of it, occurs when a cognitive system is not able to make its expectation congruent with its perception. Then the system starts an action (physical or communicative act) leading to the construction of a new expectation and a new perception. Therefore it goes through a circular process of expectation, perception and action as long as the discrepancy exists. When the discrepancy becomes too large and the system has no possibility to clear up the contradiction, the circular process will be broken off and no further action will be started.

3. The method

In order to observe learning processes, small groups out of the class are observed with video cameras during the whole period of instruction. Out of the video material suitable scenes for analysis are chosen. These scenes are transcribed, i.e., all linguistic and visible facial expressions as well as physical acts are written down. In an elaborated analysis the observer himself constructs the constructions of a pupil. For that purpose the scene to be analysed is described as a sequence of discrete single actions. In a second step ideas are assigned to each single action. The ideas represent the pupil's expectations in view of his just constructed perceptions. Single actions are discreticized as well, following a modified Powers-model, by assigning percepted objects, expected events, action programs, and others to the pupil by the observer. In this way the individual learning process of each pupil is modelled by the observer. During the whole analysis the observer must be aware of his own subjective point of view.

By this method we have applied a usual working method of empirical sciences. It leads to a model of a pupil's learning process which simplifies reality. It will allow predictions about future situations that are based on empirically provable assumptions. Sofar, we have been successful in modelling individual learning processes of pupils in a first approximation, i.e., without concern about social processes.

4. Own work

In my thesis I will built on investigations which are done by an advanced co-worker, with a group of four girls on electrostatics instruction in a 10th grade class. She is dealing with the questions when and how interactions between teacher and pupils or among pupils take effect. I will compare the analyses of the individual learning processes of two girls from that group, with the learning processes of two boys, who took part in the same instruction but in another group. The analyses are done on several action-orientated scenes, in which the pupils could experiment freely to a great extent.

The main topic will be a description of how individual learning processes are embedded in their social context. Part of the social context is the group of classmates who work together during instruction. Each formation of meaning takes place in a subject, and the interindividual meaning and public knowledge emerge from individual processes. Understanding is obviously a social process, subjects try to understand either each other or public knowledge. The understanding is mainly construed by a subject via interaction and speech. Therefore communication will be at the focus of attention of my research. Embedding individual learning processes in a social context should lead to a useful description of important terms, like motivation, objective, and social accomplishment and their influence on the organization of a pupil's actuality.

The results about the significance of interactions to be found out, should be put on a sound theoretical basis. The model of learning developed sofar should possibly be extended for that purpose.

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Small group discussion in physics: interaction and development of students' physics understanding

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1. Introduction

The use of group discussions has been investigated as a means of eliciting and restructuring children's ideas in science in a number of research and development projects. There are also studies about the effect of group discussion on individual learning in physics. However, there is limited research that attempts an in-depth analysis of the processes involved during discussion and hence the dynamics of change in students' physics reasoning. This study was undertaken with two aims:

1. to investigate the extent to which group discussion helps students to reconstruct and develop their qualitative reasoning in physics.
2. to look at the nature of the discussion processes by analysing the forms of argument construction and types of social interaction used by students during group work.

The importance of discussion in learning is acknowledged within different theoretical perspectives. Piaget, for example, emphasised the personal construction of knowledge through the individual's experience of their environment. From this perspective, the prime focus is upon the psychological process of equilibration and 'other people', that may form part of the learner's environment, are seen as simply aiding the process by, for example, helping to create cognitive dissonance. On the other hand, Vygotsky emphasises the construction of knowledge as a social process and stresses the fundamental role of language and dialogue in shaping meanings. If learning science involves 'being initiated into the culture of science', the social negotiation of meanings and the creation of shared ones within the science classroom is at the centre of the development of students' understanding. In such cases, describing the effects of group discussion and, more importantly, understanding the mechanisms of knowledge construction in group settings, can give a helpful insight to the types of intervention that would make group work more productive.

2. Description of the study

The study involved 203 Greek secondary school students aged 14-15 coming from four state schools sited in different socioeconomic areas of Athens. Two comparable mixed ability classes with the same physics teacher were chosen from each school. One class was the experimental group in which students took written pre- and post-tests and discussed the questions in small groups between the tests. The other class was the control group in which students were pre- and post-tested but no discussions were used.

Six questions, requiring qualitative reasoning in physics, were used in the study. There were two questions on heat transfer, two on change of state ideas and two on free fall. The questions related to phenomena which would be familiar to students in their daily lives. Each question required the students to make predictions and give detailed explanations since it was the reasoning behind students' predictions that was of interest. The questions were open-ended so as to facilitate discussion. The study was carried out in three phases and took place in students' own classrooms. First, all students were pre-tested with the six test items and were asked to complete them non-collaboratively. Immediately after the pre-test, students in the experimental classes discussed the questions in self-selected, single sex groups of two or four students and their discussions were audiotaped. For each question, one person, chosen by the group, had to write down on the group's leaflet their agreed answer or their disagreements as well as the supporting reasons in either case. The students in the control classes had no such intervention. Two to three weeks later, both experimental and control students were post-tested with the same reasoning tasks which had again to be completed non-collaboratively. Since the study had two aims, there were two different methodologies used in analysing the research data. First, experimental and control students' pre- and post-test responses were categorised and compared so as to see whether group discussion had an effect on experimental students' post-test performances. The categorisation of students' responses was based on a set of hierarchical response categories, including the accepted physics reasoning. Pre- and post-test comparisons were first done for each student and each question separately so as to identify cases of progress, regress and no change in students' physics reasoning. Then, for both experimental and control students, overall results were obtained which were further analysed in relations to different questions, different schools and gender. Moreover, experimental students' pre- to post-test changes were also analysed to find out if progress in physics reasoning was related to different sized groupings (pairs and fours) as well as the gender of the groups.

The second aim of the study was to understand aspects of group discussions that influence the course and the outcomes of students' interaction. The analysis of the discussions was first undertaken to find out overall patterns in the different types of discussions in terms of the forms of argument construction and types of social interaction used by students during group work. Argument construction was analysed in terms of discourse moves such as: proposes a result, proposes a cause, expands loosely, advances evidence, negates, evaluates, applies a principle to a case, restates and so no. Social interaction was analysed in terms of students' use of agreements, disagreements, questions, requests for evidence and comments. The comments used by students were also differentiated according to being supportive, aggressive, showing uncertainty or compliance and so on.

A step-by-step analysis of selected discussion sequences was also carried out in order to understand the dynamics of the processes of peers' interaction as the discussion proceeds. Group discussions were identified as progressive or regressive in reference to whether one or more group members progressed or regressed in the post test in relation to each specific question, with the other group members staying the same. The discussions that were analysed included equal numbers of progressive and regressive discussions. Moreover, they included equal numbers of male and female discussion groups and equal numbers of groups of pairs and fours.

In terms of students' pre- to post-test changes, the school factor, gender and grouping effects were found to be statistically significant. Although experimental students progressed more and regressed less than control ones, their progress was still quite modest as a result of small group discussion - especially in those questions where students hold strong alternative ideas. However, experimental students' progress or regress in physics reasoning seems to be related to the forms of argument construction and types of social interaction of the discussion groups. The extent to which peers explore their views instead of simply presenting them seems to be the main difference between progressive and regressive discussions. On the other hand, peers' efforts to construct an argument seems to be closely related to their interaction on the social level. Male and female groups have different social interaction modes when placed in pairs and fours and this seems to affect the processes and outcomes of group discussion in different ways.

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and evaluation

Second thoughts on a first summerschool

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Consolation for the reader:
Much is published, not
in order to be read, but in
order to have been written.

1. Introduction

This reflection, unfortunately, is not what I had in mind originally, i.e., an attempt to overview the research that was reported at the summerschool. Do all those, at first sight, 'one shot' PhD. studies contribute to a common goal and, if so, are we making progress in reaching it? Lack of time (and insight?), however, prevented to let this be more than only a number of more or less superficial personal thoughts. So be it.

First a personal anecdote to start with. Twenty years ago I finished my PhD. in molecular physics. I tried to measure a certain type of collision cross section, but due to experimental difficulties, I could only measure so-called total effective cross sections, i.e., averaged over a Maxwell-Boltzmann distribution of velocities and energy states. So, the interaction potentials to be extracted could only be very crude. Though I left the field, every now and then I talk to former colleagues, who tell me that due to the development of laser and beam technology, the same interaction potentials can now be determined experimentally in great detail. And thanks to the well-established procedures of quantum mechanics and modern computers, the data can now be checked theoretically as well. Thus, in twenty years, considerable progress has taken place in this field (which of course, doesn't say anything about its importance).

This experience always leaves me with some uneasy feelings, not about the story itself, but about the field of work I changed to, i.e., research in science education. What progress did we make in science education during that same period? In what respect can we say that we are now able to teach 'better'? What is our 'laser technology' and what our 'Q.M.-theory'? Do we have them? Or is it a 'category mistake' or, even worse, simply a symptom of deep misunderstanding of the nature of research in science education to ask such foolish questions? Nevertheless, the idea for summerschools for PhD's sprang from them.

From these questions, it may be clear that I see 'improving science education' as the main aim of science education research. In view of the literature, I'm not quite sure that such an aim can be taken for granted. Our 'theories' should not so much contribute to 'cognitive science' or educational psychology, though we may draw on them, but, in the first place, to understanding and improving science teaching practice. This pragmatic view may have to do with with the fact that, as in Utrecht, science education research at the European continent, is quite often organised as being part of university Science Departments, to be distinguished, e.g., from Great Britain where it is organised within Schools of Education.

The first summerschool has been an enjoyable event, according to the judgement of almost all participants (see below). In spite of the diversity of the reported research, many say to have learned much, though the learning outcome has seldom been made very explicit. Does this diversity reflect an essential characteristic of research in science education as a field of work? Or could we, from the reports of the participating institutions conclude that much research is being planned in productive research programmes? What then are the main lines of research, and how do they interrelate?

To distinguish main lines, one has to categorise the respective contributions according to rather diffuse criteria. In his contribution, in fact, Adey has tried to do so. In this reflection, however, I will not follow his useful proposal, but adopt a somewhat different view.

2. Studies on the nature of common(-sense) reasoning

A main field of research, not so much in number as well as in importance, in my opinion, is the search for fundamental patterns in common(-sense) reasoning. In a working paper, distributed at the school, Ogborn writes that his work in this area:

> 'started in part from a dissatisfaction I felt with the large body of empirical work describing children's and students' ideas. It was not clear whether this work represented more than a collection of ideas, strange or curious, of what children think. Various not very clear theories had been aired concerning their nature: that they reflect deep intuitive theories; that they are just immediate context-bound responses to adults' strange questions; that they are the outcome of individual prior

> experiences. The guiding idea (....) was somehow to get below the surface of children's responses.'

From this quotation we may indeed conclude to research productivity. A major problem with previous research, asked for looking at a deeper level. If pupils' ideas are in some way reflections of commonsense thinking, could we understand what they say (and don't say) more coherently and profoundly by looking for basic dimensions of commonsense thinking. Many philosophers have written about commonsense, Ogborn's programme, however, seems to be a creative empirical effort to unravel such basic categories.

Viennot's paper describes a related problem. Drawing on content-dependent studies, she focusses on 'transversal aspects of common reasoning, i.e., on aspects that can be observed about very different domains of physics.' She stresses 'what seems to be the most important, i.e., on ways of reasoning used by many persons about many topics.' In focussing on children's, students' and even teachers' patterns of reasoning about physics, clearly her work cannot be considered (and doesn't claim) to study common sense reasoning as such. In fact, she studies common patterns in the reasoning of students who have been taught much physics. So, what is the nature of the patterns she finds? Are they typical reasoning patterns in physics (or science?); are they patterns of misunderstanding possibly as the result of 'bad' teaching; do they show the persistent influence of commonsense reasoning, or is it a mixture of these possibilities?

This poses the problem of the relation between reasoning in physics and commonsense reasoning, which has direct consequences for the way in which the development of ideas of physics may or may not be taught. The late Dutch mathematician and mathematics educator Freudenthal (1991) writes about mathematics as follows:

> 'In order to become genuine mathematics, and in order to progress, commonsense must be systematised and organised. Commonsense experiences, as it were, coagulated into rules (such as the commutativity of addition), and these rules again became commonsense, say of a higher order, as a basis of even higher order mathematics - a tremendous hierarchy, built thanks to a remarkable interplay of forces.'

And thanks to this evolutionary process, mathematics can and should be taught as an activity in which children *mathematise* their world, i.e., as a guided activity of progressively organising and systematising commonsense, according to Freudenthal.

Is the same view possible for science teaching? 'The whole of science is nothing more than a refinement of everyday thinking,' according to Einstein, and others write in the same sense about 'science as organised commonsense'. However, what do the terms 'refinement' and 'organised' actually mean in this context? Reif and Larkin (1991), on the other hand, conclude as follows: 'An analysis and comparison of everyday life and the domain of science reveal significant differences in their goals and in the cognitive means used to attain these goals.' However, it seems as though they compare two endpoints on a scale, which doesn't say very much about how to go from one end to the other. Wolpert (1992) even advocates the 'unnatural nature' of science, while Freudenthal (again) writes:

> 'Commonsense tells you that 3+2=5 and what is the area of a rectangle. But as soon as Nature is concerned commonsense is misleading as everybody can tell. More urgently than in mathematics, and more urgently the farther a science is remote from mathematics, common sense asks for amendation and education, for enrichment by transfer of knowledge; and even where commonsense is a nuisance it may persist alongside with more educated views. Unlike the law of inertia or Newton's theory of gravity, the elements of mathematics have independently been invented at various places in the world. While sciences underwent revolutions, mathematics evolved, even during these revolutions and under their influence.'

Thus Freudenthal suggests that science did not evolve in a continuous (whatever that may mean) process of systematising commonsense, sothat science teaching encounters consequential difficulties (that differ from those in mathematics teaching). A relevant example goes, according to Ogborn, as follows:

> 'A person moving an object is not just an example of a cause, but it is the very *prototype* of a cause. Thus for Newton to deny that steady motion has any cause is to strike at the roots of commonsense reasoning. What most counts as a cause is being taken away.'

So, apparently, at the level of (philosophical) analysis, at least some confusion and disagreement seems to be present. Could it be that Ogborn's 'ontological spaces' provide some empirical contribution to this matter? Would the 'spaces' according to the answers of scientists look very much different from those of pupils? And if so, would this give new insights into basic differences (or similarities) between science and commonsense? That would be an interesting extension of that research programme, I think, though it would still leave the problem of how to deal with its consequences in education unsolved.

In the discussion following Viennot's presentation, the remark was made that focussing on common patterns would be important in teaching, not to replace or shortcut attention for content-specific reasoning, but to add to them. Both are needed and should get appropriate emphasis. So far, most studies dealing with teaching and learning science seem, however, to focus on the latter, almost to the neglect of the first.

3. Studies on the nature of teaching and learning science

A second basic field of work is the nature of teaching and learning science. In fact, one could say that this should integrate and build on two separate fields, i.e., the nature of teaching and learning and the nature of science. However, the present discussion about 'constructivism' shows their interrelatedness. At the summerschool, Driver has presented an overview of present day constructivism(s). In particular, she has tried to delineate two main streams that are usually described as personal and social constructivism. Within those, a particularly influential point of view, to be mentioned separately, is Von Glasersfeld's radical constructivism. These views on knowledge construction have influenced almost everybody working in our field. A positive result for science education is that the problem of 'conceptual change' instead of conceptual transmission has now become central. Unfortunately, however, the phrase 'conceptual change' has practically become meaningless. At the 1993 AERA-meeting, e.g., this phrase was used almost as a synonym to learning. Almost nobody said anymore 'students have learned something', but 'students have gone through a process of conceptual change'.

Von Glasersfeld's radical point of view has strong adherents as well as strong opponents. One of his main points is the rejection of objective knowledge. In a famous paper of his (1989), he writes as follows:

> 'During the last three decades faith in objective scientific knowledge, a faith that formerly served as the unquestioned basis for most of the teaching in schools and academia, has been disrupted by unsettling movements in the very discipline of philosophy of science.'

Freudenthal (1991, forgive me my chauvinist attitude) reacts to this quotation as follows:

> 'Indeed, and this is a most striking symptom of the ever broadening and, to my mind, most deplorable gulf between the philosophy of scientists and the philosophy of philosophers of sciences, at least as preached by the noisiest among them. Would any scientist who lacks faith in objective knowledge have ever had Voyager 2 launched for a visit of the big planets - as far as Neptune - to gather knowledge about them? Would he have had big accelerators built that are to discover missing elementary particles? Would he analyse long DNA strings in order to manipulate them? Would he excavate ancient cities and

> decipher ancient inscriptions? These are just a few questions out of an interminable variety (...).'

Could this more or less express the same what Ogborn had in mind when, in the discussion following Driver's talk, he uttered the provocative statement that he wondered what the attractiveness could be of a philosophy that is so demonstrably wrong? As he asked for personal reactions of the participants, I will now give mine. For me the attractiveness lies in the attempt to take really seriously what Von Glasersfeld calls 'trivial constructivism', the idea that knowledge is not passively received but actively built up by the cognizing subject. This idea may be philosophically trivial, educationally it is both old and certainly not trivial at all to deal with. From my experience in curriculum development, I know that it is extremely difficult to really deal with pupils' constructions in education. That we are always inclined to underestimate pupils' creative thinking and to overestimate the understandability of our 'good' teaching interventions and 'clear' explanations. In retrospect I could say that it is precisely because we did not pay sufficient attention to the idea of 'trivial constructivism' that the curriculum effort I participated in for years, had only very limited success as far as improved conceptual learning of pupils is concerned. Moreover, the rise of research on misconceptions meant that for the first time, educational research seemed to focus really on the content of science learning, and thus to promise results that dealt with, and could be put to use at the level of the practising science teacher. Unfortunately, this has not yet sufficiently been realized, as the apparently unavoidable urge to be 'scientific' seems to draw our attention towards theoretical and philosophical debates as an aim in itself, instead of focussing upon down to earth improvement of learning in classrooms. The debate about 'constructivism' is a case in point. Thus, as Freudenthal puts it:

> 'If I were to accept the term 'constructivism', I would mean a programme having a philosophy that grants learners the freedom of their own activity. (..) Lacking a convincing context, such terms as construction, reconstruction and constructivism are doomed to remain slogans. The only context that counts didactically is instruction itself, that is, instruction developed from the direction of the design onwards towards its realisation.'

Where does this leave radical constructivism? To my opinion it is educationally largely irrelevant. Unintendedly, Dykstra (1993) illustrates this convincingly if he asks himself: 'What would a radical constructivist rationale for teaching be?' And partly answers this by saying: 'Can we say education is for the purpose of transmitting knowledge/culture? No. Individuals can only construct this for themselves.'

Or, to give a last quotation of Freudenthal's, which, to my mind, also applies to science teaching: 'At any rate, I cannot see any bond between mathematics instruction on the one hand and an alleged or assumed lack of faith in objective mathematical knowledge on the other hand, whether it is called constructivism or anything else.'

So, it is not the philosophical but the educational context that counts. It is from that context that Klaassen, paradoxically drawing on philosophy of language, argues for the importance of 'the problem of interpretation' in knowledge acquisition. Donald Davidson's *'principle of charity'* describes a basic guideline to solve that problem. If we want teaching to be successful, we should view the teaching situation as a place where interpersonal discourse should continually be focussed on mutual 'charitable' understanding. Research in science education should therefore also focus on the essential interaction process of pupils, and of pupils and teachers, in relation to their shared world of objects and events. And on the basic question of how education can be designed so that pupils really come to know and understand more and more about that world. If we do so, the whole theoretical discussion about 'constructivism and conceptual change' may turn out to be largely of secondary importance.

This 'interpretation' approach differs largely from that represented in the 'Bremen programme,' in which learning processes are essentially described as an individual development process. Thus, this programme very much focuses on the view of personal constructivism. Study of interactions seems not to be done as an aim in itself, because it relates to the essence of education, but rather as one of the instruments that may stimulate the development of subjective domains of experience. If I understand it correctly, the focus on physics learning is also only because physics learning is supposed to go along rather well structured pathways, which makes it a good subject for studying learning processes. This work, together with their work on 'competence' most closely links with what Adey has summarised as 'cognitive science' approaches.

The duality of studying either individual or social learning processes is a recurring topic in a number of presented papers. Most studies are restricted to the learning of pupils. Only one focussed on learning of teachers. It seems to be a particular aspect of much work in Utrecht that it studies the interaction of teaching and learning and thus on learning processes of both pupils and teachers in relation to each other.

As is clear from Adey's paper, cognitive science could, in some sense, almost encompass everything that is done in science education. An essential aspect, however, seems to be that work within a cognitive science paradigm aims at general knowledge related to the operating of cognitive systems, that may subsequently be applied to (science) education. Work on thinking strategies in problem solving and on the role of analogical reasoning (as done in Lyon), seems to predominantly fit in such a cognitive science perspective.

Finally, Donnelly's paper reflects explicitly on the nature of science in relation to science education. Though this paper makes interesting reading and makes clear that 'science studies' is a flourishing field, the direct relation to science education is not unproblematic. Though it seems to be true that the process of scientific knowledge construction is in some way reflected in science classrooms, the characteristics of a teaching situation are essentially different. One cannot say, I think, that in science classrooms knowledge is created in the same sense as in science itself. Freudenthal uses the term 'guided reinvention', in which he expresses both the freedom and the restrictions of classroom learning processes.

Another 'misuse' of science studies, to my opinion, is the danger of overemphasizing that pupils should learn a proper (whatever that may be) view of science and scientific knowledge. When reading about such claims, I always anxiously ask myself whether my own view of science would pass the crucial test. How much of science do you need to have learned, to be able to reflect on it? Aren't we in a danger of, in addition to 'forced' teaching that results in conceptual misconceptions, going to add unavoidably 'forced' views about the nature of science as well?

4. Classroom studies on developing improved science education

Focussing on content specific teaching strategies

May the above deal with more or less interesting examples of broader research perspectives and reflections, the final question is what to do and how to do it in the classroom. One could say that the diagnostic phase of 'misconception' inventories has led to the acknowledgement that in science education we have to face an essential problem. In what direction do we have to look for solutions? Is it from a more general perspective, like adopted in Adey's programme for cognitive acceleration, or from other cognitive science studies? Is it from general 'constructivist' teaching strategies, if such a thing does exist? Or do we have to work on small-scale content-specific studies on the teaching and learning of a specific topic at a particular age level for a particular type of pupils, within a particular school system?

This is of course again the problem of the interrelation of the general with the specific, about which we already concluded that both have their role to play. Though I would like to add now that if *science educators* (in cooperation with teachers) do not focus on the content specific, nobody else can and will take that part, nor will anybody else be able to put whatever theory into practice. This is a main reason why the research programme in Utrecht emphasizes strongly on content-specific classroom studies.

So, I consider it essential that such a large number of studies reported at the summerschool, dealt with content specific studies of learning and teaching processes in actual classroom settings, as well as with 'situated cognition' in other 'teaching' situations. Only by going into more detail, by developing and studying actual learning/teaching processes, can we come to see how we may have to teach about colour, light, the physical state of matter, energy, biochemistry, organic synthesis, chemical bonding and particles, to name the topics that have been reported about. And about how to deal with the dimensions of commonsense and scientific reasoning patterns described above. Could it be that research on 'didactic structures' for such topics, will lead in the end to empirically supported 'didactic structures' for teaching the whole of physics or science?

Using new technologies to reach old and new aims.

Quite a number of studies look for improvements by focussing on the possibilities of present day information technology. Ogborn's work on (mathematical) modelling is an excellent example. Not only does it try to develop new ways to deepen 'traditional' conceptual insight of pupils, it also opens ways to important new aims. In particular, his modelling approach for younger pupils may lead to a rethinking of the role and place of mathematics in science curricula. As such, it strengthens my opinion that creative and well-founded development of new ways of teaching can lead to more progress than much that is called 'proper' research.

Other reported studies tried to use specific possibilities (e.g., simulation, training of professional skills) of the P.C. and/or other media, mainly in relation to some kind of 'constructivist' perspective. New information technology certainly has important potentialities for the improvement of (science) teaching. It's a pity however, that, in general, much work in this field has less to do with finding creative and realistic ways that are really useful, than with the fact that I.T is seen by policymakers as a main solution to their problems.

Learning from texts, tests and experiments

These are three special topics that got some attention at the summerschool. Much learning is done from texts and science textbookwriters (and educators) are often so busy with 'the what' they write about, that they pay little attention to 'the how'. However, much research is done on reading and information processing of texts that should be applied to science education. Sumfleth's research programme not only pays attention to this, it also relates it to research on conceptual learning.

A second aspect that got only little attention was the role of testing (see Alonso, this volume). If we have the opinion that teaching should be done differently, than we unavoidably have to realise that also the assessment should be done differently. Therefore studies about how that can be done by teachers, and about the nature of change it asks from them are essential.

The role of experiments in science learning is another specific topic that is at present a matter of much debate (see Dekkers, this volume). The optimistic views of discovery learning have faded away, but how much of it is rightfully left after 'the constructivist revolution'? That seems to be an extremely difficult question to answer, as in good teaching the role of experiments can hardly be separated from the whole.

5. Studies on the aims, development, effectiveness and structures of science curricula.

Quite a number of studies can be summarized under this heading. The main difference with the former section is that now the focus is not so much on the improvement of learning and teaching within a particular topic, but on improvement and updating of curricula as a whole. Donnelly (this volume) writes as follows:

> 'Unless both teachers and science education researchers are willing to act merely as instruments for achieving the ends of only remotely accountable policymakers, we will treat the aims of science education and science education research as matters of ongoing concern',

and I do agree with him completely. As well as, to a large degree, with his plea that therefore 'a continual evaluation and appropriation of the diverse work on the 'nature of science' is not a luxury but a necessity.' However, there is more to be done than that, as is clear from what was reported: on the development of environmental education; on what knowledge of science can really be considered as relevant for non-science vocational training; on the question how science curricula can be made more relevant to the out-of-school world of pupils, and on how they do influence perceptions and attitudes about science and technology. Finally, also research was reported that looks for the forces that determine content and structure of science curricula and to their consequences for learning.

All these questions are being tackled in research that was reported, though, of course, we can't expect them to be answered fully in the near future. So, fortunately, that leaves some space for a next summerschool.

6. Finally

Though the summerschool did succeed in making both students and staff learn from each other, its format should in the future provide more intense opportunities to exchange views at an even more detailed level. Exchange of actual teaching materials or discussion of classroom situations has not been done, nor did we really exchange research practice about how to deal with such situations. Instead of learning from doing research together, the summerschool asked too much learning from *talking about* and listening to research *results*. In fact, it looked too much like a conference and too little like an active classroom. And haven't we learned that for children to learn science, telling them about the results is not the best approach?

What may we conclude in relation to my questions about research coherence and progress? Superficially, we may be rather satisfied. As I have tried to show, all research can be categorised such that it all appears to contribute to the same aim: improving science education. And even though it is done from different theoretical perspectives and in widely different practical settings, one could say that exchange and confrontation of ideas may in the end lead to cooperative learning. It does so at several interrelated levels, by developing general and/or content specific theories; by describing empirically what happens in classrooms; and by developing new teaching/learning materials and situations. At the deeper level of research programmes, however, the situation seems to be more diffuse. All programme reports show a lot of activity going on, as science education is a broad field to work in, but only few of them give the impression that research is being planned from a well developed perspective. So, that leaves much to be discussed and worked out, which is necessary for setting up cooperation at the group or institutional level.

Nevertheless, one could say that in the last decade we have got deeper insight in what actually happens in science teaching and learning. We could also say that we know better what is going on when we look into classrooms. Reporting about these insights in research journals, conferences and summerschools leads in general to adequate knowledge exchange among researchers. A severe problem however lies at the theory-practice, or researcher-practitioner, interface. As soon as 'theories' have to be put into practice, everybody is largely inventing again more or less his or her own wheel.

Everybody who has seen examples of 'constructivist teaching' would agree, I hope, that under the same theoretical heading large differences in practice are constructed. Or, the other way around, that often the same teaching is developed from rather different theoretical positions. Unfortunately, at the level of constructing actual teaching/learning situations, much less discussion and exchange seems to be taking place, while it is at that level that the proof of the pudding is done. If we do not succeed in exchange of experiences and cooperation at that level as well, real progress will remain strongly inhibited and restricted to theoretical rhetoric. Could we, as participating institutions agree on setting up a mutual regular exchange of actual developed teaching materials and PhD.theses? And could next summerschools also contribute to filling that gap?

7. Appendix

At the end of the summerschool, an evaluation questionnaire has been distributed. It has been returned by 24 students and 12 staff members. A random selection of the answers follows. It gives a rather complete impression of the opinions that were expressed. This also relates to what was discussed during the plenary evaluation. In general one could say that the participants were positive about the event, but that refinement of the format should take place. This concerns mainly: fewer plenary sessions, more workshops or 'masterclasses', and more work in small groups, with more exchange of both people and opinions. And we should try harder to find solutions for the language problem.

All agreed, however, that summerschools of this type should become a regular event.

On a scale of 1 to 5, with 5 being the highest possible rating, the following general ratings were given.

1. Effectiveness of organisation

	5	4	3	2	1	?	av.
staff	5	7	-	-	-	-	4.42
students	18	6	-	-	-	-	4.75

Why this rating?

1. Conference centre was very comfortable and organisation of week(timing etc.) was excellent. Timetable was adhered to, sessions began promptly.
2. Events were mostly punctual, but the organisers were quite flexible.
3. Within this framework there's not much space for more effective organisation.
4. The summerschool was very efficiently organised to fulfill the goals it had set out.
5. Everything happened at one place which was well organised.
   No fault at all, perfect.

2. Usefulness of content

	5	4	3	2	1	?	av.
staff	3	8	-	-	-	1	4.27
students	7	15	1	1	-	-	4.17

Why this rating?

1. Informal content, discussion etc., provided extension of ideas in the field. Formal content, mostly presented in a very dull way & some was irrelevant.
2. I learned so much.
3. Nearly all presentations were of some relevance to my own work.
4. Inevitably, a great range of subjects was discussed. Sometimes their relation to my topic of interest was not clear.
5. Some plenary lectures were not so useful.

3. Appropriateness of teaching strategies

	5	4	3	2	1	?	av.
staff	-	8	3	-	-	1	3.73
students	4	11	2	2	-	5	3.79

Why this rating?

1. Plenary sessions could have been more varied in approach, some were extremely tedious.
2. Presentations by Ph.D.students were of varied quality (mostly poor) and more training should be given to them as to how to present effectively.
3. Not appropriate, as I did not view what was going on as a 'teaching' situation.
4. It allowed for both presentations of own work and being informed about other researcher's work in excellent balance.

5. I found that in general the teaching strategies used in the summerschool were very appropriate. They encouraged productive criticism and discussion. Perhaps in the plenaries the strategy of dividing the participants into smaller groups would be more effective in stimulating more intensive discussions.

4. Opportunities provided for meeting & talking to other participants

	5	4	3	2	1	?	av.
staff	7	3	1	1	-	-	4.33
students	20	4	-	-	-	-	4.83

Why this rating?

1. The planned programme was too intense, prompts for more informal discussions could have been given instead of constant plenary lectures. Only one 'outing', not much in one week!!
2. Lots of time to talk, discuss, argue, communicate.
3. Sufficient time & space, sufficient similarity in work to allow communication, sufficient diversity to make interesting discussions possible.
4. I found I had ample opportunities to meet and discuss my research interests with other participants, as all activities were conducted in the same building.
5. Not so much time!

5. Any other considerations?

1. A native English speaker capable of controlling a debate should be placed in every group.
   Questionnaires should *not* require names, if they are of this type.
2. Please continue these summerschools.
3. Please think of organising plenary sessions about institutes in a more informative way.
4. Possiblities for inclusion:
   - Programme time for ad hoc meetings, advertised daily.
   - 'Master classes' on special techniques.
5. Perhaps it would be more useful to have more flexibility between groups. I would have welcomed the opportunity to move between groups working in parallel. This would give me a chance to select presentations which might open new lines of enquiry.

6. Your reasons for enroling in this event including any special interests to be pursued or problems to be solved

1. I had great interests to know more about science education research in the European countries. I also had interests in having my own doctorate study discussed. The summerschool has contributed to both of my wishes.
2. Being at the writing-up process of my work, the chance to discuss and receive feedback would have been helpful.
3. To have contacts with other researchers and experience to present my work in English.
4. To present preliminary results and to discuss them with fellow Ph.D. students; to work on the theoretical background.
5. It should have been earlier, but this was the first summerschool ever.
6. To be in contact with different research programmes in science education. To discuss methodological aspects in these programmes.
   To present and get suggestions about the classroom data in my research. The timing was excellent and each student could discuss his/her research programme with small groups.
7. An excellent and unique opportunity to present one's own research to people who don't know about it and also to do it in a very supportive atmosphere.
8. Etc.

7. What did you find of special value in this event, and in what way did you find it valuable?

1. Having everybody together for one week's intensive course has produced a lot of fruitful and stimulating discussion. A good way to become up to date with current research across Europe.
2. Presentations in small groups:
   a. I now have experience in presenting my research in English; I was given advice about my approach.
   b. The presentation related to my topic was very useful; I also picked up some general ideas in the discussions.

   Plenary sessions: Some sessions about specific research topics were interesting, e.g. about linear causal reasoning, computer modelling, the nature of science, CASE.
3. The discussion in an international context, to see of what worth my work is. Where are parallels and where are difficulties.
4. The exchange about the topics of research; some staff lectures (~ 50%)
5. Free exchange of ideas, criticism, helping me in specifying perspective/background of my research; making research questions more precise.

6. Opportunity for open discussion in an informal setting, this helped me to sharpen my arguments and extended my outlook in the constructivist field. Opportunity for easy discussions with experienced researchers; difficulties in my work could be raised easily and ideas for their resolution resulted.
7. The many questions, comments, suggestions about my research which caused me to view it from different perspectives than I had before. Also, it is very useful to have to think about questions -difficult ones - and to try to answer them in a constructive way.
8. Etc.

8. *What did you find of less value, and in what way did you find it less valuable?*

1. During plenary sessions, lecturers seemed to feel that it was a forum that was almost exclusively their domain(s). Through their arguments/discussions *with each other* they often seemed to be carrying on *continuing* arguments, often -or in some cases- begun many years ago. This was neither fruitful nor particularly interesting to the students. More importantly, it had the effect of (with one or two exceptions) almost repressing contributions (questions, comments) by students.
2. Plenary sessions in which research carried out in other centres was reported. The information was presented in a very dull format, it could more interestingly be presented through informal discussion (posters). Discussions in group sessions which became dominated by the arguments between two individuals, this happened frequently. The objective that the *student* is to be helped must *always* be borne in mind.
3. Plenary sessions on research at various institutes, listing names and titles was not very informative. Plenary sessions should have paid more attention to methodology. In the group sessions, it is more interesting when the students ask 'help' about their problems, methodology, etc. than only present theory.
4. The 'condensed' programme of sessions/workshops was a bit tiring (concentration span) towards the end of the day and of the week as well. Maybe a bit longer coffee breaks? I would like to see more small group/workshop type (practical) activities. Also discussion of different methodologies & advantages/suitability or not for different types of research projects.
5. A different form of presentation of the research programmes from different universities, perhaps doing workshops on general topics, would be more useful.

6. It might have been more useful to have greater flexibility in group work. Further division into smaller groups would give people confidence to discuss the issues.
7. Plenary session contents could have been more structured and relevant to the different researches going on.

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