Changing conceptions

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Toelichting
Dit artikel is een weergave van de lezing die de schrijfster, één van de leidende figuren op het gebied van de "alternative framework movement", in september 1987 heeft gehouden op een International Seminar gewijd aan "Adolescent Development and School Science" (King's College, Londen). Dit artikel is met toestemming overgenomen uit het volledige verslag van dit (zeer interessante) seminar, dat, onder dezelfde titel, dit jaar zal verschijnen bij Falmer Press, Brighton, editors: P.Adey et.al.

1. Introduction

This paper will consider the implications of research on children's conceptions in science and current perspectives in the processes of conceptual change for the teaching of science in schools. An extensive literature has been built up in recent years which indicates that children develop ideas about natural phenomena before they are taught science in school (Pfundt and Duit 1985, Jung et al 1982, Helm and Novak 1983, Gentner and Stevens 1983, Driver, Guesne and Tiberghien 1985). In some instances these ideas (variously described as preconceptions, misconceptions, intuitions, alternative conceptions, alternative frameworks, naive theories) are in keeping with the science which is taught. In many cases, however, there are significant differences between children's notions and school science.

Surveys undertaken in various countries have identified commonalities in children's ideas and developmental studies are giving helpful insights into the characteristic ways in which these ideas progress during the childhood years (Carey 1985, Strauss and Stavy 1982). In-depth investigations have indicated that such ideas are to be seen as more than simply pieces of misinformation; children have ways of construing events and phenomena which are coherent within their domains of experience yet which may differ substantially from the scientific view.

Studies also indicate that these notions may persist into adulthood despite formal teaching (Viennot 1979).

Cognitive ethnographies undertaken in classroom settings indicate that students' prior ideas are an important factor in their understanding of school science. Students make observations and inferences about phenomena which differ from those intended because of their different interpretive schemes. Observations are selected or rejected on the basis of their "fit" with expectations (Rowell and Dawson 1983). Children's conceptual schemes also influence their investigations, the questions they ask, the variables they consider as influential or non-influential and the way results are interpreted (Driver 1983). Furthermore it has been shown that children's schemes also influence their understanding of science texts (Bell and Freyberg 1985). Children construct meaning when reading text by relating what they read to what they already know. Thus meanings other than those the writer intended are constructed. Possible outcomes of the interaction between students' conceptions and science instruction has been suggested by Gilbert, Osborne and Fensham (1982). Solomon (1983) has suggested that rather than trying to relate what is taught to their prior ideas, students may maintain them as separate domains, the "life world" and the "science world" each relevant to its own range of contexts.

The recognition of the existence of students' conceptions prior to teaching and their influence on learning outcomes has prompted a reappraisal of the assumptions underlying teaching and learning in science and has promoted the reconceptualisation of learning as conceptual change (West and Pines 1985).

If it is accepted that learning in science involves the restructuring of students' conceptions then not only do educators need to appreciate the ideas that children bring to the learning situation but they need to understand the processes by which conceptual change occurs in order that this can be taken into account in the design of learning programmes. This issue, of interest to both primary and secondary science, is currently setting the agenda for a number of research groups in various countries including Australia, Canada, New Zealand, Japan, Israel, Italy as well as here in the U.K.

The Children's Learning in Science Project at Leeds has addressed the issue of promoting conceptual change in classroom settings within the general perspective of constructivist epistemology. This paper will give an account of the rationale and research programme of this project and discuss it in relation to other theoretical and empirical studies in the field.

2. Epistemological basis of the research programme

The project's work has been framed within the general perspective of constructivist epistemology, whose central premise is that knowledge whether personal or public is a human construction. Contemporary developments in a number of fields are seen as contributing to this perspective.

Cognitive Science Perspective

a. Mental models

A key feature in this perspective is that human beings construct mental models of their environment and new experiences are interpreted and understood in relation to existing mental models or schemes.

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

Research in a number of areas of human cognitive functioning support this claim. 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). Research on human reasoning suggests that, rather than being based on generalised principles of formalogic, humans make inferences by constructing a mental representation of the problem as a basis for making deductions (Johnson-Laird 1983). Indeed as Rumelhart and Norman (1981) argue:

> "Our ability to reason and use our knowledge appears to depend strongly on the context in which the knowledge is required. Most of the reasoning we do apparently does not

> involve the application of general purpose reasoning skills. Rather it seems that most of our reasoning ability is tied to particular bodies of knowledge." (p. 338)

Students' conceptions of natural phenomena are also 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. Strauss (1981) argues that much of our common-sense knowledge is spontaneous and universal. He explains this by arguing that:

> "the common-sense representation of qualitative empirical regularities is tied to complex interactions between the sensory system, the environment that supplies the information... and the mental structures through which we organise the sensory information which guides our behaviours. I argue that individuals' common-sense knowledge about qualitative physical concepts is no different today than in the times of, say, Aristotle. (p. 297)".

There is some dispute about the last point made here by Strauss; it is argued that some mental models which are used to organise experience are culturally transmitted and that the conceptual environment of humans living in the twentieth century differs significantly from that, say, of the time of Aristotle (consider the extent to which heliocentric models of the solar system or notions of evolution through natural selection permeate our communications and culture). It is likely that individuals' prior conceptions derive from experience with the environment, their existing ideas which are used to model new situations and from cultural transmission through language (Head, 1986).

b. Learning as change in mental representations

The view of the learner as architect of his/her own knowledge is a broadly held assumption. There are, however, differences between perspectives on the types of constraints which act to shape the process. 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 process by which knowledge is constructed by the learner is broadly surmised to involve a process of hypothesis testing, a process whereby schemes are brought into play (either tacitly or explicitly), their fit with new stimuli is assessed and, as a result, the scheme may be modified.

> "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 Glaserfeld 1983 (p. 51)

Solomon (1987) also argues that social factors in conceptual change should not be overlooked and that learners may adopt a particular way of seeing for reasons of social conformity.

There is an epistemological implication of this view of knowledge as constructed which has yet to be taken seriously by educators, and that is that to know something does not involve the correspondence between our conceptual schemes and what they represent 'out there'; we have no direct access to the "real world". The emphasis in learning is not on the correspondence with an external authority 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 Glaserfield 1983 (p. 51).

c. Intentionality and effect

It is recognised that an individual's purposes play a very significant role in influencing cognition and behaviour; they act to prioritise attention, to select and order activities in complex situations. In educational settings the importance of the varied purposes of the participants, both teachers and pupils, is clearly relevant to shaping what is attended to by whom and to what end. It is also recognised that cognitive functioning involves more than the processing of information; emotion can interact significantly with cognition (Claxton 1984, Head and Sutton 1985).

Contemporary Perspectives on the Philosophy of Science

The constructivist perspective outlined in the previous section applies not only to the development of personal knowledge but also to science as public knowledge.

Although there is considerable agreement among psychologists and educators about the constructive nature of the learning process, the constructivist analysis frequently stops short of addressing the nature of the status of the knowledge to be learned, in this case the nature of scientific knowledge. Here I suggest that a constructivist perspective draws on sociology of knowledge and philosophy of science in considering not only personal knowledge but public knowledge to be a human construction (Collins, 1985). In science education in particular we have a dominant perspective of a view of knowledge as objective and unproblematic. Textbook presentations and teaching methods in school and higher education reinforce this view. Even discovery approaches in science teaching give implicit support to this perspective in that they tend to assume that the empirical method (observing, classifying, interpreting, etc.) can be undertaken objectively without reference to an observer's way of seeing the world.

Current perspectives on the philosophy of science on the other hand, tend to reject the idea of an "objective" base of observations against which our theories of the world can be checked. Instead the dominant view is that science as public knowledge is not so much a "discovery" as a carefully checked "construction". In our attempts to represent the world we construct theoretical entities (magnetic fields, genes, electron orbitals...) which in turn take on a "reality". Rather than viewing observations as the base on which we build our knowledge, there is a sense in which it is our constructions of the world which are "real" and it is through these that we interpret and re-interpret our experience.

Developing a curriculum in science which reflects this perspective needs to acknowledge that science is about more than experiences of the natural world. It encompasses the theories and models which have been constructed to interpret experiences and the way in which these are checked and evaluated as coherent and useful. Perhaps most significantly, from a constructivist perspective, these theories are not seen as absolute but as provisional and fallible. Moreover, theory making and testing is a dynamic human enterprise which takes place within the socially defined community and institutions of science.

In concluding this section it is worth noting that cognitive science itself runs the risk of misrepresenting human learning if it fails to consider the social dimension of learning and the social construction of knowledge itself. It is this broad perspective which is important if we are to provide an adequate frame for our understanding of learning processes in the complex environments of classrooms.

The Social Context of Learning

Norman (1981) recognises this when he states:

> "Human cognition exists within the context of the person, the society, the culture. To understand the human requires understanding of these different issues and the ways in which interactions among them shape the cognitive processes."

Classrooms are complex social systems. Children's learning in such environments requires a consideration of the social and cultural milieu in which learning takes place. The way individuals construe the world is influenced by communication with others through language and the physical and cultural environment. (A classroom might usefully be portrayed as a microculture with its roles, routines and rituals.) Also the opportunities any individual has for learning depends in complex ways on the aspiration, goals and ways of interacting in the social groups of which they are a part. Such a perspective suggests that learning depends on the contexts in which it occurs and that studies of learning which are going to be useful to educators need to pay attention to ecological validity.

3. Implications for science teaching

The perspectives sketched in the previous section, which derive from the view that knowledge is mind constructed, are by and large well established. What are the implications of such perspectives for learning? Here a number of features are suggested:

1. *Learners* are not viewed as passive recipients of an instructional programme but are seen as purposive and ultimately responsible for their own learning. They will have developed, through previous experiences, in school and out, conceptions about the natural world which in cases may be well adapted to the situations they have encountered.
2. *Learning* is seen as involving a change in the learner's conceptions. This process of change requires the active constrution of meaning by the learner. This constrution of meaning may take place during interaction with phenomena,

with text, through interpersonal negotiation, or through internal reflection.

3. *Knowledge* is not 'objective' but is personally and socially constructed. Its status is problematic and it is evaluated by learners in terms of the extent to which it 'fits' with their experience, is useful in giving them control over situations, and is coherent with other aspects of their knowledge.
4. *Science as public knowledge* is also a product of human corporate endeavours. If it is one of the goals of school science that children come to understand the way science itself is carried out then this will need to be reflected in the knowledge construction process undertaken in the classroom. It will not be reflected in naive pedagogical approaches such as "asking nature" or accepting unquestioningly external authority.
5. *Teaching* is not the "transmission" of knowledge, but the negotiation of meanings. It involves the organisation of situations in the classroom and the control of tasks in a way which promotes intended learning outcomes.
6. *Curriculum* is not that which is to be learned, but a programme of learning tasks, materials and resources which enable students to reconstruct their models of the world to be closer to those of school science.

An important point to make here is that the curriculum is not something that can be planned in an "a priori" way but is necessarily the subject of empirical enquiry. As Posner (1982) points out:

> ".... if we want to understand a student's experience, the process of learning, and the reasons why some learning outcomes are occurring and not others, we must understand the tasks in which students are engaging and not just the tasks the teachers think they are "giving" to students." (p.343)

Further we need to determine the extent to which the tasks students do engage in are effective in promoting the intended conceptual change.

4. Curriculum development as action research

How might the features outlined in the previous section be embodied in actual science classrooms? What might schemes of work which reflect these features be like and how might they be put into practice? What might be the outcomes of such a way of working? How might teachers and pupils respond? These were the questions the Children's Learning in Science Project set out to explore over the last three years; the aim of this phase of the project's work being to devise, trial and evaluate constructivist teaching sequences in selected science topic areas.

Before giving an account of the schemes of work and the factors involved in their design it may be useful to outline the organisational content and work grogramme of the project. Since teachers are involved in such a fundamental way in the successful implementation of a curriculum, it was decided by this project that the research and development of constuctivist approaches to science teaching should be a collaborative exercise between teachers and researchers. Malcolm Skilbeck puts the point very succinctly when he says "the best place for designing the curriculum is where learners and teachers meet".

Secondary science teachers from schools within travelling distance of Leeds University were invited to take part in an initial two year project and over 30 teachers undertook the commitment. The purpose of the project was outlined as involving the development of teaching approaches in three topic areas (energy, the structure of matter and plant nutrition[1)]). The teaching approaches were to take account of students' prior ideas and to promote conceptual change. Although the premises on which the project is based were outlined to the participating teachers (Driver and Bell 1986, Driver and Oldham 1986) these were initially construed in various ways by those involved. It is not only the students' prior knowledge which is of concern, "science teaching depends on the prior knowledge and conceptions of science educators" (Shuell 1986 p. 240). This has meant that the project has in effect had two parallel agendas,

a. the development of teaching schemes which promote conceptual change in secondary school students, and
b. the implementation of a way of working as a project which promotes the conceptual development of participating science educators.

Three working groups of about 10 teachers, each with a researcher, were set up, one for each topic area. The programme of work for the two years for each group is represented in figure 1. The first task the teachers in each group undertook was to study the learning of the topic in question by students in their own classes (in age range 12-15 years). All participants taught the selected topic in their normal way (this "current practice" involved a sequence of lessons over six to eight weeks). Students' learning was studied using a number of approaches. Teachers gave their class a diagnostic test before and after teaching the topic and kept a diary while the lessons were progressing. The researcher from the group visited some teachers and kept a more detailed account of the lessons involving field notes, audiotapes and interviews with students and the teacher.

The documents which were produced (Bell and Brook 1985; Brook and Driver 1986; Wightman 1986) were used as a basis for reflection on current practice by the group. Students' particular conceptual problems were documented and pedagogical concerns were also identified. At this stage, the groups were attempting to make explicit their views on the scientific ideas to be taught and to share their developing perspectives on the teaching and learning processes. The outcome of this stage of work included (a) a specification of the ideas to be taught, (b) an analysis of

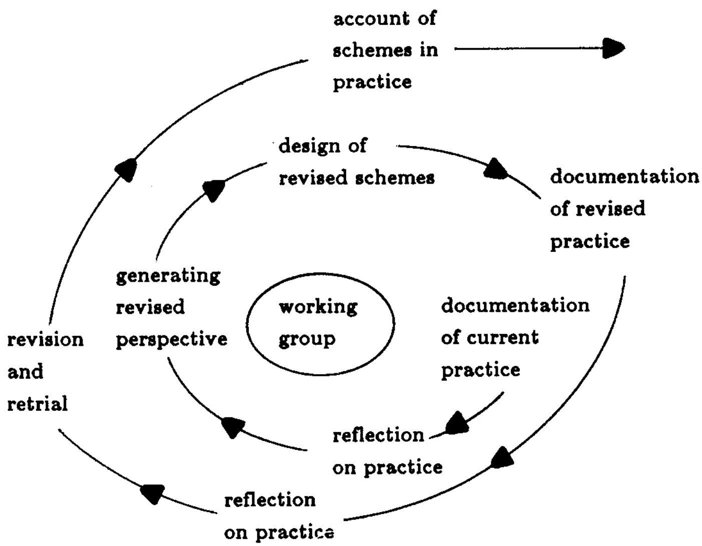

Fig.1 The programme of working groups

some of the conceptual problems students encounter and (c) a critique of current pedagogical strategies.

Towards the end of the first year each group worked together for a week to devise a revised teaching scheme for their topic, drawing on the insights gained over the year and further reading of the research literature. All the schemes were designed to take account of students' prior ideas in the topic and to provide learning activities and a learning environment aimed at promoting conceptual change. (General features of the strategies adopted are given in the next section.) The revised schemes were implemented in the second year of work and the learning taking place in the classrooms was monitored again in the same way. The groups met for a weekend to review the findings from the first trial of the schemes. Undoubtedly these first trials led to a greater understanding of some of the students' conceptual problems. It also gave insight into reactions by teachers to implementing a much more open approach in their classrooms. Revisions were made to the schemes which were then retrialled. The resulting schemes have been published (Children's Learning in Science 1987).

5. Factors involved in planning a curriculum sequence

An underlying metaphor for learning within the constructivist perspective might be that of going on a journey; there is a starting place, a route to travel (perhaps alternative routes) a method of transport, a destination and a purpose for going (even if it is curiosity to see what is over the other side of a hill!). The design of a learning programme similarly needs to take account of students' prior knowledge, to pay attention to the learning environment, to incorporate explicit strategies to promote conceptual change, as well as specifying the learning goals. In this section of the paper these factors which were involved in planning the revised teaching sequences are considered.

Learning goals

An analysis was undertaken of the intended learning outcomes. This of course is a traditional feature in curriculum planning. However, an issue which now needs to be addressed is whose goals are being considered? If the goals are those of the teacher how are they to be adopted by the learner? How might learners' interests and purposes be considered?

Students' prior conceptions

As Case (1978) points out:

> "until one understands what students do spontaneously, one will not be able to demonstrate the limits of this approach to them. Further, until one does demonstrate the limits of whatever incorrect approach students use spontaneously, they will continue to have great difficulty in understanding the correct approach."

In science there are now many domains of knowledge in which children's prior conceptions have been documented. It is generally recognised that there are "commonalities in the ways in which people who belong to the same culture account for a phenomenon, as well as at least some differences. But on a level of description between the general and the idiosyncratic, there are ways of understanding, that are neither common to everyone nor unique to anyone" (Johansson, Marton and Svensson 1985, p. 236).

Although the conceptions individual children may use tend to depend on the context, it is possible to obtain a probabilistic picture of the conceptions available within a class for a particular domain of knowledge. (Engel, Clough and Driver 1986). Information concerning these domain specific conceptions is necessary in order to decide the types of tasks to include in the teaching - perhaps to extend the range of applicability of the conception if it is limited, to provide disconfirming instances etc. It should be noted that an analysis of students' conceptions is needed not only prior to teaching but continually during teaching and although some "a priori" information can be provided to teachers as to what to expect, the teacher's role as diagnostician in the classroom is essentially an on-going one.

It is also important to recognise that students' prior conceptions may differ from scientific conceptions not just in substance but in more fundamental ways, (Driver, Guesne and Tiberghien 1985). For example, students may have context specific conceptions which may conflict with each other, yet which serve their purposes in giving the student anticipatory schemes; the need for internal coherence may not be recognised by students. Students' notions about what constitutes an explanation may also differ from the scientific perspective. Students tend to see explanations in terms of linear causal sequences, whereas the scientific explanations provided within school science are often formal or analogical models of classes of phenomena.

Prior information about students' conceptions at both a general and particular level has been used in planning materials and activities in advance and in sensitising teachers and researchers to the ideas and ways of thinking that may occur in classes. In the actual classrooms students' ideas have also been elicited as part of the process of promoting change in their thinking.

Learning environment

What are the general characteristics of a classroom environment which would, as Bereiter (1985) suggests, provide "a social setting for mutual support of knowledge construction" (p. 221)? A number of characteristics can be suggested:

a. Metacognition. A number of research groups interested in promoting conceptual change are suggesting that helping students become more aware of their own learning processes and to take responsibility for them is important (Baird and Mitchell 1986). Students tend to think of learning science as "taking in" discrete facts. Strategies which encourage students to reflect on their own learning helps them appreciate that a process of conceptual change is involved, also that their knowledge is structured and interrelated. Techniques which have been used to encourage this process include students comparing their ideas at the beginning and the end of a learning sequence also keeping personal learning logs (small notebooks in which they record their reactions to lessons, notes on what they think, things that puzzle them, things they find difficult etc.).

b. The structure of a scheme of work. Schemes may need to be structured so that students are aware that they are invited to change their way of thinking. This project has followed the pattern of phases shown in figure 2. After a scene setting *orientation* activity in which students' attention and interest in the topic is aroused, the class spends time discussing and reviewing their own ideas or models. This *elicitation* phase is usually conducted in small groups first. Each group is asked to represent their ideas on a poster or by other means and then present these to the class as a whole. Similarities and differences in students' prior ideas are identified and issues for further consideration are noted. The posters remain displayed as a record during the rest of the unit of work and may later be amended or commented on. It is not only teachers who need to be aware of students' prior conceptions, it is important that students themselves make them explicit and clarify them. The *restructuring* phase, the heart of the scheme, has involved the use of a wide range of strategies which are reviewed in the next section. The lesson sequence then gives students opportunities to try out and *apply* their revised conceptions in a range of ways. This may involve practical construction tasks, imaginative writing tasks or more conventional text book problems to solve. At the end of the lesson sequence classes are giving the opportunity to review the extent and ways in which their thinking has changed. The earlier posters may be modified or new ones constructed and compared with the earlier ones.

c. Non-threatening learning environment. A learning environment which requires students to make their ideas explicit and to test out new ways of thinking could be very threatening. If students' efforts are evaluated too early by the teacher or by other students then they will tend not to experiment but want to be told thus possibly short-circuiting the knowledge construction process. Setting up such an environment in classes has been attempted by encouraging students to express their ideas in an organised way through group work, poster display etc. It has also required teachers in many cases to change their class discussion management routines quite radically, avoiding closed questions, accepting a range of suggestions from a class without requiring premature resolution of a point.

d. Small group work. The importance of talk in enabling learners to represent their ideas to themselves has been recognised for years (Barnes 1976). Small groups of about four students form the structural unit around which the scheme of activities takes place. Group activities include discussing and representing theories or ideas on a topic, devising experiments to test ideas, developing more complex models to represent experiences, undertaking practical construction tasks in which conceptions are applied.

e. The context of learning tasks. As far as possible the learning tasks were chosen to be set in contexts which were meaningful to students (e.g. some of the work on energy was set in domestic contexts and involved reading meters, using fuel bills). We know that knowledge is contextually embedded. The contexts provided for learning may be important in maintaining attention, facilitating later applicability of the conceptions and hence breaking down the possible divide between school science and everyday knowledge.

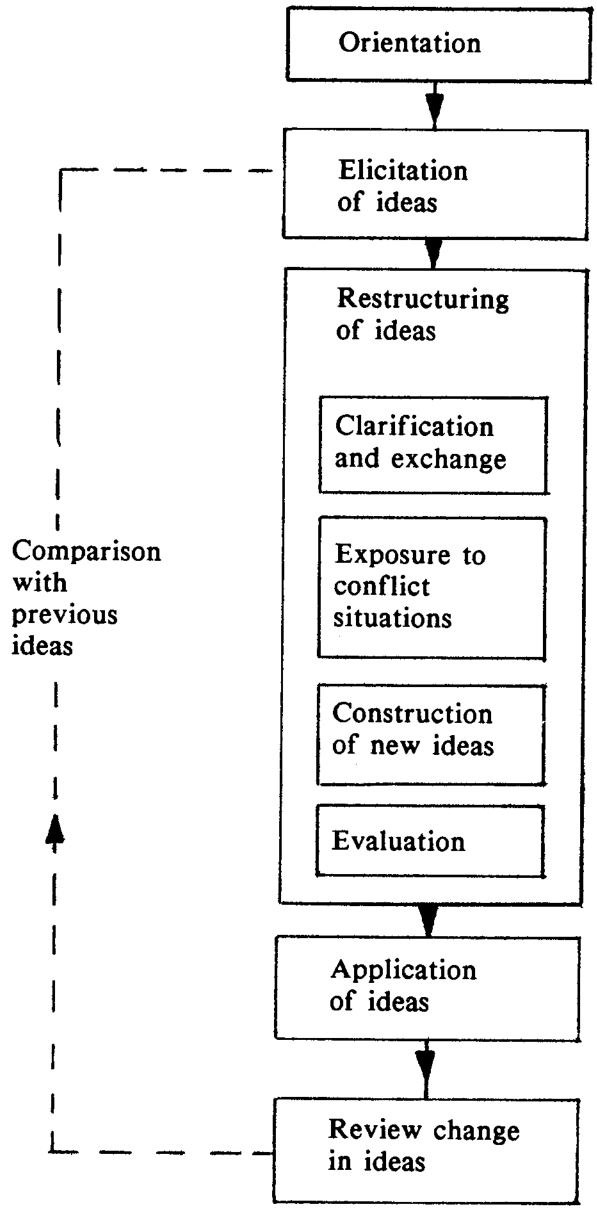

Fig.2 General structure of teaching sequence

Constraints

It is only realistic to recognise that there are constraints operating in classrooms and schools which need to be taken into account in planning. In addition to the obvious physical constraints of teaching time available, the limitations on teaching space and equipment, there are also more subtle constraints due to teachers' and learners' expectations about knowledge, science, schools and classrooms and their roles in them.

Designing learning sequences in specific topic areas

Having clarified the starting points, specified the possible learning outcomes, set the scene in terms of the appropriate type of learning environment we turn now to the heart of the problem: designing strategies and activities which promote change in students' conceptions.

a. Describing conceptions

If the aim of instruction is to promote conceptual change it is not irrelevant to reflect on what it is that might be changing. This requires us to consider the nature of learners' internal representations of the physical world. Here I think the picture is complex and necessarily so in that humans may have multiple modes of representation for physical phenomena, each playing a part in understanding, and these may or may not be interrelated. The ways that knowledge may be represented in memory is currently an open question. However there are indications that such modes may include:

Visual images - "pictures" of objects and events which embody topological relationships and time sequences. We can generate a visual image of say the solar system with the component entities, their relative sizes, positions and motions in relation to each other.

Kinaesthetic images - these are internal representations of phenomena in terms of sense experiences such as sensations of pushing, of impulse, of hot and cold. These are schemes which anticipate how the interaction with a physical system may feel. I suspect that these are developed from early days of life, they may not be mediated by language and may not even be at the level of conscious awareness. Yet they may underlie some of the difficulties students have with certain science topics, particularly mechanics, and may play an important part in students' causal reasoning. The suggestion of "gut science" by Claxton (1982) and phenomenological primatives (p-prims) by di Sessa (1983) can be seen to relate to this mode of representation. Visual and kinaesthetic images are intergrated typically through "hands on" experiences into general phenomenological schemes or models of the world.

Propositional knowledge - considerable attention has been paid to this form of mental representation among linguists, psychologists and science educators. There is a danger that we model conceptual change strategies solely with reference to this mode of representation.

Mathematical knowledge - in addition to the other forms of representation, aspects of scientific phenomena are also represented mathematically. In the example of the solar system the periods of the planets can be described in an exact way in relation to other variables and parameters of the system. At a simpler level, children use simple mathematical functions such as addition, subtraction or ratios in their representation of physical systems such as balance beams.

In some situations a learner's representation of a class of phenomena may integrate all of these aspects. However, it is commonplace in science lessons for models of representation to be unrelated (for example, for students to fail to integrate mathematical knowledge of say mechanics with their phenomenological images). Indeed perhaps one of the most important strategies to promote learning in science is to give students adequate opportunities to make associations between their phenomenal, visual, language and mathematical representations.

b. Models of conceptual change and science teaching

What theories can inform the design of teaching sequences and the selection of suitable learning tasks? This is very much an open question but one which is being actively explored by educators and developmental psychologists. As an educator I do not see a single theory, as currently formulated, providing the complete picture. This is not to say that development of strategies needs to occur in a totally a theoretical or ad hoc way. There are a number of theoretical developments and experimental studies which can inform instructional design. However, different theoretical models appear to be addressing different aspects of the conceptual change process.

One model for promoting conceptual change which has received considerable attention by science educators is that of generating cognitive conflict. This model, which derives from the

Piagetian notion of equilibration, proposes that learners, when confronted with discrepant or conflicting information, will attempt to adjust the way they conceptualize the problem in order to resolve the conflict. Classroom studies with sucessful results based on this strategy have been reported by Rowell and Dawson (1981), Nussbaum and Novick (1982) and Stavy and Berkovitz (1980) among others. An important point is made by Nussbaum and Novick - that for conflict to be effective students need to make their prior notions clear and explicit so that the conflict is recognised by them. Champagne et al (1985) report the use of an associated strategy, that of ideational confrontation, which they report as aiding the differentiation of concepts. Students are asked to predict and explain the outcome of a physical situation; controversies between the different analyses are discussed so that differences in conceptions and underlying assumptions can be made explicit.

The limitations of cognitive conflict in itself promoting conceptual change are well documented. Consider the process presented schematically as in figure 3.

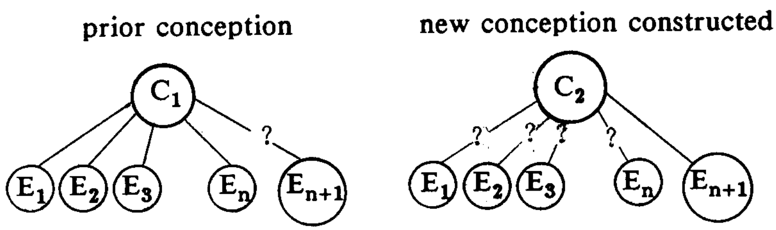

Fig.3 A representation of conceptual change

Figure 3 gives a simplified representation in which a student's initial conception (C_1) assimilates a range of experiences (E_1-E_n). The introduction of a counter example (E_{n+1}) which cannot be assimilated by C_1 may result in a number of outcomes (e.g. the experience itself may be discounted, special conditions may be invoked to account for it etc.). Even if (E_{n+1}) is recognised by the learner as a counter example, this by itself does not generate a new conception. For conceptual change to take place first a new conception has to be *constructed* and the range of experiences which had previously been accounted for have to be *reassimilated* to that new conception. Counter evidence by itself is clearly not sufficient to promote change.

As a result of studies of children's problem-solving behaviour Karmilloff-Smith (1984) proposes a model for change which does not involve conflict. Briefly she suggests that as a result of learners achieving successful, if ad hoc, solutions to separate tasks within a class of problem, they will then reflect on these and "try to understand why certain procedures are successful, unpacking what is implicit in them, and unifying separate instances of success into a single framework" (p.40). It is thus the combination of successful experiences and the opportunity to reflect on these which enables change to take place. Again, however, the process of construction of the new conception is not focussed on.

In a recent study, Rowell and Dawson (1984) offer a critique of conflict based strategies and propose and evaluate what they call an "alternative scheme" strategy, in which students after making their conceptions explicit are offered an alternative model which they *then* compare with their previous conception. Hewson and Hewson (1983) report success in using the strategy of conceptual "exchange" in teaching density. In this approach children's prior ideas are identified and analysed. Alternative conceptions are then presented for particular elements in the students' model. They are thus given the opportunity explicitly to exchange an aspect of their conception for an alternatiave one. In his "agreement hypothesis", Bryant (1982) proposes that "children progress when they realise that two ways of approaching the same problem produce the same results". He further suggests that this validation of one strategy against another provides the way in which children find out whether to and when to adopt a particular strategy. Bryant's experiments have been conducted within mathematical domains. However, in science it is possible that this also applies when learners check their expectations for physical systems between different modes of representation e.g. checking a mathematical model against a visual or kinaesthetic image. Piaget's work also refers to progress being made e.g. in the construction of object permanence when a child reorganises experiential data from more than one source. The question of how new conceptions are generated is typically answered by theorists in terms of analogical processes in which situations are interpreted by modelling them on existing schemata (Rumelhart and Norman 1981). This process involves the learner in selecting possible schemata from his/her previous knowledge and testing to see to what extent the schemata selected presents an adequate account of the new situation. In this process the original schemata may undergo modification. If the fit is poor another schemata is selected and tried. In this way the process involves learners in a trial and error way to "bootstrap" their knowledge. The implications for using this in teaching are obvious and well recognised by teachers; new ideas can be introduced by analogy to notions with which students are familiar! This may sound trite and obvious. However, what is less obvious and seems to require empirical investigation is which analogies are useful to students in acting as bridges to new conceptions. Brown and Clement (1987) report how certain thought experiments were found to help students reconstruct their model for what is a difficult conceptual problem (forces in static equilibrium or "the book on the table problem"). An important aspect of this study is that effective "bridging" analogies cannot necessarily be anticipated by experts.

The range of different hypotheses concerning the way conceptual change comes about suggests that it is premature and unwise to adopt any single model. Indeed like the fable of the blind men and the elephant, different models may be addressing different aspects of a complex process. What is called for is a careful analysis of the nature of the change process involved and the selection of appropriate strategies accordingly.

c. Manoeuvres for promoting conceptual change used in teaching. Within the teaching schemes developed by the Children's Learning in Science Project, a number of different teaching manoeuvres have been used to encourage the construction of new conceptions. The choice of the manoeuvre has depended on the nature of the students' prior conceptions and the learning goals. The following are among those that have been used:

i. Broadening the range of application of a conception:

Students' prior conceptions may be a resource which can be extended. For example, for younger children energy is attributed to human energeticness and motion. By inviting children to consider what happens to their energy the notion can be generalised to encompass the motion of inanimate objects leading on to an appreciation of energy being "stored" in springs etc.

ii. Differentiation of a conception:

In many areas students' conceptions can be global and ill defined and particular experiences are necessary to help them differentiate their notions (e.g. heat and temperature, force and energy, weight and moment). In the area of energy, we found that students did not differentiate between the weight of an object and the energy transferred when the object is lifted up (within normal experience, the force of the Earth's gravitational field on the object is constant with changes in height above the Earth's surface). Due to this confusion, students would assert that an object gained weight on being lifted up yet this was not supported by the evidence of spring balance readings. There was a need for a "something" that changed while "something else" remained constant (Brook 1987).

iii. Building experiential bridges to a new conception:

Research by Brown and Clement (1987) with college students has indicated the importance of thought experiments in constructing conceptual bridges. Our work has been with younger students and perhaps not surprisingly we find it can be important for such bridges to be constructed through practical experiences. A prior conception about energy which is widely held is that energy can disappear. In the case of a hot cup of tea in a room, students assert that the tea cools down and the heat energy disappears. To encourage the construction of the notion that energy does not disappear but that it goes somewhere, possibly "spreading out" so it is less detectable, classes conducted a series of experiments in which a hot cup of water was allowed to cool in outer containers of cold water of progressively larger volumes. The temperature of the water in the inner and outer containers was recorded and plotted at regular intervals of time. After inspecting the resulting graphs, students were then asked to think about what happens when the outer container is the room itself. Having done the activity and plotted the graghs, students were able to construct in their imagination the notion of heat being "spread out" in the room.

iv. Unpacking a conceptual problem:

In some cases a conceptual problem occurs which cannot be solved directly but which requires a deeper problem to be addressed. A clear example of this occurs in the teaching of the kinetic-molecular theory of gases where children will accept the existence of particles but have difficulty with the concept of intrinsic motion. The prior conception to be dealt with here is the well known conception of "motion requiring a force". An analysis of learning problems of this kind could give some guidance to the sequencing of topics in the curriculum as a whole.

v. The importing of a different model of analogy:

In the lessons on the structure of matter, students were asked to examine the properties of a range of substances and to describe and explain them. The observation that a gas is "squashy" elicited ideas among many students that gases are not continuous stuff but made of particles with spaces between them. (An alternative model involving "squashy molecules" has also been proposed and defended.) Simple experiences with objects in one domain are being drawn on to account for behaviour in another domain. It is probable that early experiences provide children with a series of schemes which are important for them to draw on in later science teaching. Such basic schemes could include flow in both open and closed systems, spreading out and packing together of objects, oscillating systems.

vi. The progressive shaping of a conception:

In the teaching of the particle theory of matter we find the initial idea that matter is particulate rather than continuous is rapidly adopted by 12 years old students. The properties of those particles and the way their behaviour accounts for various macroscopic properties has to be treated progressively as students come to explore the range and limitations of their theories. Experiences which focus attention on intrinsic motion of particles and the forces between particles have been found to be important. In adopting a model, students need opportunities to test it out, see where it fails in order to adapt it. Some bits will be constructed which conform to scientific ideas others will not (e.g. the notion that particles are "squashy", expand on heating or that there is air between particles are commonly used, (Scott 1987).

vii. The construction of an alternative conception:

In some cases students' prior ideas are incommensurate with the scientific conceptions, and attempting to shape their notions into the scientific ideas only leads to problems. In a case of this kind we have acknowledged students' prior ideas and discussed them. We have then indicated that scientists have a different view and an alternative model is built. Students have the opportunity later to evaluate the scientific model in relation to their prior ideas. This was the approach we took to teaching plant nutrition. Students' prior ideas about plant nutrition focussed on the notion of food as something taken in from outside the plant. Within this conception water, "goodness from the soil" and even light, are seen as food for plants. The scientific notion, however, hinges on an alternative conception for food - that of providing energy for maintaining the processes of a living system. In the case of green plants, the chemicals which are involved are synthesised. The discontinuity in the students' basic conception and that of scientists was recognised in the teaching and an alternative conceptual scheme for plant nutrition was presented together with practical experiences supporting it.

In this task of designing, trialling and evaluating teaching sequences which are better tuned to learners' understanding it has been necessary to consider the nature of learners' conceptions and how they differ from the learning goals in order to identify appropriate pedagogical manoeuvres. This leads to the suggestion that strategies for promoting conceptual change need to be investigated in the context of particular domains of knowledge. General prescriptions of the conceptual change process by itself is not enough. Information about the nature of the conceptual change to be promoted is necessary in designing instructional sequences.

6. Outcomes and results

The project has a number of different kinds of outcome. This section will review the products in terms of the teaching schemes, their influence on classroom environment and the attitudes of participants. Learning outcomes in terms of conceptual change of students and teachers are then considered.

1. The production of schemes of work

Schemes of work, all incorporating strategies which encourage active learning on the part of students, have been produced in three topic areas (Children's Learning in Science Project 1987). At the basic level of practicability we know the schemes do work in classroom settings. At a deeper level, because of the reflexive way in which they have taken account of students' interpretations of the teaching tasks and making necessary modifications, we see the schemes as *adapted* to students' thinking.

> "What is beyond doubt is that the series of lessons did 'go well' - pupils, teacher and researcher all agreed upon this... novel teaching strategies had to be adopted. What had been a problematic area... was transformed into an attractive series of lessons involving practical work, whole class discussion, small group work and so on." Scott and Wightman 1985 (p.4)

2. An example of a scheme of work

To illustrate the type of materials and approaches used, one of the schemes - on the teaching of the structure of matter - is given in outline in table 1.

A number of features are worth drawing attention to here.

a) The overall shape of the scheme moves from students' explanations towards the accepted science view.

b) The notion of scientific theory as addressed explicitly through a simulation. (It is not just the content of students' ideas but general features of their thinking that need addressing.)

c) A wide range of experiences are presented to students and these become a shared set of phenomena to be "explained"- posters on the classroom wall act as a useful paper memory.

d) Students readily generate a particle model but features of their particle model can be problematic. Experiences in a wide range of classes indicate that the same type of conceptual issues emerge. These are listed in table 1. Suggestions for dealing with these are included in the scheme.

The development of one of the issues, "What holds particles together?" is described here as an example. Students usually consider that solids are *solid* and hold their shape because the particles are close together and cannot be pushed any closer. This notion of solidity accounts for the behaviour of solids under compression. Building models of a solid using polystyrene spheres indicates to students that an explanation of holding a shape requires more than the notion of close packing.

Once the notion of "something" holding the particles together is introduced this then needs to be thought through in terms of what happens during a change in state. The following transcript illustrates the conceptual problems which are typical and also the remarkable progress that one or two students made in thinking through the problem to the point where they realise the bonding does not disappear during a change in state, but

Table 1: The teaching scheme on the structure of matter

ORIENTATION	Teacher demonstration of some eye-catching properties of substances.
ELICITATION OF IDEAS	Circus. Students work in pairs studying a range of phenomena and explaining them on their own terms. e.g. how smell reaches you air in syringe is squashy loaded wire stretches Feedback. The pairs join in fours to produce a poster giving explanation. Posters are displayed, presented and discussed.
RESTRUCTURING Theory making	Group work. Students are involved in some simulations of theory making and testing including the solution of a murder mystery. Class review. The processes involved are reviewed in order to consider how evidence is used, how solutions are generated and checked.
Patterns of properties	Circus. Students work in pairs reviewing the properties of a wide range of solids, liquids and gases. Class review. A consensus pattern of properties of solids, liquids and gases is produced.
Theory generation	Group work. Students discuss what ice, water and steam might be like inside. Posters are produced which are displayed, presented and discussed.
Theory shaping	Issues emerging from the student's models are focussed on in a responsive way by the teacher using demonstrations, group work and discussion, working towards a consensus view. Emerging issues: a. Particles are invariably the basis of student models. b. Properties of the particles are used to account for properties of substance e.g. air-squashy molecules. c. What is between the particles? Notion of continuity of substance maintained by suggesting air is between particles. d. What keeps particles moving? e. What holds particles together?
APPLICATION	Circus. Students given opportunities to try out their particle model in order to explain some new situations.
REVIEW	Group work and class review Students revisit earlier posters and comment on the changes in their explanations.

that the particles have enough energy to "overcome" it. The discussion occurred when 14 year old students were asked to explain the differences between ice, water and steam.

S2 -- we are more or less clear how things go from solids to liquids to gases, but not from gases to liquids to solids.

S1 The point is in the gas the bonding has totally gone.

S2 So how does it happen that bonding comes back?

This issue of the reversibility of the process continues to exercise the group and a number of hypotheses are raised.

S1 I suppose it works vice versa, when it's heated it destroys the bonding, when it's cold it, you know, remakes it.

S3 -- but how does it remake it? What does it --- remake it out of, though?

S2 If atoms are bonded an atom can't change into a bond to hold the other atoms together, can it?

I How do you imagine bonding?

S4 Sort of like a string between the atoms sort of holding it all together.

S1 No, it isn't. He explained to us about magnetic, magnetism. Some sort of force

S4 Static, static electricity or something like that.

S2 Yeah. That kept them together. And I suppose if it was hot, then it wasn't magnetised as much or something, and then when it was cold it -- magnetises more.

S4 When they are hot they vibrate more, so that the static isn't as strong.

S2 Yeah, I know, but they vibrate more and break the bonding and then they finally get to a gas and that's as far as they go... but *how does it get the bonding back?*

S4 When it starts to cool down, they don't vibrate as much.

S1 Ah, yeah - when they cool down, the bonding will be increased so they won't be able to move around as much. That fits in, doesn't it?

S2 Yeah, but the point is how do we get the bonding back?

S4 Slow down the vibrating --

The question of *how the bonding comes back* continues to be considered until one student suggests:

S4 I suppose it's ever present there but -- yeah it hasn't got a chance to like grip, grip them, you know, and keep them together. Well where it slows down, you know, it might get to grips with the -

S3 A bit easier to keep slower things together.

3. Status of the schemes

In preparing the schemes for use by others it was considered important not only to include the usual type of information (the aims of the schemes, the activities, apparatus required, organisational suggestions etc.), but also to give others information about the conceptual ecology of the classroom - the ideas students may tend to use at different points and how these might change. In this way the schemes try to illustrate a more diagnostic approach to teaching. In addition it is hoped this type of information will help others to be a bit more secure the first time they use the materials so they are not too taken aback by the daunting problem of responding appropriately to the range of issues which may emerge. Indeed not only do the materials provide diagnostic information but they also provide suggestions as to possible lines of action.

A further point about the schemes which is of importance to teachers is that they are presented within a coherent overall perspective on learning - the strategy "makes sense" - it is not just a set of "neat things to do to keep students busy", or "tips for teachers". Finally it should be said that the schemes are not seen as the only way to treat each of the topics in question nor necessarily the best way. Indeed in teaching in a reflective and diagnostic way, individual teachers will need to adapt the suggestions to the needs of their own classes.

4. Evaluating activities in the classroom

The detailed ethnographic documentation of the same teacher's classroom during current practice and when using the revised schemes gives clear evidence of the greater amount of active participation in lessons by students in the revised schemes. The evaluation reports are currently being written and will be available from the project. Some pilot studies have been undertaken in which the same teacher teaches the same topic to parallel classes; in one case using the school's scheme and in the other using the project's scheme. An observation schedule based on that used by Rennie and Parker (1985) was devised to record the time spent in class on different types of activity. A comparison of profiles is shown in figure 4.

The differences in the distribution of time spent on different activities is apparent with a a shift for the CLIS class away from students listening and writing to time spent on planning and discussion. This, of course, by itself says nothing about the quality of the activities - more detailed data collection methods are necessary to capture this - however it does indicate that opportunities do exist in the CLIS lessons for more active participation by students in the control of their own learning.

% Time on activity

Activity	CLIS scheme B n=13	CLIS scheme G n=15	current practice B n=11	current practice G n=15
Watch/listen	12	9	27	26
Read/write	24	28	47	51
Manipulate apparatus	23	22	12	13
Planning/discussion	24	29	3	4
Other on task	2	2	0	1
Off task	9	5	9	4
Teacher contact	6	5	2	1
Total	100	100	100	100

Fig.4 Profiles for time on different activities for classes following CLIS and normal school science. The activity of each student was recorded in a sweep round the class every 120 seconds. Data collected over 4 double periods for each class.
Total observations = 2978 CLIS scheme
= 1735 Current practice

The same pilot studies also included the coding of questioning behaviour. Overall the number of questions answered by students was slightly higher in the CLIS lessons. The data displayed by gender is shown in figure 5. The results indicate that when teachers pick from a show of hands, girls respond to questions in CLIS classes as frequently as boys whereas this is not the case in current practice.

However, the boys in both types of lesson participate more than the girls in offering unsolicited responses. In addition it was found that there were considerably more topic related student initiated questions in the CLIS classes than for current practice. Indeed one of the features noted by teachers and researchers in the CLIS classes was the extent to which students referred to out-of-school situations and examples in the science lessons.

5. Teachers' reactions to the schemes
We have found that teachers involved in the project and others who have come on courses are very positive indeed about the

	Solicited		Unsolicited		Total
	B	G	B	G	
CLIS scheme n=28	16 n=13	18 n=15	39 n=13	15 n=15	88
current practice n=26	13 n=11	7 n=15	41 n=11	19 n=15	80

Fig.5 Frequency of student response to teacher's questions by gender (data collected over four double periods, both classes taught by the same teacher).

approach being proposed. There are differences, however, in theways different teachers interpret and implement the approach in practice (Johnston, 1987). As a result of the classroom work and feedback from teachers over the last few years there are a number of features in teachers' changing ideas and practice which can be identified.

a) Eliciting children's ideas:

The value of eliciting children's ideas is quickly appreciated and techniques for doing this are employed effectively. Teachers see the value to themselves and to the members of the class of giving students opportunities to explore their own ideas.

> "I became acutely aware of the very large range and variety of ideas which the pupils were carrying and which were creating difficulties in their understanding of particulate theory. Some pupils could not conceive of there being

"nothing" between gas atoms; others could not see why atoms in all three phases should *continue* to move of their own accord... and so on. My previous teaching... never gave the opportunity for these kinds of difficulties to come to light... (it) dit not even provoke the pupils into considering that they might have conceptual difficulties."

b) Responsive teaching:

Initially teachers express concern and may even feel a sense of panic, when they consider how to deal with the notions raised by students in their classes.

"- the strategy of encouraging pupil contributions meant that a lot of unusual ideas were put forward - the "removal of the lid from a can of worms". Dealing with each contribution sympathetically *and* trying to channel ideas in the right direction demanded quick thinking." Scott and Wightman 1985 (p.4)

The shift in the perspective of a secondary school science teacher away from the security of the scientist's knowledge frame to the shifting sands of students' perspectives seems to be initially a very threatening one. It was noted, however, that the second time teachers used one of the schemes they reported feeling much more comfortable since they could anticipate the issues that would arise. Teachers also found it interesting and reassuring in meetings to find similar issues emerging across classes in different schools.

c) Group discussion:

Initially teachers were somewhat hesitant about the use of small group discussion in science classes. Concern was expressed about how to organise it effectively. There was also some lack of confidence that the students would make progress by themselves without teacher intervention.

We found that tape recording group discussions provided reassurance that given a reasonably clear task, students' discussions would be on task and useful.

"I was exceedingly *pleased* when what seemed to me to be relatively ordinary children ... went from nothing, throwing around unconnected ideas, to ... sorting out the theory ... in a discussion they will have a sense of achievement doing that."

Other teachers have commented:

"I feel happier about using (discussion work) now I understand more clearly the processes that take place in discussion groups and the time it takes."

d) Obtaining closure:

There seems to be a strong and understandable pressure within science teachers that lessons should get to the "scientific answer". This means that open ended experimentation by students, which may go in some apparently strange directions, may be dismissed as "a waste of time" or "rubbish". Furthermore, attempts by groups or a whole class to explain phenomena and reach a consensus may be frustrating to a teacher because of what appears to be lack of convergence. This can lead teachers initially to resort to exposition and to short circuit the thinking process that students have to go through to make sense of ideas. The temptation to be directive is very strong in the face of what initially appears to be a confusion of ideas. What seems to be important in dealing with this is again experience. When teachers have been through a teaching sequence once they gain a confidence that the ideas will "come together" - though it may take several lessons. The growth in awareness of students' ideas seems to be accompanied with a patience and a realisation that it is not what they teach that matters - it is what students learn.

"I think what you have to hope is that you get them interested, ... and *they* will then do the learning. It's got to be something that comes from them, not from me. It doesn't matter what *I* do really - it's what *they* do that counts." Wightman et al 1985

e) Time constraints:

Time constraints are a real dilemma for science teachers. As they begin to appreciate the issues involved in learning a topic from the students' point of view they see the need to spend more time on it. However, the realities of school teaching schemes and examination syllabuses militate against adopting a more relaxed schedule.

f) Harder work:

Teachers do acknowledge that it is harder work to teach in a more responsive way. It is the stress of thinking on your feet during the lessons coupled with the amount of flexibility which is needed in the planning between lessons which can be stressful. However, despite this there is general agreement that it is also more rewarding.

6. Students' reactions

a) In general we have found students respond well to the more open learning environment. "It is not often in science class that someone says something and nobody laughs."

b) They are very enthusiastic about being given control over the design of an experiment or to make choices about activities.

c) Though they are often hesitant and self conscious to begin with about presenting their arguments or experimental results to the rest of the class, this is appreciated as an important activity from which they can learn.

7. Learning outcomes

a) Conceptual change

The change in students' conceptions which took place in the experimental classrooms has been documented in the course of lessons. The project is also comparing the conceptual change produced by the experimental and current practice schemes using diagnostic tests before and after the teaching sequence. The analysis of these data is still in progress and the results will be included in the evalution reports together with the ethnographic accounts which will be available from the project.

A pilot study has been conducted in which the same teacher taught the same topic to two parallel groups of 13-14 year olds using the CLIS scheme with one and the school's current teaching scheme with the other. Though there was little difference between groups overall in the conceptual change produced there was an interesting interaction effect indicating that in this case the girls benefitted more from the CLIS scheme than the boys. This of course is only a small study but, together with other indicators it does suggest that a more detailed enquiry into gender effects might be worthwhile.

b) In evaluating the effectiveness of the schemes we are also aware that there may be outcomes other than conceptual change which would be useful to study including students' metacognitive skills, and their understanding of the scientific enterprise. We suspect that a six week "treatment" in one topic area is unlikely to produce major changes and what is required is the longer term evaluation of a consistent programme within a school science department.

c) An important outcome of the work has been the group of over 30 science teachers with expertise in conducting science lessons in more open ways and the language to talk about what they are doing.

Compared with many investigations of teaching where experimental and control conditions are produced and the outcomes are compared, our work has been rather 'long winded'. But maybe there is a message in that also. The reflexive produres necessary to produce the teaching materials take time. Perhaps even more significantly, the processes of change in teachers' thinking and action also require time if they are to become effectively established.

Hopefully, in the future with the current interest in active learning approaches being promoted (SSCR 1987) these will become more widespread and easily adopted.

7. Issues for future consideration

Here I will outline very briefly the on-going issues which I think are important for researchers interested in this field of work.

1. Experimental studies on conceptual change

Analyses are needed to indicate the nature of the conceptual change required in different areas of concern - then appropriate strategies need to be devised and evaluated. In the evaluations attention needs to be paid to longer term effectiveness of strategies and to the contexts in which the learning is useful to the learner.

2. Longitudinal studies of conceptual development

Not only do we need to know how to intervene effectively in students' learning, we also need a better understanding of *when* to intervene. Here longitudinal studies of the development of children's conceptions, such as those reported in the topic of light by Guesne (Driver, Guesne and Tilberghien 1985), in biological topics by Carey (1985) and in heat and temperature by Strauss and Stavy (1982) provide important information as to how ideas build on one another from the child's point of view.

3. Metacognitive learning

Studies of how students can be encouraged to take responsibility for their learning both personally and within the social settings of classrooms and schools play an important part in a constructivist agenda (Baird and Mitchell 1986).

4. Teacher education

However effective and empirically well established certain teaching approaches may be, unless the research findings are implemented they are of little value to the educational world. This raises questions not only about how well researchers communicate their findings to practitioners but also who "owns" and is committed to the enquiry in the first place.

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Note

1. These are topic areas in which the project had already undertaken research on children's thinking and which presented conceptual problems.

References

Anderson R.C. (1984) Some reflections on the acquisition of knowledge, *Educational Researcher, 13*, 5-10.

Baird J.R. & I.J.Mitchell (1986) *Improving the quality of teaching and learning*, Melbourne, Victoria: Monash University Printery.

Barnes D. (1976) *From Communication to Curriculum*, Harmonsworth: Penquin.

Bell B.F. & Brook A. (1985) *The Construction of Meaning and Conceptual Change in Classroom Settings: Case Studies in Plant Nutrition*, Children's Learning in Science Project, Centre for Studies in Science and Mathematics Education, University of Leeds.

Bell B. & P.Freyberg (1985) Language in the science Classroom. In: R.Osborne & P.Freyberg (eds.). *Learning in Science*, Heinemann.

Bereiter C. (1985) Toward a solution of the learning paradox, *Review of Educational Research, 55*, 201-226.

Brook A. & R.Driver (1986) *The construction of meaning and conceptual change in classroom settings: Case studies in the learning of energy*. Children's Learning in Science Project, Centre for studies in Science and Mathematics Education, University of Leeds.

Brook A. (1987) Designing experiences to take account of the development of children's ideas: An example from the teaching and learning of energy. Paper presented at the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics, Cornell University, July 1987.

Brown D.E. & J.Clement (1987) Overcoming misconceptions in mechanics: A comparison of two example-based teaching strategies. Paper presented at AERA, Washington, D.C. April 1987.

Bryant P.E. (1982) The role of conflict and agreement between intellectual strategies in children's ideas about measurement, *Brit. Journal of Psychology, 73*, 243-251.

Carey S. (1985) *Conceptual change in childhood*, MIT Press.

Case R. (1978) A developmentally based theory and technology of instruction, *Review of Educational Research, 48*, 439-463.

Champagne A.B., R.F.Gunstone & L.E.Klopfer (1985) Effecting changes in cognitive structures among physics students. In: L.H.T.West & A.L.Pines (eds.). *Cognitive Structure and Conceptual Change*, Academic Press.

Children's Learning in Science (1987) *CLIS in the Classroom: Approaches to Teaching*, Centre for studies in Science and Mathematics Education, University of Leeds.

Claxton A. (1982) School Science: Falling on stony ground or choked by thorns? Paper available from author at Chelsea College, London.

Claxton G. (1984) *Live and Learn*, Harper and Row.

Collins H.M. (1985) *Changing order*, Sage Publications.

DiSessa A. (1983) Phenomenology and the Evolution of Intuition. In: D.Gentner & A.L.Stevens (eds.), *Mental Models*, Lawrence Erlbaum Associates.

Driver R. (1983) *The Pupil as Scientist?*, Open University Press.

Driver R. & B.Bell (1985) Students' thinking and the learning of science: A constructivist view, *School Sience Review, 67*, 443-456.

Driver R., E.Guesne & A.Tiberghien (1985) *Children's Ideas in Science*, Open University Press.

Driver R. & V.Oldham (1986) A constructivist approach to curriculum development in science, *Studies in Science Education 13*, 105-122.

Engel Clough E. & R.Driver (1986) Consistency in the use of students' conceptual frameworks across different task contexts, *Science Education 70*, 473-496.

Gentner D. & A.Stevens (1983) *Mental Models*, Lawrence Erlbaum Associates.

Gilbert J.K., J.Osborne & P.J.Fensham (1982) Children's science and its consequences for teaching, *Science Education, 66*, 623-633.

Glaserfeld von E. (1983) Learning as a constructive activity. In: J.C.Bergeron & N.Herschovics (eds.), *Proceedings of the Fifth Annual Meeting PMR-NA*, Montreal, Canada.

Greeno J.G. (1978) A study of problem solving. In: R.Glaser (ed.), *Advances in instructional psychology*. Hillsdale: Lawrence Erlbaum Associates.

Head J. (1986) Research into "Alternative Frameworks": promise and problems, *Research in Science and Technology Education, 4*, 203-211.

Head J. & C.Sutton (1985) Language, understanding, and commitment. In: L.H.T. West & A.L.Pines (eds.) *Cognitive Structure and Conceptual Change*, Academic Press.

Hewson M.G. & P.W.Hewson (1983) The effect of instruction using students' prior knowledge and conceptual change strategies on science learning, *Journal of Research in Science Teaching, 20*, 731-743.

Helm H. & J.Novak (1983) *Proceedings of the International Seminar: Misconceptions in Science and Mathematics*, Ithaca, U.S.A.: Cornel University.

Johansson B., F.Marton & L.Svensson . An approach to describing learning as change between qualitatively different conceptions. In: L.H.T.West & A.L.Pines (eds.), *Cognitive Structure and Conceptual change*, Academic Press.

Johnson-Laird P.N. (1983) *Mental Models*, Cambridge University Press.

Johnston K. (1987) Changing teachers' conceptions of teaching and learning. Paper presented at the BERA conference on Teachers' Professional Learning, Lancaster University, July 1987.

Jung W., H.Pfund & C.Rhoneck (1982) *Problems concerning students' representation of physics and chemistry knowledge*, Ludwigsburg: Selbstverlag, Pedagogische Hochschule.

Karmiloff-Smith A. (1984) Children's problem solving. In: M.E. Lamb, A.L.Brown & B.Rogoff (eds.), *Advances in Developmental Psychology, Volume 3*, Lawrence Erlbaum Associates.

Larkin J.H. (1983) The role of problem representation in physics. In: D.Gentner & A.Stevens (eds.), *Mental Models*, Lawrence Erlbaum Associates.

Newell A. & H.A.Simon (1972) *Human problem solving*, Prentice Hall.
Nussbaum J. & S.Novick (1982) Alternative frameworks, conceptual conflict and accommodation: toward a principled teaching strategy, *Instructional Science 11*, 183-200.
Pfundt H. & R.Duit (1985) *Bibliograpy. Students' Alternative Frameworks and Science Education, Kiel:* IPN.
Posner G. (1982) A Cognitive Science Conception of Curriculum and Instruction, *Journal of Curriculum Studies 14*, 343-351.
Rowell J. & C.Dawson (1981) Volume, conservation and instruction: a classroom based Solomon Four group study of conflict. *Journal of Research in Science Teaching, 18*, 533-546.
Rowell J. & C.J.Dawson (1983) Laboratory counter examples and the growth of understanding in science, *European Journal of Science Education, 5*, 203-216.
Rowell J.A. & C.J.Dawson (1984) Controlling variables: testing a programme for teaching a general solution strategy, *Research in Science and Technology Education, 2*, 37-46.
Rumelhart D.E. & D.A.Norman (1981) Analogical processes in learning. In: J.R.Anderson (ed.), *Cognitive skills and their acquisition*, Hillsdale: Lawrence Erlbaum Associates.
Schank R.C. & Abelson (1977) Scripts, plans, goals and understanding. An inquiry into human knowledge structures. Hillsdale: Lawrence Erlbaum Associates.
Scott P. (1987) The process of conceptual change in science: A case study of the development of a secondary pupil's ideas relating to matter. Paper presented at the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics. Cornell University, U.S.A. July 1987.
Scott P. & T.Wightman (1985) Teaching the particulate theory of matter - a constructivist approach. Paper presented at British Educational Research Association Meeting, Sheffield, August 1985.
Secondary Science Curriculum Review (1987) *Better science: Approaches to teaching and learning*, Heinemann Educational Books.
Solomon J. (1983) Learning about energy: how pupils think in two domains, *European Journal of Science Education, 5*, 49-59.
Solomon J. (1987) Social influences on the construction of pupils' understanding of science, *Studies in Science Education, 14*, 63-82.

Stavy R. & B.Berkovitz (1980) Cognitive conflict as a basis for teaching quantitive aspects of the concept of temperature, *Science Education, 64*, 679-692.

Strauss S. (1981) Cognitive development in school and out, *Cognition 10*, 295-300.

Strauss S. & R.Stavy (1982) *U-shaped behavioural growth*, New York: Academic Press.

Viennot L. (1979) Spontaneous reasoning in elementary dynamics. *European Journal of Science Education 1*, 205-222.

West L. & A.Pines, (Eds.) (1985) *Cognitive Structure and Conceptual Change*, Academic Press.

Wightman T.et al. (1986) *The construction of meaning and conceptual change in classroom settings: Case studies in the particulate theory of matter* Children's Learning in Science Project, Centre for Studies in Science and Mathematics Education. University of Leeds.