CONCEPTUAL CHANGE IN SCIENCE TEACHING AND TEACHER EDUCATION

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Introduction

Conceptual change is catching on. In an elementary classroom, students argue about whether or not a table pushes up on a book it is supporting. In a secondary classroom, students produce their own models of genetic inheritance and try to persuade others of the viability of their ideas. In a science teacher education program, prospective elementary teachers make observations of the moon over an extended period and use sun-earth-moon models to explain their observations. In a graduate class, teachers talk about interviewing their students and encouraging them to express their ideas in class. At professional conferences educators present papers on using conceptual change ideas at elementary, secondary, and tertiary levels. These are current examples of events in which educators are trying to understand what conceptual change is and what it means for science education.

But what is conceptual change? A popular slogan for the latest fad that will leave the educational world unchanged as have so many earlier ones? Or an idea that has the possibility of transforming science education for the better? Initially the idea of conceptual change was used in education as a way of thinking about the learning of disciplinary content such as physics (Posner, Strike, Hewson, & Gertzog, 1982) and biology (Carey, 1985). Its use, however, has expanded in two ways. First, from the outset the notion of teaching for conceptual change has gone hand in hand with considerations of learning as conceptual change. Second, conceptual change has been considered in other domains of disciplinary content such as chemistry, earth science, mathematics, writing, reading, and teacher education.

One organization that exemplifies the growth of conceptual change ideas in the past decade is a special interest group (or SIG) on conceptual change formed as part of the American Education Research Association (AERA). The SIG was started in 1983 in order to provide an annual meeting point for like-minded individuals within a huge organization. While AERA is very largely attended by Americans, from the outset the SIG's membership has had more international members than Americans. This year's SIG sessions included papers from authors in Australia, Brazil, Britain, Canada, Israel, Italy, South Africa, and the USA. In other words there is an international interest in conceptual change. Comparing conceptual change sessions sponsored by the SIG with those sponsored by others within AERA provides some indication of the growth of interest in conceptual change. In 1988 the AERA annual meeting had six sessions that listed "conceptual change" as a descriptor; 5 of these were

sponsored by the SIG. The respective figures were 9 and 8 in 1990, 12 and 7 in 1991, and 15 and 7 in 1992. Thus, while SIG membership has hovered at around 200 for the last few years, interest in conceptual change has developed in areas other than science learning: sessions at AERA in 1992 also focused on conceptual change in mathematics, teacher education, reading, and writing.

Another indicator of the acceptance of conceptual change is its presence in documents about recent educational reform in Spain (D.C.B. 1989.) References to it include a consideration of "perspectives that view learning science as a conceptual change in the pupil's cognitive structure." (p.111) and a recognition that "[O]ne of the central objectives in teaching science is to promote changes in pupils' conceptions . . . " (p.159)

But what is conceptual change? To understand what it is and how it might influence science teaching, it is necessary, in my view, to consider its links to two other ideas that are currently popular. These are constructivism (as a view of how people learn) and students' conceptions (tenacious ideas different from those generally accepted and held by students of all ages in all countries, called among other things alternative conceptions or misconceptions). In this article I shall first consider different interpretations of the idea of conceptual change. I shall then outline with reasons what I understand conceptual change to be and explore its links to constructivism and student conceptions research. Finally I shall consider different implications that conceptual change might have for learning and teaching in both science and science teacher education.

Interpretations of Conceptual Change

When thinking of conceptual change it is helpful to recognize that the word "change" is used in different ways. One might talk, as in the fairy tale, of a princess kissing a frog who, as a consequence, changes into a prince. In this case there is only one entity before and a different one after the change; the frog is no more; there is only a prince. Here change means extinction of the former state. A second example might be an election for political office with the incumbent being beaten by the challenger: there has been a change of mayor. Both people continue to live in the city, but only one person is mayor. The incumbent loses status, while the challenger gains it. In this case, there is no extinction; change means an exchange of one entity for another. A third example might be a home that started as a small four-roomed cottage early last century, and was later extended by adding a wing at either end. When water and light became available, a bathroom and a kitchen were attached. It is still the same home: change here means extension.

Interest in conceptual change has, to a considerable degree, been focussed on the problem of students who hold one view ("a table supports a book by being in the way") in contrast to the canonical view ("a table supports a book by exerting an upward force on it.") How should one characterize a student who changes his or her mind from the former to the latter? Change as in the first example above--extinction--does not seem to be an appropriate characterization of this change. There is no sense in which one view has disappeared to be replaced by the other; students, by and large, will remember both views and simply say: "I changed my mind" or "It made more sense." Change as in the second example--exchange--seems a much better characterization of what the student has reported. It is change of this kind that is evoked for most people on hearing the term "conceptual change." I have referred to this elsewhere as "conceptual exchange." (Hewson, 1981)

In the literature on conceptual change different interpretations of related concepts have emerged. It is helpful to consider these in the context of the change examples discussed above.

Conceptual Change: Inclusive or Exclusive?

One set of interpretations of conceptual change is closely related to the growth of an awareness of the diversity and tenacity of students' views of natural phenomena. Thus when one thinks of a student learning ideas that are the goals of a given curriculum, one needs to consider whether in order to achieve a goal the student may have to give up, reject, or demote an idea particularly if it contradicts the goal idea. Such a case would entail conceptual exchange, and there is common agreement in the literature that the process of a student exchanging one idea for another is conceptual change.

For some, this is all that conceptual change means. It is thus a term applying to the problematic part of a person's experience of learning--giving up one idea for another--but by inference does not apply to learning that is not problematic. In other words, for some people conceptual change is exclusively conceptual exchange. Others, however, see sufficient similarities between problematic and unproblematic learning to think of conceptual change as including different types of learning. For example, in both cases a person goes from not knowing an idea to knowing it. This is where change as extension is a useful metaphor in thinking about learning without difficulty. Here, students learn things they didn't know by making connections to what they already know; this is not a problem when their present views can be reconciled with what they learn. Another way to think about this is to regard existing knowledge as "capturing" new knowledge (Hewson, 1981). From this perspective, conceptual

change is an inclusive term, including both exchange and extension (or capture).

Knowledge: Relative or Right/wrong?

Some alternative interpretations of conceptual change derive from alternative views of the nature of knowledge, e.g., the nature of physics knowledge. One view is that the adequacy of a set of ideas, e.g., Newton's laws of motion, depends on the context in which that set is used. While there is an incredibly wide range of phenomena that are well described by Newton's laws--planetary motion, the building of bridges, and Brownian motion all come to mind--they are less than adequate when dealing with the very fast (where relativity becomes necessary) and the very small (where quantum mechanics takes over), and they provide explanations of common, everyday events such as throwing a ball and a table supporting a book that are counter-intuitive to a large proportion of the general public. This suggests that the context in which knowledge is used needs to be considered, and thus that different viewpoints can be seen as alternative conceptions rather than one having to be right and another wrong.

An alternative view of the nature of knowledge, particularly scientific knowledge, is that its growth represents a progression towards truths about the natural world. In other words, science discovers aspects of the world as it really is. It is, as a consequence, always possible to decide in principle whether a particular view of an event or phenomenon is right or wrong. Additionally this view focuses attention more on scientific products ("the facts") than on how this knowledge was produced. This suggests that views in opposition to what is right should be labelled misconceptions and thus conceptual change means replacing misconceptions with correct conceptions.

Conceptual Change: Teaching and/or Learning?.

A third set of interpretations of conceptual change revolves around the relationship between learning and teaching. It seems inevitable that issues of teaching will arise when learning is considered: the concept of teaching has little meaning without the concept of learning. In what follows, I find it useful to differentiate learning activities from learning outcomes.

One perspective on the issue is that teaching causes learning; if no learning occurred, then you couldn't have been teaching. Possible consequences of this are a blurring of the distinction between teaching and learning--some teachers use the terms interchangeably or in combination, e.g., teaching/learning--and a focusing on teaching strategies at the expense of learning activities because of the implied assumption that "if I taught well,

my students will have learned what I wanted them to."

An alternative perspective (Hewson & Hewson, 1988) sees the relationship between teaching and learning in a different light. While teachers may require their students to carry out learning activities and intend that these will lead to particular learning outcomes, it is also necessary that learners share these intentions. In this view, then, teaching is not a cause of learning outcomes: it facilitates them. Thus teaching can take place without learning occurring and vice versa. Possible consequences of this are a sharpening of the distinction between teaching and learning and a focussing of attention on learners and what is involved when they achieve intended learning outcomes.

Examples.

Papers delivered at recent conferences of educational organizations (NARST, AERA) in the USA provide examples of some of these different interpretations of conceptual change. Westbrook & Rogers (1992, p.3) stated that the process of using "strategies to bring children's thinking into line with that of scientists . . has become known as conceptual change." Here conceptual change is explicitly identified as a set of teaching strategies with the added implications that conceptual change is exclusively exchange and children's views are wrong while scientists' views are right. Another example comes from Stofflett (1992, p.3) who writes that "research on scientists' cognition identifies the process of conceptual change as a necessary prerequisite for the formation of scientifically validated theories." The focus here is on learning rather than teaching, a sense that the basis for validating theories is important (rather than that scientists are right.) In a third example Tobin (1992, p.2) states that "[c]onceptual change is learning, which is a social process of making sense of experience in terms of extant knowledge . . Since all learning occurs in a social milieu, all learning is inherently social. . . Accordingly, all conceptual change must be considered in a socio-cultural context." For Tobin, then, conceptual change is an inclusive idea, knowledge is relative to the context, and it is firmly a learning issue.

My view of Conceptual Change

Constructivism.

The general approach that I adopt is a variation of a constructivist perspective (Magoon, 1977). This assumes that humans construct their own knowledge, using their existing knowledge in order to do so. This

construction of knowledge takes place within a context of social interaction and agreement. In the process of construction, people develop relatively stable patterns of belief. They construct knowledge in ways that to them are coherent and useful. Since the construction process, however, is influenced by a variety of social experiences, the knowledge constructed by each individual is not normally completely personal and idiosyncratic. Further, I believe individuals are boundedly rational (Shulman & Carey, 1984; Simon, 1982). Existing knowledge and social agreements about meaning not only limit how new experiences are interpreted, but also influence what is perceived in any situation. Thus, two individuals exposed to the same events may perceive and interpret them in very different ways, depending on their individual underlying knowledge and beliefs and the ways in which these beliefs influence and are influenced by the social interactions out of which they are formed. Part of the evidence to support this view comes from studies of students' conceptions such as those referenced below. It is of interest that references to constructivism appear in the goals of recent educational reform in Spain (D.C.B. 1989): "School must ensure the construction of meaningful learnings . . " (p.33) and in statements about the nature of "the pupil who . . . constructs, modifies, and coordinates her or his schemata . . . " (p.34).

Students' Conceptions of Natural Phenomena.

In recent years, many studies of students' conceptions of natural phenomena have been carried out in different disciplines, in different countries and at all educational levels from elementary school through college graduates. The research has been reviewed in articles (Driver & Erickson, 1983; McDermott,1984), conference reports (Helm & Novak, 1983; Novak, 1987), books (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985), and bibliographies (Carmichael, et al., 1990; Pfundt & Duit, 1991.)

The constructivist perspective leads to an interpretation of many of the observed regularities and consistencies in students' responses as alternative conceptions that students hold about the natural world and how it works. Two notable characteristics of alternative conceptions are that they are often significantly different from, and thus alternative to, generally accepted views of the subject, i.e., they conflict with ideas teachers want students to learn; and they are surprisingly resistant to change as a result of traditional instruction (Champagne, Klopfer, & Gunstone, 1982.) Thus even when as is generally the case, students' alternative views are not as precise, not as extensive, not as widely useful as those that teachers want students to learn, it is their tenacity in the face of instruction to the contrary that point to the need to design instruction that acknowledges students' alternative

views and does so in an environment in which students accept that their own ideas may from time to time be the object of study.

The Conceptual Change Model.

The interpretation of student responses as driven by alternative conceptions suggests that learning may involve changing a person's conceptions in addition to adding new knowledge to what is already there. This view was developed into a model of learning as conceptual change (or CCM) by Posner, Strike, Hewson, and Gertzog (1982) and expanded by Hewson (1981, 1982). From this point of view, learning involves an interaction between new and existing conceptions with the outcome being dependent on the nature of the interaction. There are two major components to the CCM. The first of these components is the conditions that need to be met (or no longer met) in order for a person to experience conceptual change. The extent to which the conception meets these three conditions is termed the status of a person's conception. The more conditions that a conception meets, the higher is its status.

The second component is the person's conceptual ecology that provides the context in which the conceptual change occurs, that influences the change, and gives it meaning. The conceptual ecology consists of many different kinds of knowledge, the most important of which may be epistemological commitments (e.g. to consistency or generalizability), metaphysical beliefs about the world (e.g. the nature of time), and analogies and metaphors that might serve to structure new information.

Learners use their existing knowledge (i.e. their conceptual ecology), to determine whether different conditions are met, that is whether a new conception is intelligible (knowing what it means), plausible (believing it to be true), and fruitful (finding it useful). If the new conception is all three, learning proceeds without difficulty. The metaphor of change as extension is helpful in understanding this by drawing attention to the need for new additions to fit coherently into an overall plan. Just as an extended house is enhanced by additions that are well thought out and consistent with the existing structure, so too will be a conception that is extended. For example, a conception of acceleration that includes a definition as rate of change of velocity is enhanced with the inclusion of methods for measuring acceleration, examples of acceleration, the important role of acceleration in Newton's second law of motion, and so on. If, however, the new conception conflicts with existing conceptions, then it cannot become plausible or fruitful until the learner becomes dissatisfied with the old conceptions. In that event,

learning requires that existing conceptions be restructured or even exchanged for the new. The linked changes of status in the metaphor of change as exchange provide one way of thinking about this process. The relationship between status change and conceptual change is examined more fully elsewhere (Hewson & Hennessey, 1991.)

A central prediction of the CCM is that conceptual changes do not occur without concomitant changes in the relative status of changing conceptions. Learning a new conception means that its status rises, i.e., the learner understands it, accepts it, sees that it is useful. If the new conception conflicts with an existing conception, i.e., one that already has high status for the learner, it cannot be accepted until the status of the existing conception is lowered. This only happens, according to the CCM, if the learner holding the conception has reason to be dissatisfied with it. The learner's conceptual ecology plays a critical role in determining the status of a conception because, amongst other things, it provides the criteria in terms of which he or she decides whether a given condition is (or isn't) met. In this regard, the person's epistemological commitments, e.g., to generalizability (Hewson & Hewson, 1984), are particularly important.

Conceptual Change.

What then, in my view, is conceptual change? For many people the term refers only to instances of conceptual exchange. But I would argue the value of including conceptual extension with conceptual exchange, because it draws attention to the status considerations that influence all learning, not just conceptual exchange. I also see conceptual change as primarily a way of thinking about learning, i.e., it is something that a learner does as an intentional act, rather than something done by a teacher. There is, of course, much that a teacher can do to facilitate a student's learning, without any need to regard this as a mechanistic, causal process. Finally, it seems to me that the knowledge a learner gains only has validity in terms of, and is thus relative to, his or her conceptual ecology. Since a learner's conceptual ecology is a product of all the experiences and social interactions he or she has had, it will have many elements in common with those of other people.

This means that a curriculum should include not only particular theories and attendant phenomena, but also the basis for their acceptance. If we can't justify curriculum content to students, we shouldn't teach it. In other words, we need to recognize that "alternative" is not a synonym for "inadequate" or "unacceptable". The purpose of conceptual change teaching of science is not to force students to surrender their alternative concepts to the teacher's or scientist's conceptions but, rather, to help students both form the habit of challenging one idea

with another, and develop appropriate strategies for having alternative conceptions compete with one another for acceptance.

Implications of Conceptual Change for Science Education

In light of the above, it is possible to think about conceptual change entering science education in at least four ways. These four issues have to do with learning science, teaching science, learning how to teach science, and teaching how to teach science.

Learning Science

As mentioned above, the research literature has shown that students come to their science classrooms with a range of different conceptions of the natural world surrounding them (Pfundt & Duit, 1991; Carmichael, et al., 1990). These conceptions vary greatly with respect to such characteristics as clarity, breadth, coherence, ambiguity, and tenacity. In particular, many of these conceptions are at variance with the currently accepted scientific view. The significance of this research lies in the fact that these are the ideas that students use when they are introduced to normal scientific content. Thus their learning of this new content is influenced by their current ideas, in ways that may hinder or may help their learning. It therefore is useful to think of learning the desired outcomes as a process of conceptual change, including both extension and exchange.

Teaching Science

Accepting that students hold different conceptions that might need to change is one thing: concluding that it is the teacher's responsibility to engage in teaching practices that might facilitate conceptual change to occur is a separate matter. While some might argue for a separation of responsibilities--teachers present the content and students learn it--it is not a position I advocate. On the contrary, I believe it is the teacher's responsibility to be aware of students' conceptions and to teach in ways that are likely to facilitate conceptual change on the part of the students.

Many teaching studies in recent years have attempted to take into account research on students' conceptions of natural phenomena. A number of different features have begun to emerge from these studies as character-

istic components of what can be called conceptual change teaching (Hewson, 1991). On one hand there are different stages in conceptual change teaching. These include:

Diagnosis or Elicitation. Does the teacher use any diagnostic techniques to elicit students' existing conceptions and reasons why they are held?

Status Change. Does the teacher use strategies designed to help students lower the status of existing, problematic knowledge, and raise the status of other, competing ideas? Are there other application sites where the new conception can be used?

Evidence of outcome. Is there evidence that students' learning outcomes are based, in part, on an explicit consideration of their prior knowledge?

On the other hand, there are particular features that are present during different stages of conceptual change teaching. These include:

Metacognition. Are students encouraged or able to "step back" from one or more ideas held by themselves or others in order to think about them and express an opinion about them?

Classroom Climate. Is there an attitude of respect by both teacher and students for the ideas of others, even when they are contradictory?

Role of Teacher. Is the teacher able to provide opportunities for students to express themselves without fear of ridicule, and to ensure that he or she is not the sole arbiter of what counts as an acceptable idea in the classroom?

Role of Learner. Are students willing to take responsibility for their own learning, to acknowledge others' ideas, and to change their views when another seems more viable to them? Can students monitor their own learning?

Teaching that has included components such as these has been successful in helping elementary, middle school, high school, and college students change in significant ways their conceptions in content areas in many different areas in physics, chemistry, biology, and earth science. Bibliographies of these and related studies are available (Pfundt & Duit, 1991; Carmichael, et al., 1990.)

Learning how to Teach Science

I would argue that, just as students develop conceptions of everyday events, prospective teachers can

similarly be expected to develop conceptions of teaching based on their own experiences as students in many different classrooms, from courses in teacher education programs, and as student teachers. Thus, they can be expected to build conceptual structures in which they incorporate classroom events, instructional concepts, socially accepted behaviors, and explanatory patterns. These structures include, possibly implicitly on the one hand, their rationale for teaching and their view of knowledge, learning, and science, their disciplinary knowledge, and on the other hand the ways in which they teach, along with detailed specific information on content, students, school procedures, etc. I call this a conception of teaching science (Hewson & Hewson, 1988.)

It seems obvious to me that teachers' knowledge, skills, and attitudes are likely to be very different in kind, serving different purposes, and not necessarily being coherent. In other words, I find it reasonable to infer that prospective teachers will enter a program with their own individual conceptions of what it means to teach science that could differ in significant ways from those that are important to the program. Thus, similarly to the science learning issue above, I would expect that student teachers may need to undergo conceptual change with respect to their conceptions of teaching science that rest, often implicitly, on their conceptions of the nature of knowledge, of science, and of learning.

In order to identify the characteristics of a conception of teaching science appropriate for conceptual change teaching, Hewson & Hewson (1988) reviewed research on students' conceptions of natural phenomena, conceptual change science teaching, and teacher thinking. They concluded that science teachers should:

- know the phenomena, the methods, and the concepts, principles, and theories that constitute the science they are teaching;
- know what conceptions their students hold about the units to be taught, and the extent to which they are scientifically acceptable;
- be aware of the role played by students' existing knowledge in understanding new material;
- be convinced of the need to use conceptual change teaching strategies particularly when students' existing conceptions conflict with those being taught; and
- be able to plan and perform teaching actions that give effect to these strategies.

Teaching how to Teach Science

Finally, conceptual change enters science education through consideration of the strategies used by pro-

gram instructors to help prospective teachers undergo the desired changes in their conceptions of teaching science. Once again, in comparison with the science teaching considered above, the issue of how the responsibility for undergoing conceptual change is to be shared between prospective teachers and the program instructor becomes a significant one. In my view, it is the instructor's responsibility to use methods in teacher education similar to those being advocated for science teaching. In this case, these would be conceptual change teaching methods. This belief stems partly from the need for a program to be consistent in its methods and content, and partly because modelling particular teaching approaches is an especially effective way of making them accessible to prospective teachers.

There are clearly different ways in which a teacher education program can implement conceptual change issues, depending on the context of each particular institution. Science teacher education programs that have documented their attempts to use conceptual change ideas in thinking about their program include Monash University in Australia (Gunstone & Northfield, 1992), the University of Utrecht in the Netherlands (Wubbels, et al., 1992), and the University of Utah (Stoddart & Stofflett, 1992) and the University of Wisconsin-Madison (Hewson, et al., 1992) in the USA.

Conclusion

The idea of conceptual change entered education as an analogy drawn from the history and philosophy of science that was helpful in understanding the difficulties people experience in changing from one explanatory framework to another. Conceptual change has, however, expanded considerably since then in my understanding of it, from a way of thinking about problematic learning in science to ways of thinking about other types of learning, about learning in domains other than science, and about teaching that facilitates conceptual change learning. It does so in ways that are coherent and complementary, that provide good explanations of many educational events, that continue to raise good questions about current practices, and that suggest fruitful ways of reorganizing these practices. For all these reasons, conceptual change is a powerful idea. It is no wonder to me that it is catching on.

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