Chapter 9
How Can Conceptual Change Contribute to Theory and Practice in Science Education?

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Theoretical Developments in Conceptual Change

Conceptual change is not solely of interest to science educators. As noted in Stella Vosniadou's (2008) *International Handbook of Research on Conceptual Change*, whilst science disciplines are the dominant conceptual area for studies in conceptual change, this focus can be found in subject areas such as medicine and health as well as the philosophy and history of science. As is evident in many of the chapters in Vosniadou (2008), because any discussion of conceptual change needs to include the nature of conceptions, many of the chapter authors begin by defining the terms used in the discussion. The notion of what is a conception that could change is an area of current interest as evidenced by the debate between researchers in science education and social science about the nature and interpretation of findings seen as conceptual change (Tobin 2008).

Our position is that conceptions can be regarded as the learner's internal representations constructed from the external representations of entities constructed by other people such as teachers, textbook authors or software designers (Glynn and Duit 1995). From a conceptual change learning perspective, learners need to be able to use different representations of entities to make sense of difficult concepts. For

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example, learning always involves some ways of representing the information learned and science teachers use different representational techniques such as speech, written text and gestures in the classroom to communicate ideas to students. Representations are ways to communicate ideas or concepts by presenting them either externally – taking the form of spoken language (verbal), written symbols (textual), pictures, physical objects or a combination of these forms – or internally when thinking about these ideas. These internal representations are often referred to as mental models and are the essential elements in some researchers' arguments about conceptual change (Treagust and Duit 2008a, b) but not necessarily of other researchers (Roth et al. 2008).

A recurring theme of research findings over the past three decades, as evidenced in many of the chapters in Sandra Abell and Norm Lederman (2007) and Stella Vosniadou (2008), is that students come to science classes with pre-instructional conceptions and ideas about the phenomena and concepts to be learned that are not in harmony with science views. Furthermore, these conceptions and ideas are firmly held and are often resistant to change. Whilst studies of students' learning in science that primarily involve conceptions of the content level continue, investigations of students' conceptions at meta-levels (namely, conceptions of the nature of science and views of learning, as well as characteristics of the learners) also have been given considerable attention in the past two decades (Duit 2009).

Research on the role of students' pre-instructional conceptions in learning science that developed in the 1970s draws primarily on the theoretical perspectives of Ausubel and Piaget. The 1980s saw the growth of studies into the development of students' pre-instructional conceptions towards the intended science concepts in conceptual change approaches. Over the past three decades, research on students' conceptions and conceptual change has been embedded in various theoretical frames with epistemological, ontological and affective orientations (Duit and Treagust 2003; Taber 2006; Vosniadou et al. 2008). A landmark paper by Paul Pintrich et al. (1993) argued that, up to that time, researchers of conceptual change had initially taken on an overly rational approach. Further, certain limitations of the constructivist ideas of the 1980s and early 1990s led to their merger with social constructivist and social cultural orientations that resulted in recommendations to employ multiple perspectives in order to adequately address the complex process of learning (Duit and Treagust 2003; Treagust and Duit 2008a; Tyson et al. 1997).

Amongst the theoretical positions described in Vosniadou (2008), aspects of epistemological and ontological challenges occur in many chapters. During the past decades, several researchers have developed theoretical positions that encompass some but not all of these challenges. Examples include framework theories/synthetic models (Vosniadou et al. 2008), hierarchical ontological categories (Chi 2008), intentional conceptual change (Sinatra and Pintrich 2003) and a multidimensional perspective (Duit and Treagust 2003). Within each of these frameworks, there are three essential aspects of conceptual change learning related to epistemology, ontology and affective/social/learner characteristics. We discuss each of these in turn.

An Epistemological Perspective of Conceptual Change

The classical conceptual change approach (Posner et al. 1982) involved the teacher making students' alternative conceptions explicit prior to designing a teaching approach consisting of ideas that do not fit students' existing conceptions and thereby promoting dissatisfaction. A new framework was then introduced based on formal science that might better explain the anomaly. However, it became obvious that students' conceptual progress towards understanding and learning science concepts and principles after instruction frequently turned out to be still limited because the students were not necessarily dissatisfied with their own conceptions and so the better explanations were not considered. Much research continues in this vein. However, students' conceptions tend not to be completely extinguished and replaced by the science view (Duit and Treagust 1998), but undergo a 'peripheral conceptual change' (Chinn and Brewer 1993) in that parts of the initial idea merge with parts of the new idea to form some sort of synthetic model (Vosniadou and Brewer 1992).

Kenneth Strike and George Posner (1985, pp. 216–217) expanded the conceptual ecology metaphor to include anomalies, analogies and metaphors, exemplars and images, past experiences, epistemological commitments, metaphysical beliefs and knowledge in other fields. Subsequently, many researchers have examined students' conceptual change using explanatory models (Clement 2008) and analogies (Treagust et al. 1996), though the actual mechanism for any observed changes is not explicitly known. One reason for the lack of conceptual change with analogy teaching is that, whilst the teacher's analogy is based on propositionally based knowledge, the student's is built on mental images (Wilbers and Duit 2006).

An Ontological Perspective of Conceptual Change

Researchers who use epistemology to explain conceptual changes do not overtly emphasise changes in the way in which students view reality. Other researchers do use specific ontological terms to explain changes in the way students develop their science conceptions (Chi 2008). Two candidates for these types of change are heat, which needs to change from a flowing fluid to energy in transit, and a gene, which needs to change from an inherited object to a biochemical process. There are many other concepts for which scientists' *process* views are incommensurable with students' *material* conceptions and the desired changes to students' ontologies are not often achieved in school science. For example Mei-Hung Chiu and her colleagues (2002) adopted Chi's ontological categories of scientific concepts in investigating how students perceive the concept of chemical equilibrium, arguing that 'although Posner's theory is widely accepted by science educators and easy to comprehend

and apply to learning activities, … it does not delineate what the nature of a scientific concept is, which causes difficulty in learning the concept' (p. 689).

Affective/Social Aspects and Learner Characteristics of Conceptual Change

The third focus of conceptual change is the affective domain, particularly involving emotions, motivation and social aspects, such as group work, and learner characteristics, such as students' self-efficacy and control beliefs; the classroom social context and the individual's goals, intentions, purposes, expectations and needs are as important as cognitive strategies in concept learning (Pintrich et al. 1993). Group factors also can advantage concept learning and Vygotsky's theories recognise the importance of social and motivational influences.

Studies reported in Gail Sinatra and Paul Pintrich (2003) emphasised the importance of the learner, suggesting that the learner should play an active and intentional role in the process of knowledge restructuring. Whilst acknowledging the important contributions to the study of conceptual change from the perspectives of science education and cognitive developmental psychology, Sinatra and Pintrich note that the psychological and educational literature of the 1980s and 1990s placed greater emphasis on the role of the learner in the learning process. However, whilst there is strong support for the ideas, initiated by Paul Pintrich et al., that there is more to conceptual change than cognition, especially in the use of theoretical models as explained by Gail Sinatra and Lucia Mason (2008), there are still few empirical studies of the relationship between these factors and conceptual change.

Indeed, teachers who ignore the social and affective aspects of personal and group learning might limit conceptual change in their classrooms; we come back to this point in the second part of this chapter. In a review linking the cognitive and the emotional in teaching and learning science, Michalinos Zembylas (2005) goes a step further by arguing that it is necessary to develop a unity between cognitive and emotional dimensions in which emotions not only are moderating variables of cognitive outcomes, but also a variable of equal status. Zembylas advocates research in which affective variables are deliberately developed and undergo conceptual changes; but not many empirical studies incorporating affective variables are available. As noted by Steve Alsop and Mike Watts (2003), the effect of affect on learning science is an 'often overlooked domain' (p. 1044).

Impact of Conceptual Change Research on School Practice

In principle, from the extant research on conceptual change, there is a large potential for improving practice in the science classroom. However, so far, the research evidence concerning the impact of teaching informed by conceptual change instructional practices in normal classes is limited and tends to be associated with various teacher factors. We address these factors in the following paragraphs.

Teachers' Views of Teaching and Learning Science

One of the major obstacles to success in implementing science standards in the United States is that teachers usually are not well informed about the recent state of research on teaching and learning science and hold views of teaching and learning that are predominantly transmissive and not constructivist (Anderson and Helms 2001). Indeed, research has shown that many teachers hold conceptions of science concepts and processes that are not in accordance with the science view and often are similar to students' pre-instructional conceptions. Research has also shown that many teachers hold limited views of the teaching and learning process (Duit et al. 2007) and of the nature of science (Lederman 2007). Hence, teachers' conceptions of various kinds also need to undergo conceptual changes. Basically, the same conceptual change frameworks for addressing students' conceptions have proven valuable for developing teachers' views of science concepts (Hewson et al. 1999a, b).

Many studies of teachers' views about teaching and learning carried out since the 1990s suggest that it is essential to encourage science teachers to become familiar with the recent state of educational research and to help them to develop their views about efficient teaching and learning. Analysis of videotapes on the practice of German and Swiss lower secondary physics instruction showed that most teachers are not well informed about key ideas of conceptual change research (Duit et al. 2007). Teachers' views of their students' learning usually are not consistent with recent theories of teaching and learning. Indeed, many teachers appear to lack an explicit view of learning. Several teachers hold implicit theories that contain some intuitive constructivist issues; for instance, they are aware of the importance of students' cognitive activity and the interpretational nature of students' observations and understanding. However, teachers were identified who characterised themselves as mediators of facts and information and who were not aware of students' interpretational frameworks and the role of students' pre-instructional conceptions. These teachers mostly think that what they consider to be good instruction is a guarantee for successful learning.

Are Conceptual Change Approaches More Efficient Than More Traditional Ones?

Usually researchers who use a conceptual change approach in their classroom-based studies report that their approach is more efficient than traditional ones. Efficiency exclusively or predominantly involves cognitive outcomes of instruction. The development of affective variables during instruction is often not viewed as an intended outcome (Murphy and Alexander 2008). In summarising the state of research on the efficiency of conceptual change approaches, there appears to be ample evidence in various studies that these approaches are more efficient than traditional approaches dominated by transmissive views of teaching and learning. This seems to be the case, particularly if more inclusive conceptual change approaches, based on multidimensional perspectives as outlined above, are employed.

Recent large-scale programmes for improving the quality of science instruction (as well as instruction in other domains) include instructional methods that are oriented towards attempts to implement constructivist principles of teaching and learning into practice (Beeth et al. 2003). Three other characteristics of high-quality development approaches referred to by Michael Beeth et al. (2003) are: the need to support schools and teachers in rethinking the representation of science in the curriculum; the necessity to enlarge the repertoire of tasks, experiments, and teaching and learning strategies and resources; and showing how to promote strategies and resources that attempt to increase students' engagement and interests. This set of characteristics requires teachers to be reflective practitioners (Schon 1983) with a non-transmissive view of teaching and learning. Students need to be seen as active, self-responsible, cooperative and self-reflective learners. Indeed, these features are at the heart of inclusive constructivist conceptual change approaches.

The Practice of Teaching Science in Normal Classes

In summarising findings of student narratives from interpretive studies of students' experiences of school science in Sweden, England and Australia, Lyons (2006, p. 595) noted that 'students in the three studies frequently described school science pedagogy as the transmission of content expert sources – teachers and texts – to relative passive recipients'. Students were overwhelmingly critical of this kind of teaching practice, leaving them with an impression of science as being a body of knowledge to be memorised. The normal practice of science instruction described in the above studies was not significantly informed by constructivist conceptual change perspectives. Of course, there was large variance within the educational culture of certain countries and also between the educational cultures of the countries. But still there is a large gap between instructional design based on recent research findings on conceptual change and what is normal practice in most of the classes observed.

Conceptual Change and Teacher Professional Development

Investigating teachers' views of teaching and learning science and the means to improve teachers' views and their instructional behaviour through teacher professional development has developed into a research domain that has been given much attention since the late 1990s (Borko 2004). Two major issues are addressed in teacher professional development projects. First, teachers become familiar with research knowledge on teaching and learning by being introduced to recent constructivist and conceptual change views, and then they become familiar with instructional design that is oriented towards these views. Second, attempts to link teachers' own content knowledge and their pedagogical knowledge play a major role. The most prominent theoretical perspective applied is Shulman's (1987) idea

of content-specific pedagogical knowledge or Pedagogical Content Knowledge (PCK, Abell, 2007).

It is important to note, however, that attempts to explicitly employ the more recent multidimensional and inclusive conceptual change perspectives, as outlined in the first part of the present chapter, currently appear to be missing. Clearly, Peter Hewson et al. (1999a, b) take into account teacher change processes of various kinds, but the conceptual change perspectives applied appear to be largely concerned with teachers' epistemologies.

Further Developments Needed to Enhance Conceptual Change Research in Science Education

We believe that researchers of conceptual change in science education can greatly contribute to this field of activity by investigating conceptual change from multidimensional perspectives; paying more attention to the context of learning; acknowledging the importance of dialogue in facilitating learning; emphasising the need for replication studies; and determining the necessary and sufficient evidence for identifying conceptual change. We discuss each of these points in this section.

Investigating Conceptual Change from Multidimensional Perspectives

Conceptual change approaches as developed in the 1980s and early 1990s contributed substantially to improving our understanding of science learning and teaching. Most of the early studies of learning science were oriented towards the epistemological views of learning and ignored other existing views such as Michelle Chi's ontological categories and Stella Vosniadou's framework theory. However, the latter perspective appears to have had little influence in encouraging science education researchers to follow these lines of research. Similarly, there is ample evidence in research on learning and instruction that cognitive and affective issues are closely linked. However, the number of studies of the interaction of cognitive and affective factors in the learning process is limited, except for studies of correlations between interest in science and cognitive results of learning. The interplay of changes of interest in science and conceptual change has been investigated only in a small number of studies.

Our view is that research on conceptual change approaches needs to take into account multiple perspectives and focus on ways in which the various theoretical perspectives are linked and can constructively interact in a complementary way. On the theoretical plane, individuals construct mental models which are consistent with theories that involve internal representations in thinking processes. Indeed, cognitive scientists view models as internal representations that reflect external reality

and that are built from prior knowledge, perceptions, schema and problem-solving strategies.

By the very nature of an individual acting in his or her social environment, a single perspective, no matter how well argued, cannot identify the nature of these interactions (Duit and Treagust 1998, 2003; Greeno et al. 1997). One perspective is likely to miss more than is identified. In the study by Venville and Treagust (1998), for instance, science learning was investigated from four different theoretical positions of conceptual change. Each theoretical position (e.g. an epistemological position or an ontological perspective) enabled identification of learning issues that another theoretical approach did not. In a similar vein, Tiberghien (2008) argues that a theory which does not take into account different components – social situation, kinaesthetic perceptions, type of knowledge, types of lexical and syntactical forms of language – is not relevant to her research programme. Briefly summarised, multi-perspectives of conceptual change that encompass epistemological, ontological and affective domains have to be employed in order to adequately address the complexity of teaching and learning processes.

In contrast to the approach of being committed to one theoretical perspective of conceptual change as a framework for their data analysis and interpretation, Venville and Treagust (1998) utilised different perspectives of conceptual change – epistemological, ontological and affective – in analysing different classroom teaching situations in which analogies were used to teach genetics. Venville and Treagust (1998) found that each of the perspectives of conceptual change had explanatory value and enabled different theoretical frameworks for interpreting the role that analogies play in each of the classroom situations.

Paying More Attention to the Importance of Context in Learning

In the debates about conceptual change in *Cultural Studies in Science Education*, one of the points made by the social scientists was the importance of describing the context in more detail than is usual. In the chapters in Vosniadou (2008), whilst some authors (e.g. Brown and Hammer 2008, p. 135) state that 'there is a wide consensus … that at least some of the misunderstandings [of physics concepts] vary with context', there is little discussion of context throughout this volume.

Context in learning involves both the internal context as perceived by the learner and the external context of the discourse presented. From a sociocultural perspective, there is a need to recognise the importance of the emotions/affective domain as well as learner characteristics. The affective aspect of learning is much overlooked and its inclusion is encouraged when using a broader socio-cultural framework. A multi-perspective position of conceptual change recognises the importance not only of the context in which teaching and learning happens, but also of the environment in which student interviews or interactions take place in interpreting findings about conceptual change.

Acknowledging the Importance of Dialogue in Facilitating Learning

A key issue from the cultural studies aspects of conceptual change is the importance of dialogue. Learning is always deeply shaped by the particular social and material characteristics of the learning environment (Wells 2008). Hence, the discourse in small-group inquiry, individual learning or whole-class instruction is essential for discerning the quality of the learning outcomes (Duit et al. 2008). Further, we have discussed previously (Duit et al. 1996) the importance of co-construction of knowledge in exchanges between interviewer and interviewee.

Emphasise the Need for Replication Studies

In their synthesis and meta-analysis of research on conceptual change reported in the 5-year period, 2001–2006, Murphy and Alexander (2008, p. 584) considered conceptual change as 'a latent variable … a theoretical variable that cannot be directly observed or measured but is presumed to exert influence on other observable variables such as learning or achievement'. Their detailed analysis, which included 20 of an original 47 studies meeting specified criteria, supported the conceptual change models of Posner et al. and Vosnaidou. However, Murphy and Alexander reported few replication studies and that most studies included in the analysis were single interventions without the benefit of repeat trials.

Determining the Necessary and Sufficient Evidence for Identifying Conceptual Change: Towards Mixed-Methods Studies

In approaches near to the classical conceptual change model, data collection includes written tests, interviews and, less frequently, thinking-aloud protocols; however, this is developmental research and not conceptual change research. Because studies need to show how concepts have changed over time, it is usually necessary to include a quasi-experimental research design that involves pre- and post-measures and preferably continuous kinds of data. These process studies have shown evidence of conceptual change. The importance of good dialogue and detailed and careful analysis is crucial to making claims about conceptual change. Whilst recognising the importance of dialogue in investigating a student's conceptual change as he or she interacts with a teacher or a fellow student, Mercer (2008) also emphasises the need for conceptual change researchers to consider more deeply how both social and cognitive aspects of dialogue contribute to conceptual change.

Concluding Comments

This chapter discussed three distinct but closely connected issues concerning conceptual change in science. First, we discussed theoretical perspectives of conceptual change and illustrated how researchers have conceptualised teaching and learning science from these different perspectives. Second, we reported implemented conceptual change teaching and learning approaches and examined the degree of success of these interventions. Third, we suggested how conceptual change research involving science domains can be improved.

The state of theory building on conceptual change has become more and more sophisticated and the teaching and learning strategies developed have become more and more complex over the past 30 years. Whilst these developments are necessary to address the complex phenomena of teaching and learning science more adequately, there has been an increase in the gap between what is necessary from researchers' perspectives and what might be set into practice by normal teachers. Therefore, a paradox arises in that, in order to adequately model teaching and learning processes, research alienates the teachers and hence widens the theory-practice gap. However, we should deal with this paradox by developing theoretical frameworks, more finely focused research methods, and more efficient conceptual change instructional strategies. Fortunately, the frameworks for studying student conceptual change – being predominantly researched so far – also might provide powerful frameworks for teacher change towards employing conceptual change ideas. We believe that more research based on inclusive conceptual change perspectives is most desirable.

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