Chapter 4
Conceptual Change: Still a Powerful Framework for Improving the Practice of Science Instruction

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4.1 Introductory Remarks

This is a position paper that draws on recent, more elaborated reviews of the state of conceptual change conceptions in science education research. The first review was written for a handbook on conceptual change (Duit et al. 2008). The second review appeared in a special issue of the journal *Cultural Studies of Science Education* (Treagust and Duit 2008a). This special issue includes two papers attempting to outline major features of the state of research concerning conceptual change (our paper) and social cultural studies (Roth et al. 2008). Both papers are commented by authors from the social cultural studies camp (our paper) and by conceptual change-oriented authors (the paper by Roth et al.). Our response to the comments further clarifies the conceptual change view we hold (Treagust and Duit 2008b). In the following, we will summarize our views that are more fully outlined in the mentioned documents.

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4.2 Theoretical Developments in the Area of Conceptual Change

4.2.1 Students' Conceptions: Towards Multiple Conceptual Changes

Students may 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. Initially, research in the 1970s focused on conceptions on the content level. Whilst such studies continue to be produced, investigations of students' conceptions at meta-levels, namely, conceptions of the nature of science and science processes (McComas 1998; Lederman 2007) as well as meta-cognitive views of learning (Baird and Mitchell 1986), have been given attention only in the late 1980s and 1990s. It turned out that usually multiple conceptual changes of all three aspects are necessary.

As the term 'conceptual *change*' invites several misunderstandings, it is necessary to point out that in 'mainstream' conceptual change research, this term has not been interpreted as 'exchange' of ideas. Research has clearly shown that a simple exchange of students' pre-instructional ('alternative') conceptions is not possible: 'Conceptual change is considered not as a replacement of an incorrect naïve theory with a correct theory but rather, as an opening up of conceptual space through increased meta-conceptual awareness and epistemological sophistication, creating the possibility of entertaining different perspectives and different point of views' (Vosniadou 2008).

4.2.2 Teachers' Conceptions: A Major Obstacle for Efficient Teaching

Research starting in the 1980s has shown that many teachers hold conceptions of science concepts that are not in accordance with the science view and often are similar to students' pre-instructional conceptions. It became also evident that many teachers hold limited views of the teaching and learning process as well of the nature of science and science processes (Duit 2009; Duit et al. 2008). 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 to develop teachers' conceptions (Hewson et al. 1999). To further develop and hence change teachers' conceptions of various kinds is generally seen as a major issue in attempting to improve instructional practice (Anderson and Helms 2001; Borko 2004; Abell 2007).

4.2.3 The 'Classical' Conceptual Change Approach

Research on the role of students' pre-instructional ('alternative') conceptions in learning science developed in the 1970s primarily draws on two theoretical perspectives (Driver and Easley 1978): Ausubel's (1968) dictum that the most important single factor influencing learning is what the learner already knows and on Piaget's idea of the interplay of assimilation and accommodation. The 'classical' conceptual change approach introduced by Posner et al. (1982), which may be briefly characterized by the quadriga of 'dissatisfaction, intelligibility, plausibility and fruitfulness', draws on Toulmin's metaphor of conceptual ecology, T. S. Kuhn's view of revolutionary and evolutionary changes of concepts in the history of science and also on Piaget's terms, assimilation and accommodation. The 'classical' approach clearly has been the most influential perspective in the domain of conceptual change. However, it has been further developed in various ways as will be outlined below.

4.2.4 Affective Variables

The 'classical' conceptual change approach – at least implicitly – includes affective variables as influential factors (moderating variables) in facilitating conceptual change. Pintrich et al. (1993), therefore, overstated matters when accusing the classical approach being primarily or even totally cognitively oriented. They explicitly argued that affective variables are essential in fostering conceptual change. Drawing on their seminal paper, the role of affective variables was more fully investigated in the 1990s (e.g. Tyson et al. 1997). Usually, however, affective variables were primarily seen as variables needed to support conceptual change. But it appears that neglected affective variables such as interest or self-concept have to be deliberately developed during instruction, so these variables also have to undergo conceptual change. In other words, affective variables like interest need to be developed through notions of intelligibility, plausibility and fruitfulness in order to be realized. More recently, Zembylas (2005), who argues for the necessity of linking cognitive and emotional variables of science learning, sees both variables of equal status in the learning process. However, the kinds of linking that are needed are still not clear. Further work, both theoretically and empirically, is needed.

4.2.5 Constructivist Views and Conceptual Change

Conceptual change perspectives are closely linked to constructivist epistemological views. More recently, we witnessed a development of constructivist views from initially (in the 1980s) radical constructivist views focusing on the construction of the individuals towards multi-perspective constructivist views (Taber 2006). These views include features of radical constructivism and social constructivist (as well as social cultural) origins (Phillips 2000). More recent conceptual change views often are embedded in such multi-perspective constructivist views – or at least should be based on these views. However, more work is also needed here, for example, in which way the epistemologically different perspectives may be linked needs further theoretical considerations. So far, there is still a certain danger that a mere patchwork of epistemological perspectives is applied. It also has to be further investigated what it means that perspectives are complementary. The previously mentioned special issue of the journal *Cultural Studies in Science Education* may be seen as an attempt to address such questions (Tobin 2008).

4.2.6 Towards More Inclusive Conceptual Change Views

The development of conceptual change views from the early 1980s to the present state may be characterized as a progression towards more inclusive views. On the one hand, these more recent views allow addressing the dynamics of teaching and learning processes more comprehensively than the initial views (like the 'classical' view). However, the theoretical frameworks have become more and more complicated and may cause serious problems for teachers using them in regular classrooms as will be argued below.

4.3 Efficiency of Conceptual Change-Oriented Instructional Design

Usually, researchers who use a conceptual change approach in their classroom-based studies report that their approach is more efficient than traditional ones. Efficiency concerns predominantly cognitive outcomes of instruction. The development of affective variables during instruction is often not viewed as the outcome per se. Only more recent multi-dimensional conceptual change perspectives as outlined above consider both cognitive and affective outcomes (Tyson et al. 1997; Zembylas 2005). With regard to cognitive outcomes, there appears to be ample evidence in various studies now that these approaches are more efficient than traditional approaches dominated by transmissive views of teaching and learning. This seems to be the case in particular if more inclusive conceptual change approaches based on multi-dimensional perspectives are employed (Duit et al. 2008). Recent large-scale programmes to improve the quality of science instruction include instructional methods that are clearly oriented towards constructivist conceptual change approaches (Beeth et al. 2003; Ostermeier et al. 2010). A large spectrum of conceptual change-oriented instructional methods has been developed the past decades (Widodo 2004). Particular attention was given to cognitive conflict. Cognitive conflict plays a major role in Piagetian approaches such as the 'learning cycle' (Lawson et al. 1989) but also in 'constructivist teaching sequences' (Driver 1989). Research has shown, however, that much care is needed if cognitive conflict strategies are used for facilitating conceptual change. It is not only necessary to carefully ensure that students experience the conflict but also consider the role of specific, usually small scale, sudden insights within the long-lasting gradual process of conceptual change (Vosniadou and Ioannides 1998).

4.4 Embedding Conceptual Change into Models of Instructional Planning

Beeth et al. (2003) argue that the following three characteristics of quality development approaches are essential for improving instruction: (1) supporting teachers to rethink the representation of science in the curriculum; (2) enlarging the repertoire of tasks, experiments and teaching and learning strategies and resources; and (3) promoting strategies and resources that attempt to increase students' engagement and interests. They claim that not only conceptual change-based instructional methods need to be introduced in order to improve teaching and learning of science but that also the traditional science content structure needs to be changed. The term *content structure* includes the particular content elements and the relations of these elements. The content structure *for* instruction needs to be designed taking into account the actual knowledge of what we know about students' pre-instructional conceptions and learning processes from conceptual change studies. Interestingly, this issue seems to be neglected or given only little attention in many studies on conceptual change. However, it seems to be essential to embed studies of conceptual change in models of instructional planning that deliberately take into account the aims of instruction and the student cognitive and affective perspectives when planning content structure for instruction. It seems that the *Model of Educational Reconstruction* (Duit et al. 2005b; Duit et al. 2012) provides such a theoretical frame. Within the framework of the model, the following three tasks are intimately linked: (1) clarification and analysis of science subject matter (e.g. in the field of evolution, energy or combustion), (2) taking into account student perspectives (cognitive and affective) with regard to the phenomena and (3) design of learning environments that deliberately support student learning processes.

4.5 Conceptual Change and Instructional Practice

It seems that conceptual change ideas so far do not inform practice to a considerable extent. Anderson and Helms (2001) argue that teachers usually are not well informed about the recent state of research on teaching and learning and hold views that are predominantly transmissive. This is true not only for the domain of science education but also for the individual professional development of teachers in other domains such as mathematics (Borko 2004). Some studies providing information on teachers' views about teaching and learning also include findings on teachers' ways of teaching (Anderson and Helms 2001; Jones and Carter 2007). Lyons (2006, p. 595) summarizes interpretive studies on students' experiences in Sweden, England and Australia in stating: 'Students in the three studies frequently described school pedagogy as the transmission of content expert sources – teachers and texts – to relative passive recipients'. Video studies on the practice of substantially large samples of teachers in science and mathematics revealed basically the same findings. The seminal TIMSS Video Study on Mathematics Teaching (Stigler et al. 1999) compared the practice of mathematics instruction in the United States, Japan and Germany. Instruction was observed to be primarily teacher-oriented, and instructional scripts based on transmissive views of teaching and learning predominated. The TIMSS Video Study on Science Teaching (Roth et al. 2006) investigated instructional scripts in Australia, the Czech Republic, Japan, the Netherlands and the United States. Again, the predominating impression was instructional scripts informed by traditional transmissive views of teaching and learning. However, instructional features oriented towards constructivist conceptual change perspectives, though not frequent, did occur in both studies to different degrees in the participating countries.

A video study on the practice of German and Swiss lower secondary physics instruction also revealed basically similar predominating instructional scripts (Duit et al. 2005a; Seidel et al. 2005). As part of a pilot study, Widodo (2004) investigated teachers' instructional behaviour explicitly from constructivist perspectives and also analysed to what degree the practice could be seen as informed by conceptual change views of teaching and learning. Analysis of the data gained in these studies showed that most teachers are not well informed about key ideas of conceptual change research. Further, their views about their students' learning usually are not consistent with the state of recent theories of teaching and learning. Many teachers appear to lack an explicit view of student learning. Considerations about the content to be taught predominate teacher planning. Reflections about students' perspectives and their role in the learning process play a comparably minor role (Duit et al. 2007).

4.6 Conceptual Change and Teacher Professional Development

As briefly mentioned previously, investigating teachers' views of teaching and learning science and the means to improve teachers' views and their instructional behaviour through teacher professional development have developed into a research domain that has been given much attention since the late 1990s (Borko 2004; Harrison et al. 2008; Abell 2007). Two major issues are addressed in these teacher professional development projects. First, teachers are made familiar with research knowledge on teaching and learning by being introduced to recent constructivist and conceptual change views and are introduced to instructional designs that are oriented towards these views. Second, how teachers link their own content knowledge and their pedagogical knowledge is an essential aspect of this process; only when teachers can effectively relate these two knowledge bases will constructivist and conceptual change views be implemented in an effective manner (van Driel et al. 1998; West and Staub 2003).

Consequently, the process of teacher professional development can be viewed as a set of substantial conceptual changes that teachers have to undergo. Learning to teach for conceptual change means 'that teachers must undergo a process of pedagogical changes themselves' (Stofflett 1994, p. 787). The conceptual change perspectives developed to analyse and improve student learning have also proven to be the basis of a valuable framework for teacher learning (Hewson et al. 1999).

4.7 Challenges for Future Research and Development

Research on conceptual change in science offers several challenges for the furthering of this field of scientific and educational endeavour. These challenges are (a) conceptual – with the need to consider the usefulness of the term conceptual change, (b) theoretical – with the need to examine conceptual change from multiple perspectives, (c) methodological – with the need to determine the necessary and sufficient evidence for identifying conceptual change and (d) universally practicality – with the need to bring successful conceptual change teaching approaches to normal classrooms.

Challenge 1. *Is conceptual change still an adequate term to indicate its actual meaning?*

The above overview of the development of theoretical conceptual change perspectives shows that conceptual change has grown to one of the leading paradigms in research on teaching and learning. It is interesting to see a continuous progress since early conceptual change research occurred and to realize that the definition of what changes in conceptual change has revised substantially over the past three decades (Duit et al. 2008). Initially, the term change was frequently used in a somewhat naïve way – if seen from the inclusive perspectives that have since developed. The term conceptual change was even frequently misunderstood as exchange of the students' pre-instructional (or alternative) views for the science view. The meaning of change in the 'classical' conceptual change view (Posner et al. 1982), however, is somewhat far from the actual predominating view outlined, for instance, by Vosniadou and Ioannides (1998). They claimed that learning science should be viewed as a 'gradual process during which initial conceptual structures based on children's interpretation of everyday experience are continuously enriched and restructured' (p. 1213).

Taking into account that misunderstandings of the term conceptual change may be invited by various meanings of change in everyday language and considering the substantial changes of the initial meaning of conceptual change, it may be timely to replace that term. We agree with Kattmann (2007) that his term 'conceptual reconstruction' more appropriately indicates the actual meaning predominating as outlined above, and we recommend the use of this latter term be considered in future to indicate conceptual learning (Treagust and Duit 2008b).

Challenge 2. *Research on conceptual change needs to take into account multiple perspectives, including knowledge of the essential defining elements of the theoretical frame and affective variables.*

As outlined above, 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 (see also Limon and Mason 2002 as well as Sinatra and Pintrich 2003). Whilst these developments are necessary in order to address the complex phenomena of teaching and learning science more and more adequately, several demands are affiliated with these achievements:

(a) On the theoretical plane: As briefly outlined above, it is necessary to further investigate in which way the various theoretical perspectives brought together are linked and may constructively interact in a complementary way.
(b) Particular attention has to be given to the more recent notion that instruction should give cognitive and affective outcomes equal attention, that is, both have to be developed.
(c) On the empirical plane: Research methods applied need to address the various perspectives (see below).
(d) On the plane of improving instructional practice: Multiple perspectives are particularly demanding for the teachers who have to transfer the findings into practice (see below).

In a nutshell, research on conceptual change has developed to a rich and significant domain of educational research since the 1970s. The theoretical frameworks and research methods developed allow fine-grained analyses of teaching and learning processes. The findings of research provide powerful guidance for the development of instructional design for science education that societies need. However, various demands still need to be addressed.

Challenge 3. *Conceptual change approaches of teaching and learning science need to be embedded in more inclusive models of instructional planning.*

The focus of many studies in the field of conceptual change is primarily on improving the way science is taught. Conceptual change denotes, in most studies, developing student pre-instructional ideas towards the science point of view by conceptual change-oriented instructional methods. However, it is necessary to give equal attention to traditional science content structures for instruction from the perspectives of the aims of instruction and the learners (Fensham 2001). In other words, it is essential to embed conceptual change approaches into models of instructional planning that take into account the intimate interaction of all components of instruction, namely, the aims of instruction, the structure of the science content taught in instruction, the instructional methods employed and students' prior knowledge as well as their interests and self-concepts. In many conceptual change studies, such an inclusive theoretical frame is not explicitly taken into account. Hence, it is necessary to further develop existing models like the *Model of Educational Reconstruction* (Duit et al. 2012).

***Challenge 4**. Determine the necessary and sufficient evidence for identifying conceptual change.*

Typically, researchers of students' conceptual change collect data from written tests, interviews and, less frequently, think-aloud protocols. However, reports of conceptual change often simply refer to changes in concepts, such as on a test, without any identification of the learning processes that have taken place. In addition, it is often the case that more than one source of evidence – for example, classroom observations of a students' discussion with the teacher in addition to interviews – is needed to judge conceptual change. Even when a theoretical framework is clearly enunciated, there are often different interpretations of the data, and oftentimes these decisions are not unambiguous.

Research as outlined in the first lines of the above paragraph is often quite near the 'classical' conceptual change perspective. As has been argued, multi-perspective views are needed in order to address the complexity of teaching and learning processes more adequately. Therefore, a wider spectrum of research methods is necessary, for example, including variants of learning process studies with a certain focus on discourse analyses. In other words, mixed method studies including quantitative and qualitative data have to be further developed and applied.

***Challenge 5**. Bring successful conceptual change teaching approaches to normal classrooms.*

Successful teaching that has outcomes of students' conceptual change is perhaps the major challenge for researchers working in the field of conceptual change. As outlined above, a major contributing factor to the lack of successful implementation of conceptual change approaches to teaching in normal classrooms is that teachers usually are not well informed about actual views of efficient teaching and learning available from the research community. Most teachers hold views that are limited if seen from the recent inclusive conceptual change perspectives. Further, instructional practice is also usually far from a practice that is informed by conceptual change perspectives. Taking into account science teachers' deeply rooted views of what they perceive as good instruction, it becomes apparent that various closely linked conceptual changes on the teachers' beliefs about teaching and learning are necessary to commence and set recent conceptual change views into practice. Consequently, it appears that the gap between what is necessary from the researchers' perspective and what may be set into practice by normal teachers has increased. In order to bridge the gap between the researchers' and teachers' perceptions of conceptual change, it is necessary to describe how opportunities for conceptual change can be built on existing teachers' instructional strategies.

Interestingly, the frameworks of student conceptual change – being predominantly researched so far – may also provide powerful frameworks for teacher change towards employing conceptual change ideas. There are attempts to use this potential as discussed above. However, more research in this field based on the recent inclusive conceptual change perspectives is most desirable.

An additional demand seems to be that closer cooperation of various groups working to improve instructional practice is needed. On the one hand, it seems that more recent conceptual change perspectives seriously consider the necessity of improving student scientific literacy and research findings available provide valuable instructional methods to improve scientific literacy (Duit et al. 2008, pp. 636–637). On the other hand, the major 'quality development' programmes draw on instructional methods proposed by conceptual change research (Beeth et al. 2003; Ostermeier et al. 2010). It is also most pleasing that such 'conceptual change-oriented' methods have proven to be more efficient than more traditional methods (e.g. Schroeder et al. 2007). However, closer cooperation between teachers and researchers may allow better use of the still limited research and development sources for improving practice.

Finally, we would like to point out that research on instructional quality has shown that usually a single instructional method (like addressing students' pre-instructional conceptions) does not lead to better outcomes per se. Quality of instruction is always due to a certain orchestration (Oser and Baeriswyl 2001) of various instructional methods and strategies. Hence, conceptual change strategies may only be efficient if they are embedded in a conceptual change supporting learning environment that includes many additional features such as specially organized instruction based on models of teaching.

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