24

Teaching Science for Conceptual Change: Theory and Practice

Reinders Duit
IPN – Leibniz Institute for Science Education at the University of Kiel

David F. Treagust
Science and Mathematics Education Centre, Curtin University

Ari Widodo
Indonesian University of Education

INTRODUCTION

This chapter contains two parts. In the first part, we discuss a range of theoretical perspectives giving rise to different notions of conceptual change and illustrate how researchers have conceptualized teaching and learning science from these different perspectives. In the second part, we report on studies about the awareness and implementation of these perspectives in regular science classes and document that there is still a large gap between what is known about effective teaching and learning science from conceptual change perspectives and the reality of instructional practice. Finally, we argue that more research is necessary on how teachers in regular classrooms can become more familiar with the key ideas of conceptual change.

THEORETICAL DEVELOPMENTS IN THE AREA OF CONCEPTUAL CHANGE

Over the past three decades, research has shown 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 resistant to change (Duit, 2006; Duit & Treagust, 1998, 2003). While studies on students' learning in science that primarily investigate conceptions on the content level continue to be produced, investigations of students' conceptions at meta-levels, namely conceptions of the nature of science and views of learning, also have been given considerable attention since the 1980s.

The 1980s saw the growth of studies investigating the development of students' pre-instructional conceptions towards the intended science concepts in conceptual change approaches.

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

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 & Treagust, 2003; Taber, 2006; Zembylas, 2005).

Research on the role of students' pre-instructional ("alternative") conceptions in learning science developed in the 1970s drawing primarily on two theoretical perspectives (Driver & Easley, 1978). The first was Ausubel's (1968) dictum that the most important single factor influencing learning is what the learner already knows and hence to teach the learner accordingly. The second theoretical perspective was Piaget's idea of the interplay of assimilation and accommodation. His clinical interview method deeply influenced research on investigating students' conceptions (White & Gunstone, 1992). By the end of the 1970s and the beginning of the 1980s, preliminary conceptual change ideas addressing students' conceptions were revealed in the various studies that developed.

Conceptual change viewed as epistemology, namely when the research looks at students' learning of concepts, initially involved only an understanding of how students' conceptions evolved. Later, constructivist ideas developed by merging various cognitive approaches with a focus on viewing knowledge as being constructed. These approaches were influenced by the already mentioned Piagetian interplay of assimilation and accommodation, Kuhnian ideas of theory change in the history of science and radical constructivism (Duit & Treagust, 1998).

As is discussed more later in this chapter, conceptual change viewed as ontology, namely how students view the nature of the conception being investigated, sought to examine the way that students viewed scientific conceptions in terms of reality. Conceptual change from an epistemological and an ontological perspective refers to students' personal views, on the nature of coming to know — what we refer to as epistemological in this chapter — and on the nature or reality — what we refer to as ontological.

Other researchers were concerned that conceptual change had initially taken on an over rational approach (Pintrich, Marx, & Boyle, 1993). Certain limitations of the constructivist ideas of the 1980s and early 1990s led to their merger with social constructivist and social cultural orientations that more recently resulted in recommendations to employ multi-perspective epistemological frameworks in order to adequately address the complex process of learning (Duit & Treagust, 2003; Tyson, Venville, Harrison, & Treagust, 1997; Zembylas, 2005).

An Epistemological Perspective of Conceptual Change

The "classical" conceptual change approach as introduced by Posner, Strike, Hewson, and Gertzog (1982) involved the teacher making students' alternative frameworks explicit prior to designing a teaching approach consisting of ideas that do not fit students' existing conceptions and thereby promoting dissatisfaction. A new framework is then introduced based on formal science that may 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. There appears to be no study which found that a particular student's conception could be completely extinguished and then replaced by the science view (Duit & Treagust, 1998). Indeed, most studies show that the old ideas stay alive in particular contexts. Usually, the best that can be achieved is a "peripheral conceptual change" (Chinn & Brewer, 1993) in that parts of the initial idea merge with parts of the new idea to form some sort of hybrid concept (Jung, 1993) or synthetic model (Vosniadou & Brewer, 1992).

In the classical conceptual change model that emphasised students' epistemologies (Posner et al., 1982), student dissatisfaction with a prior conception was believed to initiate dramatic or revolutionary conceptual change and was embedded in radical constructivist epistemological views with an emphasis on the individual's conceptions and his/her conceptual development. If

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

the learner was dissatisfied with his/her prior conception *and* an available replacement conception was intelligible, plausible and/or fruitful, accommodation of the new conception may follow. An intelligible conception is sensible if it is non-contradictory and its meaning is understood by the student; plausible means that in addition to the student knowing what the conception means, he/she finds the conception believable; and, the conception is fruitful if it helps the learner solve other problems or suggests new research directions. Posner et al. insist that a plausible conception must first be intelligible and a fruitful conception must be intelligible and plausible. Resultant conceptual changes may be permanent, temporary or too tenuous to detect.

In this learning model, resolution of conceptual competition is explained in terms of the comparative intelligibility, plausibility and fruitfulness of rival conceptions. Posner et al. (1982) claimed that a collection of epistemological commitments called the student's conceptual ecology (Toulmin, 1972) mediated conceptual intelligibility, plausibility, and fruitfulness. Strike and 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.

Different ways that researchers have measured students' conceptual change from an epistemological position are conceptual status and epistemological profiles.

Students' Conceptual Status

Conceptual status classifies a conception's status as intelligible, plausible or fruitful (Hewson, 1982; Hewson & Lemberger, 2000; Hewson & Thorley, 1989) and is particularly useful for assessing changes in students' conceptions during learning. When a competing conception does not generate dissatisfaction, the new conception may be assimilated alongside the old. When dissatisfaction between competing conceptions reveals their incompatibility, two conceptual events may happen. If the new conception achieves higher status than the prior conception, accommodation, which Hewson (1982) terms *conceptual exchange*, may occur. If the old conception retains higher status, conceptual exchange will not proceed for the time being. It should be remembered that a replaced conception is not forgotten and the learner may wholly or partly reinstate it at a later date. Both Posner et al. (1982) and Hewson (1982) stress that it is the student, not the teacher, who makes the decisions about conceptual status and conceptual changes. This position is in harmony with constructivist learning theory and the highly personal nature of mental models (Norman, 1983).

Studies utilising the notion of conceptual status include that by Treagust, Harrison, Venville and Dagher (1996) which set out to assess the efficacy of using analogies to engender conceptual change in students' science learning about the refraction of light. Following instruction by the same teacher, two classes of students, one of which was taught analogically and one that was not, were interviewed three months after instruction using an interview-about-instances protocol. Factors related to status were identified from the interview transcripts to help in the process of classifying each student's conception of refraction as being intelligible, plausible or fruitful. Hewson and Hennessey (1992, p. 177) developed descriptors to guide this process, and these were used in the research. For example, descriptors for intelligible included "I must know what the concept means — the words must be understandable, the words must make sense"; descriptors for plausible included "'it first must be intelligible — it must fit in with other ideas or concepts I know about or believe"; descriptors for fruitful included "it first must be intelligible it should be plausible and I can see it is something as useful — it will help me solve problems."

Most of the evidence from this study indicated that conceptual change which meets the criteria of dissatisfaction, intelligibility, plausibility and fruitfulness is not necessarily an exchange of conceptions for another, but rather an increased use of the kind of conception that

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

makes better sense to the student. The two groups of students performed similarly on the teacher's classroom test. However, when students were interviewed and their conceptions were analysed graphically with elements of status — no status, intelligibility, plausibility and fruitfulness — on the ordinate and test scores on the abscissa, those student in the class introduced to the analogy held conceptions of higher status than those students in the class who were not introduced to the analogy. Consequently, the application of the idea of status of a conception showed the degree to which students understood, believed and were able to apply their scientific knowledge to otherwise unsolved problems. Nevertheless, the research showed that an increased status of a conception made possible by analogical teaching does not necessarily lead to different learning outcomes as measured on traditional tests.

Epistemological and Conceptual Profiles

A different but useful way to understand student reactions to multiple conceptions or models is Bachelard's (1968) epistemological profile. People often possess more than one way for describing objects and processes, and this is especially so in science. For example, mass can be described in everyday terms of "bigness," measured instrumentally using a spring balance, expressed in dynamic terms like $F = ma$ or relativistically. Scientists use different methods depending on context so why should not students use the same differences as they learn? What may appear to be a change in conception by a scientist or a student could simply be a contextually-based preference for one conception or model over another. For instance, many secondary teachers and textbooks simultaneously use the electron shell or Bohr model when discussing atomic structure, use balls or space-filling models to explain kinetic theory and Lewis electron-dot diagrams for bonding.

The ability to select intelligible, plausible and fruitful representations or conceptions for a specific context is itself a measure of expertise; however, researchers need to be aware that apparent conceptual changes may in fact be context-driven choices rather than conceptual status changes. In learning settings, Mortimer (1995) proposed the use of conceptual profiles to help differentiate conceptual changes from contextual choices.

An Ontological Perspective of Conceptual Change

Researchers who use epistemology to explain conceptual changes do not overtly emphasize changes in the way students view reality. Other researchers, however, use specific ontological terms to explain changes in the way students develop their science conceptions (Chi, Slotta, & de Leeuw, 1994; Thagard, 1992; Vosniadou, 1994). Chinn and Brewer (1993, p. 17) described ontological beliefs as being about "the fundamental categories and properties of the world." In showing that "some of the child's concepts are incommensurable with the adults'," Carey (1985, p. 269) argued for strong knowledge restructuring during childhood, and Vosniadou called similar changes radical restructuring and explained that revisions to central "framework theories" (pp. 46–49) involve both ontological and epistemological changes. Chi et al. (1994) called their strongest ontological changes "Tree swapping" and Thagard (1992) also has a strongest change which he calls "tree switching." Two candidates for these types of change are heat which needs to change from a flowing fluid to kinetic energy in transit and a gene which needs to change from an inherited object to a biochemical process. There are many other concepts where scientists' *process* views are incommensurable with students' *material* conceptions, and the desired changes to students' ontologies are not often achieved in school science. Chiu, Chou, and Liu (2002) adopted Chi's ontological categories of scientific concepts to investigate how students perceived the concept of chemical

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. In S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

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).

An Affective Position of Conceptual Change

The third focus of conceptual change is the affective domain, particularly involving emotions, motivation and social aspects such as group work which has had limited attention in the epistemological position and no attention in the ontological position. Pintrich et al. (1993) proposed that a hot irrational explanation for conceptual change is as tenable as cold cognition and argued that 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. Similarly, Solomon (1987) and Dykstra, Boyle, and Monarch (1992) claim that group factors can advantage concept learning, and Vygotsky's theories (van der Veer & Valsiner, 1991) highlight the importance of social and motivational influences. Pintrich et al.'s review of the social and motivational literature highlights the importance of interest, personal and situational beliefs to students' engagement in learning activities. Indeed, they claim that teachers who ignore the social and affective aspects of personal and group learning may limit conceptual change. In a recent review of linking the cognitive and the emotional in teaching and learning science, Zembylas (2005) goes a step further arguing that it is necessary to develop a unity between the cognitive and emotional dimensions that views emotions not only as a moderating variable of cognitive outcomes but as a variable of equal status.

Intentional Conceptual Change

Recent studies in an edited volume, *Intentional Conceptual Change*, by Sinatra and Pintrich (2003) emphasized the importance of the learner, suggesting that the learner should play an active intentional role in the process of knowledge restructuring. While 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. It is this emphasis on the impetus for change being within the learner's control that forms the basis of the chapters in the text. The notion of intentional conceptual change is in some ways analogous to that of mindfulness (Salomon & Globerson, 1987, p. 623), a "construct which reflects a voluntary state of mind, and connects among motivation, cognition and learning."

Multidimensional Perspectives of Conceptual Change

Conceptual change approaches as developed in the 1980s and early 1990s contributed substantially to improving our understanding of science learning and teaching. Most studies on learning science so far have been oriented towards views of learning that are monistic to a certain extent. Only recently have there been powerful developments towards admitting that the complex phenomenon of learning needs pluralistic epistemological frameworks (Greeno, Collins, & Resnick, 1997) in order to adequately address the many facets emphasized by different views of learning. In science education, there are a growing number of multi-perspectives of conceptual change which appear to be promising to improve science teaching and learning (Duit, 1998; Duit & Treagust, 1998, 2003; Zembylas, 2005). Briefly summarized, multi-perspectives of conceptual change that consider epistemological, ontological and affective domains have to be employed in

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

order to adequately address the complexity of the teaching and learning processes. Only such frameworks can sufficiently model teaching and learning processes and address the ambitious levels of scientific literacy that are presented in the following paragraphs.

Much of the research on conceptual change has taken a particular perspective, namely an epistemological perspective, an ontological perspective or an affective perspective. There is ample of evidence in research on learning and instruction that cognitive and affective issues are closely linked. However, the number of studies on the interaction of cognitive and affective factors in the learning process is limited. There are, for instance, many studies on the relations between interest in science and acquisition of science concepts. However, these studies are usually restricted to 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. The multi-dimensional perspectives for interpreting conceptual change by Tyson, Venville, Harrison, and Treagust (1997) includes, for instance, an epistemological, an ontological and an affective domain, though the affective domain has not been fully elaborated. A fruitful outcome for future studies is to merge ideas of conceptual change and theories on the significance of affective factors. It also seems to be most valuable to view the issue of interest in science and science teaching from the perspective of conceptual change. Clearly, an important aim of science instruction is to develop interest in much the same way as to develop students' pre-instructional conceptions towards the intended science concepts.

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) utilized four different perspectives of conceptual change to analyse different classroom teaching situations in which analogies were used to teach genetics (also see Venville, Gribble, & Donovan, 2005). The authors used Posner et al.'s (1982) conceptual change model, Vosniadou's (1994) framework theory and mental model perspective, Chi et al.'s (1994) ontological categories, and Pintrich et al.'s (1993) motivation perspective. Venville and Treagust (1998) found that each of the perspectives of conceptual change had explanatory value and contributed a different theoretical perspective on interpreting the role that analogies played in each of the classroom situations. For example, the epistemological perspective in terms of students' conceptions of genes indicated the degree of acceptance of the conception by the students. In this study, there was likely concordance with the status of the conception and different ontological models that students used to think about genes. From a social affective perspective, almost all these grade 10 students demonstrated in interviews that they were not interested in the microscopic explanatory nature of genetics, preferring to use simple Mendelian genetics to answer questions about themselves.

THE ROLE OF COGNITIVE CONFLICT IN CONCEPTUAL CHANGE

Cognitive conflict has played a major role in various conceptual change approaches since the advent of classical conceptual change approaches in the early 1980s. As mentioned earlier, Piagetian ideas of the interplay of assimilation and accommodation have provided a powerful framework for conceptual change. Cognitive conflict plays a key role in Piagetian approaches such as the "learning cycle" (Karplus, 1977; Lawson, Abraham, & Renner, 1989) and hence also in conceptual change approaches like "constructivist teaching sequences" (Driver, 1989; Scott, Asoko, & Driver, 1992). In these constructivist approaches, however, not only Piagetian ideas but also Festingers' theory of cognitive dissonance is referred to (Driver & Erickson, 1983). Hashweh (1986) provided a critical view of the role of cognitive conflict in learning science, arguing that various forms of cognitive conflicts have to be distinguished and that it is essential that students actually experience the conflict.

] dou (Ed.).
International Handbook of Research on Conceptual Change. New York: Routledge.

Studies on the use of cognitive conflict reveal conflicting results. Guzetti, Snyder, Glass, and Gamas (1993) carried out a meta-analysis of conceptual change approaches. Those approaches employing cognitive conflict strategies were found to be more efficient than studies in which this was not the case. Some studies (e.g., Limon & Carretero, 1999; Mason, 2001) report that cognitive conflict may be linked with positive learning results such that these can facilitate conceptual change while other studies (e.g., Chan, Burtis, & Bereiter, 1997) showed that cognitive conflict may also be inefficient because even when students are confronted with contradictory information, they do not necessarily change their conceptions. In a review on the effectiveness of strategies for facilitating conceptual change within constructivist frameworks, Harlen (1999) suggested that there is no convincing evidence about the effectiveness of one strategy over the other. Vosniadou and Ioannides (1998) argued (see also Limon, 2001) that the conceptual change approaches as developed in the 1980s and early 1990s put too much emphasis on sudden insights facilitated by cognitive conflict. They claimed that learning science should be viewed as a "gradual process during which initial conceptual structures based on children's interpretations of everyday experience are continuously enriched and restructured" (p. 1213). Briefly summarized, research has shown 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 to consider the role of specific, usually small scale, sudden insights within the long-lasting gradual process of conceptual change.

Impact of Research on Conceptual Change in School Practice

As outlined in the previous part, conceptual change has became a powerful domain of research on teaching and learning that developed in the early 1970s. Since this time, cognitive psychologists and science educators have worked closely together with both domains of educational research substantially profiting from this cooperation. However, what also became evident in reviewing the literature is a certain polarisation of researchers in the two domains such that one can read exellent research in one domain that has little reference to research in the other domain. The text by Sinatra and Pintrich (2003), for instance, brings many of these researchers together in one volume. But this is not always the case, as for example in the very informative text by Limon and Mason (2003) based on a symposium as part of the activities of a Special Interest Group of the European Association for Research on Learning and Instruction (EARLI), where there are virtually no references to science education and science education researchers who have worked in this area. Our intention is that the present review can help to overcome this issue of polarization of the two research domains.

In the research domain of conceptual change as outlined, multidimensional theoretical perspectives allow researchers to investigate teaching and learning processes at a fine-grained level. The perspectives also provide support for the design of teaching and learning environments that usually are superior to more traditional instructional designs. In principle, there is a large potential for improving practice. However, so far the research evidence concerning the impact of teaching informed by conceptual change instructional practices in normal classes is still rather limited. We address this issue in the following paragraphs.

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. Predominantly, efficiency concerns exclusively or predominantly cognitive outcomes of instruction. The development of affective variables during instruction is often not viewed as the outcome per se. This appears to

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. In S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

be only the case in more recent multi-dimensional conceptual change perspectives that consider both cognitive and affective outcomes of learning as conceptual change as discussed by Tyson et al. (1997) and Zembylas (2005).

Quite frequently, individual research studies do provide convincing empirical evidence for this claim (e.g., more recently Bryce & MacMillan, 2005; Piquette & Heikkinen, 2005) though an actual summarizing meta-analysis is not available. Previously, Guzetti et al. (1993) provided a meta-analysis that included studies that only employed a treatment-control group design, and Wandersee, Mintzes, and Novak (1994) reviewed conceptual change approaches with a cautious remark that their analysis gave the impression that conceptual change approaches usually are more successful than traditional approaches in guiding students to the science concepts. However, a problem with research on conceptual change is that it is difficult to compare the success of conceptual change approaches and other approaches. Usually different approaches to teaching and learning address different aims, and hence it is only possible to evaluate whether the particular aims have been adequately met. An additional problem is that quite frequently the focus of conceptual change approaches is on particular pedagogical means like analogies (Bryce & MacMillan, 2005). Research on instructional quality, however, has shown that usually a single intervention (like addressing students' preinstructional conceptions) does not lead to better outcomes per se (Weinert, Schrader, & Helmke, 1989; Baumert & Köller, 2000). Quality of instruction is always due to a certain orchestration (Oser & 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.

In summarizing 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 in particular if more inclusive conceptual change approaches based on multi-dimensional perspectives as outlined above are employed. Recent large scale programs to improve the quality of science instruction (as well as instruction in other domains) include instructional methods that are clearly oriented toward constructivist conceptual change approaches, i.e., attempts to set constructivist principles of teaching and learning into practice (Beeth, Duit, Prenzel, Ostermeier, Tytler, & Wickman, 2003). The other characteristics of quality development approaches by Beeth et al. (2003) refer to: (1) Supporting schools and 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. Clearly, this set of characteristics requires the teachers to be reflective practitioners (Schoen, 1983) with a non-transmissive view of teaching and learning. The students need to be seen as active, self-responsible, co-operative and self-reflective learners. Indeed, these features are at the heart of inclusive constructivist conceptual change approaches.

Scientific Literacy and Conceptual Change Approaches

The 1990s saw another intensive debate on the aims of science instruction, in many countries, namely preparing students for the demands of the 21st century (de Boer, 2000; Millar & Osborne, 1998). A widely accepted view of scientific literacy is the conception developed for the international monitoring study PISA 2000 (Programme for International Student Assesment; OECD, 1999). In PISA, scientific literacy is seen as the capacity to identify questions and to draw evidence-based conclusions in order to understand and help to make decisions about the natural world and the changes made to it through human activity. This is a rather ambitious definition which includes student competencies not only at the level of understanding science concepts and

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

principles but also comprises understanding of science inquiry as well as views about the nature of science. Further, the focus is not only on understanding but also on using knowledge and views in everyday situations (including issues of relevance of science for modern societies). It appears that such an ambitious definition of scientific literacy may only be set into practice if the multi-dimensional conceptual change perspectives as outlined above provide the framework for instructional design. Such frameworks are at the heart of recent quality development programmes mentioned by Beeth et al. (2003).

Teachers' Views of Teaching and Learning Science

In discussing opportunities to implement science standards in the United States, Anderson and Helms (2001) highlighted the major obstacles to success — 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. In many studies investigating teachers' views about teaching and learning carried out since the 1990s (Duit, 2006), it becomes apparent that science teachers usually hold rather limited views of teaching and learning science. Research shows that this limited view not only holds for science but for other instructional domains as well (Borko, 2004). In their teacher professional development approach of content-focused coaching, West and Staub (2003) claimed that it is essential to encourage teachers to become familiar with the recent state of educational research and to help develop their views about efficient teaching and learning.

A video-study on the practice of German and Swiss lower secondary physics instruction supports the above findings. In the first phase of this study, 13 German teachers participated; in the second phase, 50 German and 40 Swiss teachers were involved from a variety of randomly selected schools (Prenzel, Seidel, Lehrke, Rimmele, Duit, Euler, Geiser, Hoffmann, Müller, & Widodo, 2002; Seidel, Rimmele, & Prenzel, 2005). In these two phases, lessons of each teacher were videotaped, and additional data on teachers' thinking were provided by questionnaires and interviews. Findings from the first phase concerning the practice of physics instruction and teachers' views of teaching and learning science were summarized by Duit, Widodo, and Wodzinski (2007). Additional data from the second phase are available from Duit, Fischer, Labudde, Brückmann, Gerber, Kauertz, Knierim, and Tesch (2005) and Seidel, Rimmele, and Prenzel (2005).

Analysis of these data showed that most teachers are not well informed about key ideas of conceptual change research. Their views of their students' learning usually are not consistent with the state of 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 want to be learning counselors, and they are aware of the importance of students' cognitive activity and the interpreting nature of students' observations and understanding. However, teachers were identified who characterized 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.

The teachers' views and beliefs about good physics teaching and learning as revealed by the teacher interviews also showed a rich repertoire of thinking patterns about instruction on the one hand and a certain narrowness on the other (Müller, 2004). Many teachers hold elaborated ideas about their way of teaching. However, considerations about the content in question predominate teacher planning. Reflections about students' perspectives and their role in the learning process play a comparably minor role.

Briefly summarized, two general orientations of instruction may be distinguished from the

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

video-study: (1) *Transmissive* — Oriented towards physics with a focus on physics concepts and learning viewed as knowledge transmission; (2) *Constructivist* — Focus on student learning, in particular which conditions are necessary to support learning, with learning viewed as student construction.

The transmissive orientation predominates teaching behaviour and teachers' beliefs. There is a large gap between the kind of thinking about efficient teaching and learning physics as discussed in the research-based literature and the thinking of the teachers in this study. The above characteristics of teacher thinking about teaching and learning physics are valid for the above small sample of 13 teachers, but the subsequent video-study carried out in some 90 classes in Germany and Switzerland led to similar findings. However, more formal analyses are only in progress. Similar findings concerning teachers' limited familiarity of constructivist conceptual change ideas and rather limited views of teaching and learning also are reported from another video-study conducted in German classrooms (Reyer, 2004).

The Practice of Teaching Science in Normal Classes

The literature on the actual practice of science instruction in normal classes is not extensive. But there are several studies showing that normal instructional practice is somewhat far from what multi-perspective conceptual change approaches outlined in this chapter. This may be expected taking into account the findings on teachers' limited views of teaching and learning science presented in the previous section. A number of studies on teachers' views also provide information on their teaching practice (cf. Anderson & Helms, 2001) with findings from studies that deliberately address the issue of investigating practice discussed below.

In summarizing findings of student narratives from interpretive studies on students' experiences of school science in Sweden, England, and Australia, Lyons (2006, p. 595) pointed out 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." It is interesting to note that 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 memorized.

The seminal TIMSS Video Study on Mathematics Teaching (Stigler, Gonzales, Kawanaka, Knoll, & Serrano, 1999; Stigler, Gallimore, & Hiebert, 2000) compared the practice of instruction in the United States, Japan, and Germany. Instruction was observed to be primarily teacher-oriented and instructional scripts based at transmissive views of teaching and learning predominated. However, it also became apparent that there are significant differences between the participating countries according to the degree of constructivist-oriented teaching and learning. In Japan, for instance, students had many more opportunities for self-guided problem solving than in the other two countries. Although instruction in Japan was also teacher controlled, students spent much of the class time solving problems using a variety of strategies. This was not the case in the German and the United States mathematics classrooms.

The TIMSS Video Study on science teaching (Roth, Druker, Garnier, Chen, Kawanaka, Rasmussen, Trubacova, Warvi, Okamoto, Gonzales, Stigler, & Gallimore, 2006) investigated the instructional scripts of science teaching in five countries: Australia, 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 to different degrees in the participating countries.

The video-study discussed previously in German and Swiss schools on the practice of physics instruction resulted in similar findings. Specifically, there was a strong teacher dominance in German physics instruction though students worked in groups or individually for 15% of the

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. In S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

lesson time (Duit et al., 2005). Nevertheless, in this somewhat narrow kind of classroom discourse, experiments played a significant role in instruction but students had few opportunities for self-organized inquiry. In Switzerland, instruction was less teacher-dominated and there were also significantly more opportunities for student inquiry. But still, the percentage of instruction oriented toward constructivist conceptual change views was small.

For the first phase of the above physics video-study, more detailed analyses from constructivist conceptual change perspectives are available (Duit, Widodo, & Wodzinski, 2007). In his investigation of the practice of instruction from constructivist perspectives, including deliberate analyses from the point of view of conceptual change strategies, Widodo (2004) observed that the teaching behaviour of several teachers comprised various features that were characteristic of constructivist-oriented science classrooms. In these classrooms, teachers provided, for instance, cognitive activity by addressing thought-provoking questions as well as incorporating certain features of conceptual change supporting conditions such as dealing with everyday phenomena. Further, a key phase of constructivist-oriented teaching sequences (Driver, 1989), namely, elicitation of students' pre-instructional knowledge frequently occurred as did teachers dealing with students' conceptions, another key phase of conceptual change approaches. However, cognitive conflict was infrequent; usually, the teachers attempted to guide students step-by-step from their own ideas to the science views. Such attempts to elicitate students' ideas and to address them were not deliberately linked. For example, after extended elicitation of what students already knew about electricity or forces, the findings usually did not play any significant role in subsequent instruction. Seldom were students' initial ideas explicitly taken into account when elaborating their conceptions. Finally, there were limited examples where students followed their own ideas in the video data, indicating that students had little voice in instruction.

Briefly summarized, the normal practice of science instruction described in the above studies was not significantly informed by constructivist conceptual change perspectives. Of course, there was a 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 are made familiar with research knowledge on teaching and learning by being introduced to recent constructivist and conceptual change views and are made familiar with instructional design that is oriented toward these views. Second, attempts to link their 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 — briefly referred to as PCK — Pedagogical Content Knowledge (Gess-Newsome, & Lederman, 1999; van Driel, Verloop, & de Vos, 1998; West & Staub, 2003).

The process of teacher professional development can be viewed as a set of substantial conceptual changes that teachers have to undergo. As briefly outlined in a previous section of the present chapter, teachers' views of teaching and learning are limited when seen from the perspective of the implemented constructivist conceptual change ideas about teaching and learning. Instead, deep changes are necessary. Learning to teach for conceptual change means "that teachers must undergo a process of pedagogical conceptual changes themselves" (Stofflett, 1994, p. 787).

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

Hence, the conceptual change perspectives developed to analyze student learning should also be valuable frameworks for teacher learning. In fact, there are several attempts to apply these frameworks in teacher education. Stofflett (1994) primarily draws on the classical conceptual change model by Posner et al. (1982) using the conceptual change quadriga of intelligibility-plausibility-dissatisfaction-fruitfulness to analyse the change processes in a teacher development project. A similar approach to teacher development using the theoretical base of classical conceptual change was proposed by Feldman (2000) who argued that because teacher practical reasoning is similar to scientific reasoning, "a model of practical conceptual change can be developed that is analogous to the conceptual change model" (Feldman, 2000, p. 606).

This classical conceptual change model by Posner et al. also provided the major orientation of a large study on professional development of biology teachers (Hewson, Tabachnick, Zeichner, Blomker, Meyer, Lemberger, Marion, Park, & Toolin, 1999a; Hewson, Tabachnick, Zeichner, & Lemberger, 1999b). Constructivist perspectives with a particular emphasis on the classical conceptual change model were observed to provide a powerful framework to design the change processes that teachers had to undergo and to analyse the characteristics of these processes. Interestingly, the changes that were initiated not only comprised teachers' views about teaching and learning but also their views of science and the nature of knowledge (Hewson et al., 1999a, p. 254): "... we use the term conception of teaching science as an inclusive one that encompasses science (the nature of science, scientific knowledge, etc.), learning, and instruction, and the relationships between these three conceptions." The various analyses that were provided clearly showed that conceptual change perspectives may not only provide powerful frameworks for designing and analysing student learning but also for teacher learning.

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, 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.

CONCLUSIONS

The present chapter discusses two distinct but closely connected issues concerning teaching science for conceptual change. In the first part, we provide on overview of theoretical conceptual change perspectives that have developed since the 1970s and that have been employed to design approaches that allow for teaching science more effectively than with instructional designs drawing on transmissive views of teaching and learning. In the second part, we discuss situations where conceptual change perspectives have been put into practice in normal schools.

Concerning the first part, it becomes obvious that conceptual change has developed to one of the leading paradigms in research on teaching and learning. It is interesting to see a continuous progress over the three decades since early conceptual change research occurred. As science educators, we note that science education research contributed greatly to the development of the broader research domain of conceptual change.

Very briefly summarized, we witness a development from early conceptual change perspectives based on Piagetian, Ausubelian, Kuhnian, and further epistemological views. In general, the conceptual change ideas of the early 1980s were based on individualistic and somewhat radical constructivist views. Only later, in parallel with the development of constructivist ideas towards including variants of social constructivism, more inclusive views of conceptual change have developed.

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

It is noteworthy that also the definition of what changes in conceptual change has changed substantially over the past three decades. 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' preinstructional (or alternative) views for the science view. However, it became clear very soon that such an exchange is not possible. Major meanings given to the term *conceptual change* (such as status change proposed by Hewson and Hennessey, 1992) are discussed in the first part of the present chapter. Conceptual change now denotes that learning science includes various changes of perspectives. Most of these changes of epistemological and ontological perspectives are not simple but rather difficult as the "everyday" perspectives and the science perspectives often are not in accordance but are at best complementary.

The role given to affective issues in the process of conceptual change is also worth noting. Already the classical conceptual change approach (Posner et al., 1982) included affective issues, but only implicitly. Pintrich et al. (1993) initiated attempts to investigate the role of emotions, interests, and motivation more fully. Affective issues were, however, mainly viewed as variables moderating conceptual change. Only more recently, cognitive and affective perspectives are viewed as equally important with both having to undergo substantial conceptual changes during instruction (Zembylas, 2005). This more recent view also provides cognitive and affective outcomes of instruction with the same importance.

Instructional design oriented at conceptual change perspectives has proven more efficient than traditional design oriented toward transmissive views of teaching and learning. However, a cautious remark is needed here: A formal meta-analysis supporting this claim is so far not available.

The significance of instructional design oriented at recent inclusive conceptual change perspectives for improving practices is twofold. First, recent, rather ambitious and multi-faceted conceptions of scientific literacy may be set into practice only if instructional design is informed by inclusive conceptual change perspectives. Second, as mentioned, usually such design leads to improved learning outcomes. For this reason, it appears that recent quality development approaches in science education are based on these designs.

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, there is a large gap between what is known in the research domain of conceptual change about more efficient teaching and learning and what may be set into practice in normal classes. In the second part of the present chapter, we argue that teachers usually are not well informed about actual views of efficient teaching and learning available in the research community. Most teachers hold views that are limited if seen from the recent inclusive conceptual change perspectives. At best, some isolated features of these perspectives are embedded within predominantly transmissive views. Further, instructional practice is also usually far from a practice that is informed by conceptual change perspectives. Taking into account teachers' deeply rooted views of what they perceive to be 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.

Although much research is now carried out on teacher professional development, the research community involved in conceptual change appears to contribute only marginally to investigating opportunities to implement their results and ideas into practice. It may be argued that

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

many conceptual change strategies have been developed and evaluated in actual classrooms and often in close cooperation with teachers (e.g., Driver, 1989; Biemanns, Deel, & Simons, 2001; Vosniadou, Dimitrakopoulou, & Papademetriou, 2001) but what works in special arrangements does not necessarily work in everyday practice.

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. Of course, these developments are necessary in order to address the complex phenomena of teaching and learning science more and more adequately. But 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. Maybe we have to address the paradox that in order to adequately model teaching and learning processes, research alienates the teachers and hence widens the theory-practice gap.

The message of the present chapter is that we should deal with this paradox. Taking into account the state of research on conceptual change as presented in the present handbook, the focus is on further developing theoretical frameworks, research methods, and more efficient conceptual change instructional strategies. However, in which way all this may become part of actual practice has been given little attention. 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.

REFERENCES

Anderson, R. D., & Helms, J. V. (2001). The ideal of standards and the reality of schools: needed research. *Journal of Research in Science Teaching*, *38*, 3–16.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view.* New York: Holt, Rinehart and Winston.

Bachelard, G. (1968). *The philosophy of No. A philosophy of the new scientific mind.* New York: The Orion Press.

Baumert, J., & Köller, O. (2000). Unterrichtsgestaltung, verständnisvolles Lernen und multiple Zielerreichung im Mathematik- und Physikunterricht der gymnasialen Oberstufe [Instructional design, learning and achievement of multiple goals in mathematics and science upper secondary instruction]. In J. Baumert, W. Bos, & R. Lehmann (Eds.), *TIMSS/III. Dritte Internationale Mathematik- und Naturwissenschaftsstudie. Vol. 2.* (pp. 271–315). Opladen, Germany: Leske + Budrich.

Beeth, M., Duit, R., Prenzel, M., Ostermeier, C., Tytler, R., & Wickman, P.O. (2003). Quality development projects in science education. In D. Psillos, P. Kariotoglou, V. Tselfes, G. Fassoulopoulos, E. Hatzikraniotis, & M. Kallery (Eds.), *Science education research in the knowledge based society* (pp. 447–457). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Biemanns, H. J. A., Deel, O. R., & Simons, P. R.-J. (2001). Differences between successful and less successful students while working with the CONTACT-2 strategy. *Learning and Instruction, 11*, 265–282.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*, 3–15.

Bryce, T., & MacMillan, K. (2005). Encouraging conceptual change: the use of bridging analogies in the teaching of action-reaction forces and the 'at rest' condition in physics. *International Journal of Science Education, 27*, 737–763.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: The MIT Press.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction, 15*(1), 1–40.

Chi, M. T. H., Slotta, J. D., & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction, 4*, 27–43.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science education. *Review of Educational Research, 63*, 1–49.

Chiu, M-H, Chou, C-C, & Liu, C-J (2002). Dynamic processes of conceptual change: Analysis of constructing mental models of chemical equilibrium. *Journal of Research in Science Teaching, 39*, 713–737.

De Boer, G. E. (2000). Scientific literacy: another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*, 582–601.

Driver, R. (1989). Changing conceptions. In P. Adey, J. Bliss, J. Head, & M. Shayer (Eds.), *Adolescent development and school science* (pp. 79–104). London: The Falmer Press.

Driver, R., & Easley, J. A. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5*, 61–84.

Driver, R., & Erickson, G. L. (1983). Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education, 10*, 37–60.

Duit, R. (1998, April). *Towards multi-perspective views of science learning and instruction*. Paper presented at the annual meeting of the American Educational Research Association in San Diego.

Duit, R. (2006). *STCSE — Bibliography: Students' and teachers' conceptions and science education.* Kiel, Germany: IPN — Leibniz Institute for Science Education (http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html).

Duit, R., & Treagust, D. F. (1998). Learning in science - From behaviourism towards social constructivism and beyond. In B. J. Fraser & K. Tobin (Eds.), *International handbook of science education, Part I* (pp. 3–25). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Duit, R., & Treagust, D. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*, 671–688.

Duit, R., Widodo, A., & Wodzinski, C. T. (2007). Conceptual change ideas — Teachers' views and their instructional practice. In S. Vosniadou, A. Baltas, & X. Vamvokoussi (Eds.), *Re-framing the problem of conceptual change in learning and instruction* (pp. 197–217). Amsterdam, The Netherlands: Elsevier.

Duit, R., Fischer, H., Labudde, P., Brückmann, M., Gerber, B., Kauertz, A., Knierim, B., & Tesch, M. (2005). Potential of video studies in research on teaching and learning science. In R. Pintó & D. Couso (Eds.), *Proceedings of the Fifth International ESERA Conference on Contributions of Research to Enhancing Students' Interests in Learning Science* (pp. 829–842). Barcelona, Spain: Universitat Autonoma de Barcelona.

Dykstra, D. I., Boyle, C. F., & Monarch, I. A. (1992). Studying conceptual change in learning physics. *Science Education, 76*, 615–652.

Feldman, A. (2000). Decision making in the practical domain: A model of practical conceptual change. *Science Education, 84*, 606–623.

Gess-Newsome, & Lederman, N. G. (1999). *Examining pedagogical content knowledge.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Greeno, J. G., Collins, A. M., & Resnick, L. B. (1997). Cognition and learning. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 15–46). New York: Simon & Schuster Macmillan.

Guzetti, B. J., Snyder, T. E., Glass, G. V., & Gamas, W. S. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly, 28*, 116–159.

Harlen, W. (1999). *Effective teaching of science: A review of research.* Edinburgh: The Scottish Council for Research in Education.

Hashweh, M. Z. (1986). Toward an explanation of conceptual change. *European Journal of Science Education, 8*, 229–249.

Hewson, P. W. (1982). A case study of conceptual change in special relativity: The influence of prior knowledge in learning. *European Journal of Science Education, 4*, 61–78.

Hewson, P. W., & Thorley, N. R. (1989). The conditions of conceptual change in the classroom. *International Journal of Science Education, 11*, 541–553.

Hewson, P. W., Tabachnick, B. R., Zeichner, K. M., Blomker, K. B., Meyer, H., Lemberger, J., Marion, R., Park, H.-J., & Toolin, R. (1999a). Educating prospective teachers of biology: Introduction and research methods. *Science Education, 83*, 247–273.

[illegible] iadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

Hewson, P. W., Tabachnick, B. R., Zeichner, K. M., & Lemberger, J. (1999b). Educating prospective teachers of biology: Findings, limitations, and recommendations. *Science Education, 83*, 373–384.

Hewson, P. W., & Lemberger (2000). Status as the hallmark of conceptual change. In R. Millar, J. Leach, & J. Osborne (Eds.), *Improving science education* (pp. 110–125). Buckingham, UK: Open University Press.

Hewson, P., & Hennessey, M. G. (1992). Making status explicit: A case study of conceptual change. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 176–187). Proceedings of an international workshop. Kiel, Germany: IBN-Leibniz Institute for Science Education.

Jung, W. (1993). Hilft die Entwicklungspsychologie dem Physikdidaktiker [Does developmental psychology help the physics educator?]. In R. Duit, & W. Gräber (Eds.), *Kognitive Entwicklung und naturwissenschaftlicher Unterricht* (pp. 86–107). Kiel, Germany: IPN – Leibniz Institute for Science Education.

Karplus, R. (1977). Science teaching and the development of reasoning. *Journal of Research in Science Teaching, 14*, 33–46.

Lawson, A. E., Abraham, M., & Renner, J. (1989). *A theory of instruction: Using the Learning Cycle to teach science concepts and thinking skills* (NARST Monograph Number One). University of Cincinnati, Cincinnati, OH: National Association for Research in Science Teaching.

Limon, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: a critical appraisal. *Learning and Instruction, 11*, 357–380.

Limon, M., & Carretero, M. (1999). Conflicting data and conceptual change in history experts. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New Perspective on conceptual change* (pp. 137–160). Oxford: Pergamon.

Limon, M., & Mason, L. (Eds.). (2003). *Reconsidering conceptual change. Issues in theory and practice.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Lyons, T. (2006). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education, 28*, 591–613.

Mason, L. (2001). Responses to anomalous data on controversial topics and theory change. *Learning and Instruction, 11*, 453–484.

Millar, R., & Osborne, J. (1998). *Beyond 2000: Science education for the future. The report of a seminar series funded by the Nuffield Foundation.* London: King's College London, School of Education (http://www.kcl.ac.uk/education).

Mortimer, E. F. (1995). Conceptual change or conceptual profile change? *Science & Education, 4*, 267–285.

Müller, C. T. (2004). *Subjektive Theorien und handlungsleitende Kognitionen von Lehrern als Determinanten schulischer Lehr-Lern-Prozesse im Physikunterricht* [Teachers' subjective theories and cognitions and teaching and learning processes in physics instruction]. Studien zum Physikunterricht, Band 33. Berlin: Logos.

Norman, D. A. (1983). Some observations on mental models. In D. Gentner & A. L. Stevens (Eds.), *Mental models* (pp. 7–14). Hillsdale, NJ: Erlbaum.

OECD-PISA. (1999). *Measuring student knowledge and skills: A new framework for assessment.* Paris: OECD.

Oser, F. K., & Baeriswyl, F. J. (2001). Choreographies of teaching: Bridging instruction to learning. In V. Richardson (Ed.), *AERA's handbook of research on teaching – 4th edition* (pp. 1031–1065). Washington DC: American Educational Research Association.

Piquette, J. S., & Heikkinen, H. W. (2005). Strategies reported used by instructors to address student alternate conceptions in chemical equilibrium. *Journal of Research in Science Teaching, 42*, 1112–1134.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 6*, 167–199.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211–227.

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

Prenzel, M. Seidel, T., Lehrke, M., Rimmele, R., Duit, R., Euler, M., Geiser, H., Hoffmann, L., Müller, C., & Widodo, A. (2002). Lehr-Lern-Prozesse im Physikunterricht — eine Videostudie [Teaching and learning processes in physics instruction — a videostudy] (pp. 139–156). *Zeitschrift für Pädagogik*, 48 [45, Beiheft].

Reyer, T. (2004). *Oberflächenmerkmale und Tiefenstrukturen im Unterricht. Exemplarische Analysen im Physikunterricht der gymnasialen Sekundarstufe* [Surface structures and deep structures in instruction: Exemplary analysis of lower secondary physics instruction]. Berlin: Logos.

Roth, K., Druker, S., Garnier, H., Chen, C., Kawanaka, T., Rasmussen, D., Trubacova, S., Warvi, D., Okamoto, Y., Gonzales, P., Stigler, J., & Gallimore, R. (2006). *Teaching science in five countries: Results from the TIMSS 1999 Videostudy. Statistical Analysis Report.* Washington, D.C.: NCES – National Centre for Educational Statistics.

Salomon, G., & Globerson, T. (1987). Skill may not be enough: the role of mindfulness in learning and transfer. *International Journal of Educational Research, 11*, 623–637.

Schoen, D. A. (1983). *The reflective practitioner*. London: Temple Smith.

Scott, P. H., Asoko, H. M., & Driver, R. (1992). Teaching for conceptual change: A review of strategies. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 310–329). Kiel, Germany: IPN – Leibniz Institute for Science Education.

Seidel, T., Rimmele, R., & Prenzel, M. (2005). Clarity and coherence of lesson goals as a scaffold for student learning. *Learning and Instruction, 15*, 539–556.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–21.

Sinatra, G. M., & Pintrich, P. R. (Eds.). (2003). *Intentional conceptual change*. Mahwah, NJ: Erlbaum.

Solomon, J. (1987). Social influences on the construction of pupils' understanding of science. *Studies in Science Education, 14*, 63–82.

Stigler, J. W., Gonzales, P., Kawanaka, T., Knoll, S., & Serrano, A. (1999). *The TIMSS Videotape Classroom Study. Methods and findings from an exploratory research project on eighth-grade mathematics instruction in Germany, Japan and the United States.* Washington, D.C.: U.S. Department of Education.

Stigler, J. W., Gallimore, R., & Hiebert, J. (2000). Using video surveys to compare classrooms and teaching across cultures: Examples and lessons from the TIMSS video studies. *Educational Psychologist, 35*, 87–100.

Stofflett, R. T. (1994). The accommodation of science pedagogical knowledge: The application of conceptual change constructs to teacher education. *Journal of Research in Science Teaching, 31*, 787–810.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. West & L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 211–231). Orlando, FL: Academic Press.

Taber, K. S. (2006). Beyond constructivism: the progressive research programme into learning science. *Studies in Science Education, 42*, 125–184.

Thagard, P. (1992). *Conceptual revolutions*. Princeton, NJ. Princeton University Press.

Toulmin, S. (1972). *Human understanding: Vol. I.* Oxford: Oxford University Press.

Treagust, D. F., Harrison, A. G., Venville, G. J., & Dagher, Z. (1996). Using an analogical teaching approach to engender conceptual change. *International Journal of Science Education, 18*, 213–229.

Tyson, L. M., Venville, G. J., Harrison, A. G., & Treagust, D. F. (1997). A multidimensional framework for interpreting conceptual change in the classroom. *Science Education, 81*, 387–404.

van der Veer, R., & Valsiner, J. (1991). *Understanding Vygotsky: A quest for synthesis.* Oxford: Blackwell.

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*, 673–696.

Venville, G., Gribble, S. J., & Donovan, J. (2005). An exploration of young children's understandings of genetics concepts from ontological and epistemological perspectives. *Science Education, 89*, 614–633.

Venville, G. J., & Treagust, D. F. (1998). Exploring conceptual change in genetics using a multidimensional interpretive framework. *Journal of Research in Science Teaching, 35*, 1031–1055.

Vosniadou, S. (1994). Capturing and modelling the process of conceptual change. *Learning and Instruction, 4*, 45–69.

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. In S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: a study of conceptual change in childhood. *Cognitive Psychology, 24*, 535–585.

Vosniadou, S., & Ioannides, C. (1998). From conceptual change to science education: a psychological point of view. *International Journal of Science Education, 20*, 1213–1230.

Vosniadou, S., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction, 11*, 381–419.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177–210). New York: Macmillan.

Weinert, F. E., Schrader, F. W., & Helmke, A. (1989). Quality of instruction and achievement outcomes. *International Journal of Educational Research, 13*, 895–914.

West, L., & Staub, F. C. (2003). *Content-focused coaching: Transforming mathematics lessons*. Portsmouth, NH: Heinemann/Pittsburgh, PA: University of Pittsburgh.

White, R., & Gunstone, R. (1992). *Probing understanding*. London: The Falmer Press.

Widodo, A. (2004). *Constructivist Oriented Lessons: The learning environment and the teaching sequences*. Frankfurt: Peter Lang.

Zembylas, M. (2005). Three perspectives on linking the cognitive and the emotional in science learning: Conceptual change, socio-constructivism and poststructuralism. *Studies in Science Education, 41*, 91–116.

Duit, R., Treagust, D. F. & Widodo, A. (2008). Teaching science for conceptual change. in S. Vosniadou (Ed.). *International Handbook of Research on Conceptual Change*. New York: Routledge.