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Multiple Perspectives of Conceptual Change in Science and the Challenges Ahead

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Conceptual change views of teaching and learning processes in science, and also in various other content domains, have played a significant role in research on teaching and learning as well as in instructional design since the late 1970s. Conceptual change can be interpreted from different individual perspectives or from multiple perspectives. In the classical epistemological perspective, cognitive outcomes predominate whilst a multiple perspective can include both cognitive and affective outcomes. In this article we refer to the interpretation of conceptual change from a multiple perspective when an analogy was used in teaching optics. Here is evidence of the potential of a significant improvement in instructional practice. However, it becomes also evident that actual practice is far from what conceptual change perspectives propose and that change of this practice continues to be a rather difficult and long-lasting process. In this article, five challenges for future research and development in conceptual change at theoretical, methodological and practical levels are identified with a deliberate emphasis on their contribution to improve instructional practice.

***Key words**:* Conceptual change; Multiple perspectives; Student learning; Teaching approaches; Epistemology; Ontology; Affective domain

Introduction

Research on students' and teachers' conceptions and their roles in teaching and learning science has become one of the most important research domains in science education. For more than three decades, researchers have investigated students' pre-instructional conceptions in physics (for example, electric circuit, force, energy) in chemistry (for example, chemical bonding, combustion, particulate nature of matter) and biology (for example, photosynthesis and respiration, genetics, evolution). From the results of many thousands of studies reported in Duit (2009), research has shown that individuals are not simply passive learners but make sense of new information in terms of their previous ideas and experiences. One outcome of such learning is that learners' knowledge is not consistent with the scientists' science. These conceptions are referred to as children's science or misconceptions or alternative conceptions dependent on the author's philosophical position. Furthermore these views are often firmly held, are resistant to change and present difficult challenges for teachers of science and researchers of science education.

Generally, the ideas of constructivism help explain how learners develop their understanding of scientific phenomena. Constructivism emphasises that knowledge is not received passively but is built up by the cognising subject and that the function of cognition is adaptive and enables the learner to construct viable explanation of experience (Driver, 1989). Such constructivist ideas include many facets of Piaget's genetic epistemology and often serve as a reference position for discussions of constructivism in education (Treagust, Duit, & Fraser, 1996). Constructivist teaching approaches consider students' beliefs and conceptions towards student-centred pedagogy in science instruction with the focus on the students, their interests, their learning skills, and their needs in actively constructing their knowledge. Indeed, how constructivist approaches have been used to challenge students' alternative conceptions have been well documented in the science education research literature.

The 1970s and early 1980s saw the growth of studies investigating the development of individual students' pre-instructional conceptions towards the intended science concepts. From the mid 1980s onwards researchers became more interested in the social environment in which learning took place, leading to the notion of social constructivism. Many researchers investigating learning outcomes are interested in the notion of conceptual change, namely how individual conceptions change over time and, of particular interest, when these changes result in scientific understanding or understanding more closely related to the scientific conception. Over the past three decades, researchers of students' conceptions and conceptual change have conceptualised learning as being embedded in various theoretical frames with epistemological, ontological and affective orientations (Duit & Treagust, 1998; 2003; Pintrich, Marx & Boyle, 1993; Taber, 2006; Zembylas, 2005). Other studies on conceptual change emphasise the importance of the role of the learner, suggesting that the learner can play an active intentional role in the process of knowledge restructuring (Sinatra & Pintrich, 2002).

The Concept of Conceptual Change

Research on the concept of conceptual change has developed a unique vocabulary because conceptual change can happen at a number of levels and different authors use alternative terms to describe similar learning. The most common analysis is that there are two types of conceptual change, variously called weak knowledge restructuring, assimilation or conceptual capture and strong/radical knowledge restructuring, accommodation or conceptual exchange. Consequently, because the term conceptual change has been given various meanings in the literature, the term change often has been misunderstood as being an exchange of pre-instructional conceptions for the science concepts. In this article, the term conceptual change is used for learning in science domains where the pre-instructional conceptual structures of the learners are fundamentally restructured in order to allow understanding of the science concepts under consideration. In a general sense, conceptual change denotes learning pathways from students' pre-instructional conceptions to the science concepts to be learned.

Epistemology and Conceptual Change

The classical conceptual change model in science education arose from the work of Posner, Strike, Hewson & Gertzog (1982) based on students' epistemologies – examining how students think about their world. In this conceptual change model, student dissatisfaction with a prior conception was believed to initiate dramatic or revolutionary conceptual change and was embedded in constructivist epistemological views with an emphasis on the individual's conceptions and his/her conceptual development. If 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. The extent to which the conception meets these three conditions is termed the status of a learner's conception. Resultant conceptual changes may be permanent, temporary or too tenuous to detect. Chinn and Brewer (1993) report some interesting analyses of these changes in conception which have been used in studies in Australian classrooms reported by Liew and Treagust (1995) and by Sookraj (2008).

An important aspect of conceptual change is a learner's conceptual status. 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 things may happen. If the new conception achieves higher status than the prior conception, 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 because the learner, not the teacher, makes the decisions about the status of the new concept and any conceptual changes.

Ontology and Conceptual Change

Changes in conception can also occur as a consequence of changes in students' ontologies - the ways they view reality (Chi, Slotta & De Leeuw, 1994). Examples for these types of ontological change needed for students to develop a more scientific understanding are the conception of heat changing from a flowing fluid to kinetic energy in transit and a conception of gene changing 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.

Affect and Conceptual Change

While the classical conceptual change approach implicitly included affective variables as influential factors facilitating conceptual change, Pintrich, Marx, and Boyle (1993) explicitly argued that affective variables such as interest, self-concept, emotions, motivation and the social aspects of group work are essential in fostering conceptual change. Giving even more credence to the affective domain, Zembylas (2005) argued for the necessity of linking cognitive and emotional variables of science learning such that both variables are given 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.

A Multi-Perspective Position of Conceptual Change

To construct a holistic picture of learning, it is both possible and beneficial to consider a learning situation from more than one theoretical perspective of conceptual change. For example, rather than only considering conceptual changes in knowledge that a student constructs in moving from, say a pre-scientific notion to a scientific view of a concept, a more complete and informative picture would be painted if these changes were viewed from a multidimensional perspective. The way the student views a concept in terms of its status (Posner, et al., 1982), its ontological category (Chi, et al., 1994) and the motivational and contextual factors (Pintrich, et al., 1993) can provide a more holistic picture of conceptual change. Consequently, a multi-dimensional framework utilising differing perspectives of conceptual change to view a learning situation has merit though the affective domain needs to be more fully elaborated. It appears to be most valuable to view the issue of motivation and interest in science and science teaching from the perspective of conceptual change. 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.

Examining Conceptual Change from Epistemological and Affective Perspectives

Appropriate analogies help students make connections between familiar knowledge and new science concepts. Consequently, analogical-based instruction can engender interest as well as cognitive gains as measured by a conceptual change approach. Research has shown that analogical teaching approaches can enhance student learning although analogies for teaching and learning can be a friend or a foe depending on the approach taken by the teacher (Harrison & Treagust, 2006). An example of analogies being friends is from the findings of a study involving the teacher's use of analogies in a topic/unit on optics in a 10th-grade physics class in an all-girls school (Treagust, et al., 1996). The curriculum design involved an approach for teaching with analogies in an effective manner (Treagust, et al., 1998). The teacher's use of a cart with wheels moving obliquely over different surfaces as an analogy for refraction of light successfully engendered conceptual change in student learning about the refraction of light. One class was taught without this analogy and another with the analogy. On a standard test at the end of the unit, comparison of the means and the patterns for the two classes indicated that the non-analogy class scored as well as the analogy class. However on responses to an interview protocol involving ray tracing tasks then scored as a conventional test, the analogy group produced explanations of refraction which were of a higher status than those in the non-analogy group.

It is asserted that the analogy enabled these higher status explanations to be generated; alternatively, these data can be interpreted from the perspective that the analogy was acting simply as a tool of explanation. It is certainly likely that the concrete nature of the analogy enabled the students to remember what they had learned about refraction. Students have difficulty articulating the refraction phenomenon; subsequently, it would seem reasonable that students who possess a familiar analogy will produce the dichotomy seen in the class results. That is, the analogy provided students with language they could comfortably utilise to transform an abstract idea into an articulate explanation. The non-analogy group lacking a familiar means for describing their conceptions could explain the difference in status between the two classes. The point at issue in this paper is the need to measure and record both the cognitive and the affective outcomes. The cognitive outcomes are discussed in terms of results on tests. The affective domain is much more difficult to report in any conventional way – there was no questionnaire involved.

An illustration of the analogy's affective dimension shows how crucial it was to learning. One such case in the study (Treagust, et al., 1996) involved Dana who was vague and unenthusiastic during the initial phase of the interview. When asked "what do you think will happen to the ray of light when it hits the surface of the water?" she responded, "It will probably be stopped and spread." Her sketch depicting this and her subsequent responses when asked "Why does that happen?" were "I don't know", and a similar reply was given for other questions. Dana did not volunteer any explanation, however simple, to account for refraction. However, after Dana had completed three sketches in the interview, the interviewer asked her if she could think of any simple analogy that would help you explain to a friend why those pencils appear to be bent? After a little hesitation Dana recalled "a car type of thing with wheels when it was changing from a piece of carpet to paper". In the subsequent interview, Dana confidently answered the interviewer's questions about the optical phenomena under investigation, acknowledging that when she thought of the wheels, she could work out which way the light rays bend. Dana's answers to the subsequent ray tracing problems (glass block and prism) were among the best we saw of the 39 students. Her physics score on these tasks became 10/10 and this from a student the teacher placed in the bottom 25% of the class and from a student who failed the Optics unit! The tape recording of the interview adds another facet to this story. Until the advent of the analogy, Dana was quietly spoken and disinterested. When the analogy was recalled, she became enthusiastic and the interview produced another four pages of transcript. Dana's initial answer to the first question was inaccurate and showed little evidence of understanding. The introduction of the analogy led to her becoming dissatisfied with her initial answer to the first question and she confidently changed her vague sketch into a correct response.

Conceptual Change and Instructional Practice

Despite instances as mentioned in the study (Treagust, et al., 1996), conceptual change ideas so far do not inform practice to a considerable extent. Anderson and Helms (2001) argued that teachers usually are not well informed about the recent state of research on teaching and learning and hold views that are predominantly transmissive and not constructivist. Some studies providing information on teachers' views about teaching and learning also include findings on teachers' ways of teaching (Anderson & Helms, 2001). 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, Gonzales, Kawanaka, Knoll, & Serrano, 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.

Challenges for Future Research and Development

Based on the aforementioned ideas, 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 be 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 realise that the definition of what changes in conceptual change has changed substantially over the past three decades (Duit, Treagust, & Widodo, 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 (2008) that his term "conceptual reconstruction" more appropriately indicates the actual meaning predominating as outlined above and recommend the future use of this latter term to indicate conceptual learning (Treagust & 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 variable.

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 & Mason, 2002 and Sinatra & 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, i.e. that 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 to develop student pre-instructional ideas towards the science point of view by conceptual change oriented instructional methods. However, it is necessary also to give rethinking traditional science content structures for instruction from the perspectives of the aims of instruction and the learners' perspectives the same attention as the instructional method side. 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, and the instructional methods employed. 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, Gropengießer, & Kattmann, 2005).

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 identifiers. We would argue that this is more developmental research than conceptual change research. 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, e.g., including variants of learning process studies with a certain focus on discourse analyses. In other words, mixed methods 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 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. 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.

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 paper is that we should deal with this paradox by investigating all kinds of theoretical frameworks, research methods, and more efficient conceptual change 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 in fact take the necessity to improve student scientific literacy seriously into account – and research findings available provide valuable instructional methods to improve scientific literacy (Duit, Treagust, & Widodo, 2008). On the other hand, the major "quality development" programs draw on instructional methods proposed by conceptual change research (Beeth et al, 2003). It is also most pleasing that such "conceptual change oriented" methods have proven to be more efficient than more traditional methods (e.g., Schroeder, Scott, Tolson, Huang, & Lee, 2007). However, closer cooperation could allow gathering the forces to better use 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 & 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.

Note:
This article draws on recent more elaborated reviews of the state of conceptual change conceptions in science education. The first review was written for a handbook on conceptual change (Duit, Treagust, & Widodo, 2008). The second review and a further commentary appeared in a special issue of the journal "Cultural Studies of Science Education" (Treagust & Duit, 2008a; 2008b). Finally, two keynote addresses, Duit, R. & Treagust, D. F. (2009). "Towards improving the practice of science instruction: On the state of conceptual change oriented research and development" at the biennial meeting of the International Science Education conference, Singapore in November, and Treagust, D. F. & Duit, R. H. (2009). "The challenges ahead for research and development on conceptual change in science" at the International Conference on Science and Mathematics Education (CoSMEd), Penang in November.

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