Conceptual Change in Science Teaching and Learning

The Role of Pre-Instructional Conceptions

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Abstract: Conceptual change, defined as learning that requires the revision of prior knowledge and the acquisition of new concepts, is essential for learning in science. Research has often been framed in the context of misconceptions that need to be corrected. Conceptual change is difficult and essential and should be approached intentionally by recognizing that all learners (including students and teachers) bring pre-instructional conceptions to the classroom. A renewed emphasis for conceptual change research on practical classroom implementation of instructional strategies is necessary for science education to improve. This article builds on the theoretical work done by decades of researchers, while focusing on the real classroom research that has been done on intentional conceptual change.

Introduction

Students come to the science classroom with pre-instructional conceptions about how the natural world works. Many of these commonsense ideas are based on experiences from both outside and in the classroom. However, these experiential preconceptions are often not complete or accurate descriptions of the way the natural world works. Engaging students in scientific education aimed at creating clear and accurate conceptions of natural phenomena is an important outcome of science education. Conceptual change, defined as learning that requires the revision of prior knowledge and the acquisition of new concepts, is essential for learning in science. Conceptual change is difficult and not always long lasting because pre-instructional conceptions are often robust and strongly held.

What research exists on the connection between K-12 science education and the decisions that everyday citizens make around such critical scientific issues as healthcare, climate change, and environmental problems? In science education it is often argued that one way to improve learning is to make the subject matter relevant to students. One of the principal challenges of science education is teaching about phenomena that are not readily observable by students. Creating models of phenomena is often challenging and hindered by preconceptions that students bring to the science classroom.

Perspectives on Conceptual Change

Educational research about learning in the 20th century was dominated by the individual view based on Piaget's theory of equilibration. This view focuses on the individual as the site of learning and the internal mental schema as where conceptual learning takes place. Thus, early research on conceptual change was based on these ideas of the individual brain as the site of learning. Later in the 20th century a shift towards a social understanding of learning took place based largely on the earlier work of Vygotsky. Leach and Scott (2003) present these two theories of learning that inform the practice of science teaching, the individual and sociocultural views. Leach and Scott present a logical rationale for their construct, and it is important because it attempts to synthesize two broad sets of theories that have often been in conflict. This construct fits with other theories because it draws on well-established research traditions in individual psychology (Piaget) and constructivist learning theory (Vygotsky). The authors place the 'alternative conceptions' literature in the individual view of learning while recognizing that it is useful for improving the effectiveness of science teaching.

Classical Approach to Conceptual Change

In the first stage of research on alternative conceptions, researchers attempted to understand individual pre-instructional conceptions (Taber, 2002). From this point of view, individual mental constructs are logical and reasonable because individuals are rational, and they check their mental constructs against sensory perceptions. According to this view conceptual change can be intentional as teachers introduce new knowledge and concepts which students cannot assimilate (Sinatra & Pintrich, 2003). The goal was to provoke a sense of discomfort so that students will change their schema through accommodation.

The second strand of theory is based on Vygotsky's sociocultural view on the role of internalization and language in learning. While Piaget's learning is active, the focus is still on the individual; for Vygotsky learning is a social process that recognizes that preconceptions are an individual's way of communicating in everyday social language. In science there is a high learning demand because the social languages of everyday life and science are very different.

Multidimensional Perspective on Conceptual Change

Studying preconceptions using a constructivist framework beginning in the 1990s, Duit and his various coauthors have made a large impact on the field of science teaching by proposing a theory based on a multidimensional approach to conceptual change (Duit & Treagust 2003; Duit et al. 2013; Treagust & Duit, 2008). Duit and Treagust (2003) describe the individual approach to preconceptions as the epistemological framework. In this view student learning can be seen as different forms of representation and knowledge where the role of the teacher is to make student preconceptions explicit, introduce new information and knowledge that does not fit their ideas, and create dissatisfaction.

In Duit et al. (2013) the authors contrast the epistemological theory to an ontological approach. Here students' views of science concepts are based on different views of reality so strong that knowledge restructuring is needed. Misconceptions arise when student preconceptions are in different fundamental categories of reality. For example, Chi (2005) explains that some student preconceptions are robust and long lasting because of the ontological distinction between process conceptions and material conceptions. According to Duit et al. (2013), science has a process view that is often at odds with students' material views of the natural world. These examples illustrate that preconceptions based on ontological distinctions are robust and difficult to change.

Duit and his coauthors also discuss the affective domain of conceptual change, which involves student motivation and interest. Here the sociocultural constructivist perspective from Vygotsky brings attention to the role of social and group learning. Instead of relying on an epistemological approach that assumes students will easily and quickly change their scientific understanding when presented with accurate facts, emotions should be taken into account as well. According to Duit et al. (2013) it is appropriate to be skeptical of the rational epistemological view and open the door for the possibility that teachers who ignore the social and affective domain of student's lives may be impeding conceptual change.

After decades of research, there is agreement that the best approach to understanding learning and preconceptions is a multidimensional perspective that combines cognitive and affective understandings of conceptual change. According to Treagust and Duit (2008) "the complex phenomenon of learning needs pluralistic epistemological frameworks" (p. 302). A multidimensional perspective combines cognitive (epistemological and ontological) and affective domains to address teaching and learning in science. An example of taking a multidimensional perspective on conceptual change, can be found in Brown and Ryoo (2008). In this study the authors took the theoretical approach that teaching science is teaching language, and that beginning with an approach that reduced learning demand by focusing on teaching content using everyday language instead of scientific language would lead to increased learning. If the goal is to reduce preconceptions, then meeting students where they are in their language abilities is one way to apply a theoretical approach that combines epistemological, ontological and affective perspectives on conceptual change.

An Example of Pre-Instructional Conceptions

Taber (2014) calls traditional teaching techniques the Xerox model of teaching. In this model "the process of teaching…is one of transfer or copying of information from the source (the teacher's mind, the textbook) to the learners' mind" (p. 61). For Vosniadou et al. (2001) this traditional teaching model is the empiricist approach that is based on enrichment mechanisms. Both of these sets of authors argue for a constructivist approach to teaching, learning and conceptual change. Learning is a process of change from this naive physics that is slow and gradual and is characterized by fragmentation, misconceptions and the creation of "synthetic models" (Vosniadou 2013). I will apply the framework theory approach, which is one specific multidimensional conceptual change approach, to a number of examples.

Example: Photosynthesis

The process of photosynthesis is a scientific concept that has proven to be difficult for students to understand. Photosynthesis is a chemical process that combines many elements of science learning from the nature of light and energy to the conservation of matter. Synthetic models of photosynthesis in young students often start with analogies to humans and animals around the concepts of eating and breathing. Young students do not believe that plants breathe and conceptualize that they eat food from an external source much like animals do. This model is based on a psychological framework theory that applies ideas about intentional causality of entities that are analogous to humans and animals in general (Vosniadou, 2013).

As science instruction is introduced, students create synthetic models that incorporate concepts about breathing in plants being separate from feeding (photosynthesis is about the exchange of gases but not related to feeding; plants get their food from the soil through their roots). Finally, students can understand that photosynthesis is a feeding process while continuing to believe that plants feed through their roots as well and that carbon dioxide is involved without an understanding of the chemical nature of photosynthesis (Vosniadou, 2013).

In my student teaching, I used a formative assessment probe that explored plant growth and photosynthesis to investigate students' understanding of the concept of conservation of matter (Keeley, 2016). In this probe students are presented with a thought experiment of a seed planted in a sealed transparent jar with soil and water. No matter can enter or leave the jar. The students are asked to imagine the seed in the soil and then the plant that has grown after a few weeks. Where does the matter that makes up the plant come from? In my class, high school Honors Chemistry, none of the students correctly identified the source of the mass in the new plant growth as the carbon dioxide in the air inside the jar. As in the synthetic models described above, most students identified the soil or water as the source of food and growth for plants. This example illustrates the persistent nature of student pre-instructional conceptions and the difficult task of conceptual change.

Research into Actual Classrooms and Instructional Strategies

If the goal is conceptual change, then more research is needed into instructional strategies that can be implemented in normal classrooms. Much research in the past ten to fifteen years has combined theory and practice to apply theoretical understandings to classroom instructional strategies (e.g., Adadan, 2013; Barthlow and Watson, 2014; McLure et al., 2020; Sadler et al., 2013; Venville & Dawson, 2010; Zhang et al., 2021).

One example of this applied research in the study by Adadan (2013) which questioned whether instructional strategies that used multiple representations (verbal and visual) led to better understanding of the scientific concept of the particle theory of matter than strategies that relied on verbal representations alone. This is important because many students have pre-instructional conceptions of the particle nature of matter that prevents them from having a clear understanding of the states of matter and phase changes. This study was quasi-experimental and involved two introductory chemistry classrooms with the same teacher. One classroom was randomly assigned Instruction with Multiple Representations (IMR) and the other Instruction with Verbal Representations (IVR). The researcher conducted pre, post, and delayed questionnaires of both classrooms along with student interviews. The research findings are that both groups of students began with poor conceptual understanding of the particle nature of matter, and after instruction the IMR group outperformed the IVR group and retained the understanding after three months. One limitation of this research is that it is not longitudinal because it only lasted three months. In addition, the role of metacognition in student development of scientific conceptual understanding was recognized but not included in the instructional design. According to Adadan (2013), teachers should place more emphasis on the use of multiple levels (macro, submicroscopic, symbolic) and modes (visual, verbal) of representation by students while describing and explaining a target phenomenon during instruction. This study is a specific example of how teachers can intentionally promote conceptual change and eliminate preconceptions through practical

Another study, reviewed in Treagust and Duit (2008), evaluated students' understanding of chemical equilibrium using the instructional strategy of a cognitive apprentice approach. This strategy combines coaching, modeling, scaffolding and exploration and the study compared this approach to a more traditional teaching strategy of direct instruction and demonstrations. The cognitive apprentice group developed more accurate conceptions of the microscopic particulate changes taking place, while both groups demonstrated that matter concepts were more easily understood compared to process concepts based on the random movement of particles in equilibrium.

Conclusion

The nature of pre-instructional conceptions in science learning has been a topic of research for almost fifty years. Starting with cognitive approaches based on the framework of Piaget, research has progressed to a multidimensional perspective influenced by constructivism that incorporates epistemological and affective domains. After decades of research, it is clear that pre-instructional conceptions in science are often robust, long-lasting and resistant to change. Research has moved from trying to understand the nature and origin of preconceptions to an approach that argues for a constructivist theory of conceptual change that can be applied in classroom instruction.

Bridging the theory and practice gap is essential for educational research to remain relevant to teachers. In this article I have summarized the research about the nature of preconceptions and how conceptual change can be encouraged. Yet the answer has often been that teachers need to be aware of their own preconceptions and those of their students. The next step is to determine how to implement change. A full understanding of the cognitive, affective, and ontological underpinnings of pre-instructional conceptions can help researchers and educators recognize the nature of the problem; rigorous research about effective strategies to implement conceptual change is the current challenge in the area of educational research. In this article I have provided the background knowledge about intentional conceptual change that will allow teachers to recognize preconceptions in their students and themselves and plan and implement instructional strategies based on that knowledge

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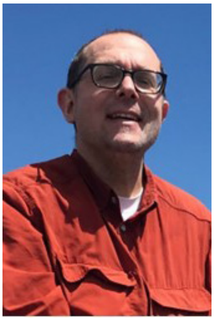

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Andrew Heller has his grades 7-12 science license. In the previous school year he student taught classes at Toledo Public Schools in high school chemistry, biology and environmental science. He has a B.S. in Chemistry, a M.Ed. in Secondary Education and a Ph.D. in Sociology.