

Conceptual Change in Science: A Process of Argumentation

George Zhou

University of Windsor, Windsor, CANADA

Received 18 September 2009; accepted 13 March 2010

Learning is a process of knowledge construction, individually and socially. It has both rational and irrational features. From this stance, the paper reviews an earlier model of conceptual change and its related pedagogical interventions for their inadequate attention to the irrational and social dimensions of learning. More recent developments in conceptual change pedagogy advocate the incorporation of motivational constructs and social-cultural factors, but fail to explicitly address some important issues in science education. In order to advance the conceptual change theory, the paper proposes an argument approach to teaching for conceptual change. It embraces what past models or approaches have achieved while simultaneously addressing their shortcomings.

Keywords: Argument, Cognitive Conflict, Conceptual Change, Meta-Cognition.

INTRODUCTION

Students come to school classrooms with their own understanding of the world (Driver et al., 1985). Literature has referred to students' ideas as "preconceptions" (Clement, 1982), "misconceptions" (Helm 1980), "naïve or intuitive ideas" (McCloskey, 1983; Osborne & Freyberg, 1985), "alternative frameworks" (Driver & Erickson, 1983), or "alternative conceptions" (Gilbert & Watts, 1983). In consideration that students' conceptions are formed before receiving formal instruction in class, this paper will use the term "preconception." A plethora of studies have been conducted to identify preconceptions in numerous scientific content areas (e.g. Bar et al., 1997; Bishop & Anderson, 1990; Clement, 1982; Erickson, 1979, 1980; McCloskey, 1983; Taber 1998).. A common conclusion merging out of these studies is that preconceptions are often at odds with scientific ideas (Driver & Erickson, 1983) and continue to persist following traditional

instruction (Clement, 1982). A restructuring of preconceptions is required for learning under these circumstances. This restructuring is referred to as conceptual change (Vosniadou, 1999). It carries an implication that students' less acceptable conceptions are replaced by more sophisticated scientific concepts that are capable of accounting for phenomena where preconceptions were unable to do so.

In addition to identifying students' preconceptions, scholars have proposed various models and strategies to describe or facilitate teaching for conceptual change. These works normally derived from Kuhn's philosophy of science (Kuhn, 1970) and Piaget's cognitive developmental theory (Piaget, 1970). The concepts and terminologies Kuhn and Piaget used, including "anomaly," "revolution," "cognitive conflict," "disequilibrium," and "accommodation" frequently appears in the relevant literature. The proposed teaching strategies share a common process that involves first creating cognitive conflict before providing a new framework (Hewson & Hewson, 1988). This paper will critically analyze the conceptual change literature, examine the views of both science educators and educational psychologists on this topic, and propose an argument model for conceptual change based on an analysis of the significance of argument in both science development and science education.

*Correspondence to: George Zhou,
Associate Professor of Science Education,
Faculty of Education, University of Windsor
401 Sunset Ave. Windsor, ON, Canada N9B 3P4
E-mail: gzhou@uwindsor.ca*

State of the literature

- There is a plethora of research studies on student preconceptions about the natural phenomena.
- Although there exists an abundance of ways to deal with such difficulties, there is a lack of and a need for studies dealing with students' progress according to the instruction that they are given.
- The theoretical thinking of conceptual change focuses on cognitive conflict. However cognitive conflict is often insufficient to induce change.

Contribution of this paper to the literature

- The paper critically analyzes a “cold” conceptual change model developed by science educators and the “warm” models proposed by educational psychologists.
- The paper offers new insights into the role of argument in science development and science education. It points out that it is the argument, not the experiment that drives the discourse of science. Experiment is one of the measures that provide scientists with insights and justification for their arguments. However, the interpretation of experimental results can vary between scientists.
- The paper proposes an authentic way of teaching science which brings argument into the classroom. This argument approach to teaching science for conceptual change is a general one that is applicable to a wide range of domains in order to close the gap between the needs of learners and designs of instruction.

A “Cold” Model for Conceptual Change

One of the earliest conceptual change models came from Posner and his colleagues (Posner, et al., 1982). Its development was inspired by Kuhn's (1970) theory of scientific revolution as Posner et al. stated that “a major source of hypotheses concerning this issue [conceptual change] is the contemporary philosophy of science...” (p. 211). In Kuhn's picture of scientific progress, some necessary preconditions can be detected for scientific revolutions. They include the appearance of anomalies that eventually lead to scientists' dissatisfaction with the old paradigm, the appearance of a new paradigm that provides scientists with a choice, and the merits of the new paradigm such as solving more problems, more accurate predictions, closer match with subjective matter and more compatibility with other specialties. Paralleling these conditions for scientific revolution, Posner et al. (1982) state that there are several cognitive conditions that must be fulfilled before any conceptual

change can occur. These conditions could be briefly described in terms of students' dissatisfaction with the old conception and the intelligibility, plausibility, and fruitfulness of the new conception.

Posner et al.'s model attracted much attention from science educators. Most theoretical analysis and practical strategies for conceptual change constructed during the 1980s and 1990s were based on or closely related to this model (Smith et al., 1993). For example, Nussbaum and Novick (1981) suggested a three step approach: (a) making children's alternative frameworks explicit to them, b) inducing dissatisfaction by presenting evidence that does not fit, (c) presenting the new framework and explaining how it can account for the anomaly. Champagne et al. (1985) suggested the teacher to give students opportunities to become aware of their preconceptions by arguing their own interpretations, then present the scientific explanation, and lead the class to compare students' interpretations with the scientific explanation. Minstrell (1985) proposed four instructional stages: (a) engaging students' preconceptions, (b) using lab activities or other experiences that are discrepant with students' preconceptions, (c) encouraging students to resolve the discrepancies through class discussion, and (d) providing students with opportunities to apply newly encountered scientific ideas.

Empirical studies, which attempt to bridge the gap between a personally held concept and the scientific view, however have generally revealed that preconceptions are resistant to change. Clement (1982) provided one example of Aristotelian versus Newtonian view of motion. In his study, 88% of pre-university physics students thought a coin experienced an upward force on the way up after it was thrown up. After the university mechanics course, there were still 75% of students who held this concept, namely “motion implies force.” Studies have also documented that preconceptions are apparently changed in school settings but may quickly reassert themselves in the broader context of daily life. Redish and Steinberg (1999) described a case in which a student struggled with Newton's 3rd law. The student knew what the law was, but she changed her answer numerous times between the physics class model and her common sense for one particular test question which asked whether a truck or a car exerted a bigger force during a mutual collision between the two. The common-speech wording of the question brought up her common sense: “Larger objects exert a larger force.” The difficulty that practical efforts have encountered in facilitating conceptual change forces scholars to question the accountability of Posner et al.'s model. Is there something wrong with it?

Learning and Irrational Factors

Pintrich et al. (1993) criticize Posner et al.'s model as a "cold" model because it overlooked the irrational characteristics of learning. This overlooking is clearly reflected in one statement Posner and his colleagues made in their paper: "Our central commitment in this study is that learning is a rational activity" (Posner et al., 1982, p. 212). According to this model, when students meet new experiences in the classroom which do not match their existing mental structure, they will feel dissatisfied and be willing to accept new concepts to overcome this conflict. In other words, academic understanding is seen as the goal of student learning. However, "the assumption that students approach their classroom learning with a rational goal of making sense of the information and coordinating it with their prior conceptions may not be accurate." (Pintrich et al., 1993, p. 173). Piaget reminded us that affectivity plays an essential role in human beings' behavior. Affectivity, including interests, feelings, values, goals, and so on, "constitutes the energetics of behavior patterns whose cognitive aspect refers to the structures alone. There is no behavior pattern, however intellectual, which does not involve affective patterns as motives." (Piaget & Inhelder, 1969, p. 158). Affectivity is a doorkeeper. It controls whether or not the mechanism of assimilation, accommodation and equilibration happens during certain experiences. In some instructional events, cognitive conflict is clearly there from the perspective of an instructor, but students may not buy it (Watson & Konicek, 1990). These events will not result in cognitive development.

Students come to class with different goals and motivations, which can influence their cognitive engagement in academic task. Wentzel (1991) stated that students may have many social goals in the school context besides academic understanding such as making friends, impressing peers, or pleasing instructors. These goals may push students to passively face the conceptual discrepancy by just memorizing the scientific concepts without understanding them. If we roughly sort students' learning goals into two groups: mastery learning and performance learning, the normative goal theory tells us that students with the goal of mastery learning are more engaged in deeper cognitive processing and use more sophisticated cognitive strategies. Whereas students with performance-orientated goals more often use surface processing and have less cognitive engagement (Ames, 1992; Dweck & Leggett, 1988; Nolen, 1988, 1996; Pintrich & De Groot, 1990).

Learning Has a Dimension of Social Construction

Posner et al.'s model also lacks a clear account of socialcultural factors for learning. It describes that when students become dissatisfied with their original beliefs, they will try to find an alternative one that is intelligible, plausible, and fruitful. This description focuses on personal cognition and implies that all reasoning happens within an individual's mind. However, Piaget considers social interaction as a requirement for children to construct social knowledge and as a resource of occasions for cognitive disequilibrium that leads to the reconstruction of knowledge. In Vygotsky's account, all higher mental functions originate from social relationships:

Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological), and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals (Vygotsky, 1978, p. 57).

The awareness of this significance of social construction for learning has spread out to the research of conceptual change. "Most researchers in this area [conceptual change] now agree that conceptual change should not be seen as only an individual, internal, cognitive process, but a social activity that takes place in a complex socialcultural world." (Vosniadou, 2008, p. xix). In other words, conceptual change learning is therefore both an individual cognitive activity and a social construction. When Piaget insisted that children-in-action individually invent knowledge, he did not forget the function of social interaction in knowledge acquisition. Although Vygotsky stated that knowledge is the internalization of a social/cultural relationship by mind-in-society, he did not mean "transmission." Internalization is an active process. In the words of Leont'ev (1981), a student of Vygotsky, "the process of internalization is not the transfer of an external activity to a pre-existing, internal plane of consciousness. It is the process in which this plane is formed." (p. 57). Some experimental studies support this conclusion about the individual and social components of conceptual change learning. In a study designed to investigate whether and how collaborative learning at the computer fosters conceptual changes, Tao and Gunstone (1999) found that computer-supported collaborative learning provided students with experiences of co-construction of shared understanding. They also found that when co-construction of knowledge was accompanied by personal construction, conceptual change became stable over time. When

students did not personally make sense of the new understanding, their change was short lived.

“Warm” Models for Conceptual Change

Following Pintrich et al.’s article (1993), a “warming trend”, in contrast to the “cold” nature of Posner et al.’s model, took place in conceptual change research (Sinatra, 2005). With a belief in the importance of motivational constructs in learning, Sinatra and Pintrich (2003) propose the term “intentional conceptual change,” which is defined as “the goal-directed and conscious initiation and regulation of cognitive, metacognitive, and motivational processes to being about a change in knowledge” (p.6). They argue that conceptual change interventions inspired by Posner et al. focused mainly on what teachers can do to manipulate the context to support learners’ knowledge restructuring. What is lacking in this model and its related instructional strategies is a description of the role of students’ intentions in bringing about change. They criticize that the conceptual change pedagogy is simplified as a matter of placing students in circumstances that highlight points of conflict. They argue that cognitive conflict is often insufficient to induce change (Dole & Sinatra, 1998).

The Cognitive Reconstruction of Knowledge Model (CRKM) by Dole and Sinatra (1998) and Cognitive-Affective Model of Conceptual Change (CAMCC) by Gregoire (2003) are two typical examples of “warm” models that incorporate motivational constructs into the complexity of conceptual change learning. The CRKM describes how learner and message characteristics interact, leading to a degree of engagement with the new concept. The learner characteristics entail existing knowledge and motivational factors. The strength and coherence of a learner’s existing knowledge and his or her commitment to it influence the likelihood of conceptual change. Motivational factors refer to a learner’s interest, emotional involvement, self-efficacy, value, need for cognition, as well as the social context that supports or undermines his or her motivation. Message characteristics refer to the features of the instructional content or persuasive discourse designed to promote conceptual change, which can be described by using adjectives such as comprehensible, coherent, plausible, and rhetorically compelling. It is the interaction of the existing knowledge, instructional message, and individual motivational factors that creates a space for knowledge reconstruction. The CAMCC shares much similarity with the CRKM, but posits a greater role for affective constructs such as anxiety and fear in conceptual change. Gregoire (2003) claimed that stress and threat appraisals “happen automatically before characteristics of the message are seriously considered”. That is, the message characteristics may

never be full processed by a learner if the affective appraisals create a strong tendency to dismiss the message. The CAMCC was proposed to interpret teachers’ resistance to reform-oriented curricula that conflict with their teaching beliefs. It therefore reads more suitable for the case of belief change. However, since the conceptual change in science involves self-efficacy beliefs and epistemological beliefs (Andre & Windschitl, 2003), the CAMCC provides insights for instructional inventions that take affective appraisals into account.

The CRKM and CAMCC describe a process of conceptual change that involves cognitive, motivational, and affective constructs, leading to a choice between the existing knowledge and the instructional message. However they have little description about the presentation of instructional message. How do learners become aware of the instructional message before they struggle for a position between the existing knowledge and the new message? To be told or socially invented or constructed? To the author of this paper, this is one of the most fundamental issues in teaching and learning for conceptual change. Science educators have not yet done a good enough job either in this regard. As reviewed in the previous session, they pointed out the importance of the creation of cognitive conflict and a demonstration of scientific conceptions’ merits over preconceptions in the conceptual change pedagogy, but largely ignored the issue of how the scientific notion becomes available to students. This rather leaves the readers an impression that scientific ideas are told by the teacher to students, which is contradictory to the vast literature on inquiry-based learning. The rest of this paper will attempt to advance the study of conceptual change through examining the implications of argument for science teaching and learning. First, it starts with an examination of the role of argument in both science development and science education. Next it offers an explanation of how the argument process can accommodate what we have so far achieved in conceptual change pedagogy as well as address the shortcomings of both science educators’ and educational psychologists’ models.

Argument in Science Development and Science Education

Argument is one primary component of scientists’ work. In the discourse of constructing scientific knowledge that is consistent and acceptable to the scientific community, scientists argue with themselves through frequent idea changes. More importantly, they argue with each other through publication, conferences, and informal occasions in order to build knowledge with minimum bias. The role argument plays in science is even more obvious and important at the time of

scientific revolutions or paradigm changes. As Kuhn (1993) and Thagard (1992) state, in the history of science a new framework takes the place of the previous one through scientific argument. The dialogues between the caloric and kinetic views of heat, the particle and wave views of light, and the debate between Bohr and Einstein on quantum mechanics are typical cases in which argument plays a major role.

Experiment has been widely viewed as a fundamental characteristic of science, particularly with the success of so-called experiment-based modern science which began in Galileo's times. However, if we look at science as a process of argument, experiment becomes one of the measures that provide scientists with insights and justification for their arguments. Yet, it is not the only measure as intuition, guessing, and imagination can play important functions in scientists' work. As Posner and his colleagues (Posner et al., 1982) observed, "many conceptual changes in science have been driven by the scientists' fundamental assumptions rather than by the awareness of empirical anomalies." (p. 224).

Einstein states that a scientific hypothesis does not come directly from experiment but it comes out of imagination and guesses. This statement precisely describes his creative work on relativity. A more convincing example for this point is the famous Frank-Hertz experiment in the area of atomic physics. Frank and Hertz started an experimental study on the ionization of atoms by electron impact in 1911, which won them physics Nobel Prize in 1925. In 1914 when Frank and Hertz first published their experiment report, they interpreted their typical experimental value of 4.9eV as the ionization voltage of mercury atoms. Bohr however believed that this value represents the excitation voltage of an atom from one energy state to another. In other words, he took this experiment as a direct verification of his hypothesis about the stationary state of atoms. Bohr published a paper in 1915 to criticize the interpretation of Frank and Hertz for their experiment. In 1916, Frank and Hertz published a paper to announce their rejection of Bohr's explanation. Not until 1919, five years after their first publication and eight years after their first attempt on their experiment, did Frank and Hertz start to accept Bohr's interpretation. They won the 1925 physics Nobel Prize because their experiment directly verified Bohr's hypothesis, which turned out to be Bohr's interpretation of their experimental results. Frank mentioned this five year long argument in his Nobel Prize lecture (Frank, 1925). The case of Frank and Hertz experiment clearly demonstrates that it is the argument, not the experiment itself that defines the meaning of experiments in the discourse of science.

Science should be taught in a way that reflects the nature of science (American Association for the

Advancement of Science, 1990; National Research Council, 1996). The central position of argument in science development has caused science education scholars to show an interest in the function of argumentation in the classroom. Based on their understanding of the history and philosophy of science, Driver, Newton and Osborne (2000) considered the importance of discursive practice to the construction of scientific knowledge. In addition, Osborne (2001) from a rhetorical perspective provides insights into the aims and purpose of science teaching and recommends the use of argument for students' deeper learning about science. He stated that:

A rhetorical characterization of the practice of science itself shows that argument is a central feature of the practice of science and that if developing epistemic goals and understandings about science within science education is important, the consideration of argument and reasoning should be a core feature of the practice of science education (p. 271).

The central position of argument in science development assures itself a place in classroom practice. However, this group of literature moves onto the investigation of the development of students' skills to construct scientific arguments (Osborne, Erduran, & Simon, 2004; Simon, Erduran, & Osborne, 2006), rather than considering how argument can be used in the process of conceptual change.

The use of argument in science education can well address the criticisms that Posner et al.'s model received. Effective learning is a self-regulated activity and a process of social construction. Like scientists, students need to expose their ideas to evidence and common regulations for judgment and be convinced before accepting any new ideas. As the word argument itself implies, it puts the teacher and students at the same power level. The aim of this new science teaching approach is to persuade rather than force students to appreciate scientific views. As the result of argument, students may prefer scientific views over their own concepts, or at least become a step closer to scientific views. In the discourse of argument, students are provided with opportunities to present and defend their ideas. Whatever ideas they bring up are significant to the classroom community. This process will make students feel respected and consequently be motivated to get involved.

Argument is a social process because it involves the dialogues between at least two sides. When argument is implemented in the classroom, it can happen between individuals or groups depending on the nature of learning tasks. For the simple topics, the in-class dialogue may work well enough. However, for those more complex topics, students can be divided into groups to build arguments collaboratively, after which they can share their ideas and discussions in a class

conference. In either case, the teacher is a facilitator as well as an “arguer” who represents scientific notions.

Argument can not only address the importance of motivation and collaboration in learning, but can also effectively incorporate metacognition, which is claimed to be important for conceptual change learning by Sinatra and Pintrich (2003) and Georghiades (2000). Paris and Winograd (1990) state: “any cognition that one might have relevant to knowledge and thinking might be classified as metacognition” (p. 19). Based on a review of many studies, Paris and Winograd conclude that students can enhance their academic learning and cognitive development “by becoming aware of their own thinking as they read, write, and solve problems in school” (p. 15). They also claim that “a teacher can promote this awareness directly by informing students about effective problem-solving strategies and discussing cognitive and motivational characteristics of thinking” (p. 15). This statement suggests that metacognition should be explicitly discussed in the classroom. Von Wright supports this claim by stating that “since reflective thinking and metacognitive strategies do not automatically develop in learners, learning activities need to be structured so that they teach and support the use of metacognitive skills” (1992, p. 60).

Argument is a process that can implement the teaching of metacognition skills and metaknowledge. Toulmin (2003) believes that no argument can be fruitful without a given set of conventions or criteria that are accepted by all arguers. In science, criteria implemented by scientists such as logic consistence, testability, predictive power, explanatory coherence, and so on should be explicitly addressed to students. In the discourse of argument, these common criteria for evaluating hypotheses or knowledge claims are applied, discussed, and reinforced. This kind of meta-knowledge is valuable for students to initiate, coordinate, and control their processes of learning science and understand issues about science. In other words, students with this knowledge are more likely to become an intentional learner defined as “one who uses knowledge and beliefs to engage in internally initiated, goal-directed action, in the service of knowledge or skills acquisition” (Sinatra & Pintrich, 2003, p. 5).

Argument Approach for Conceptual Change

An argument deals with disagreements. Students’ preconceptions are in most cases different from scientific notions and there often exist disagreements among students as well. These differences provide an

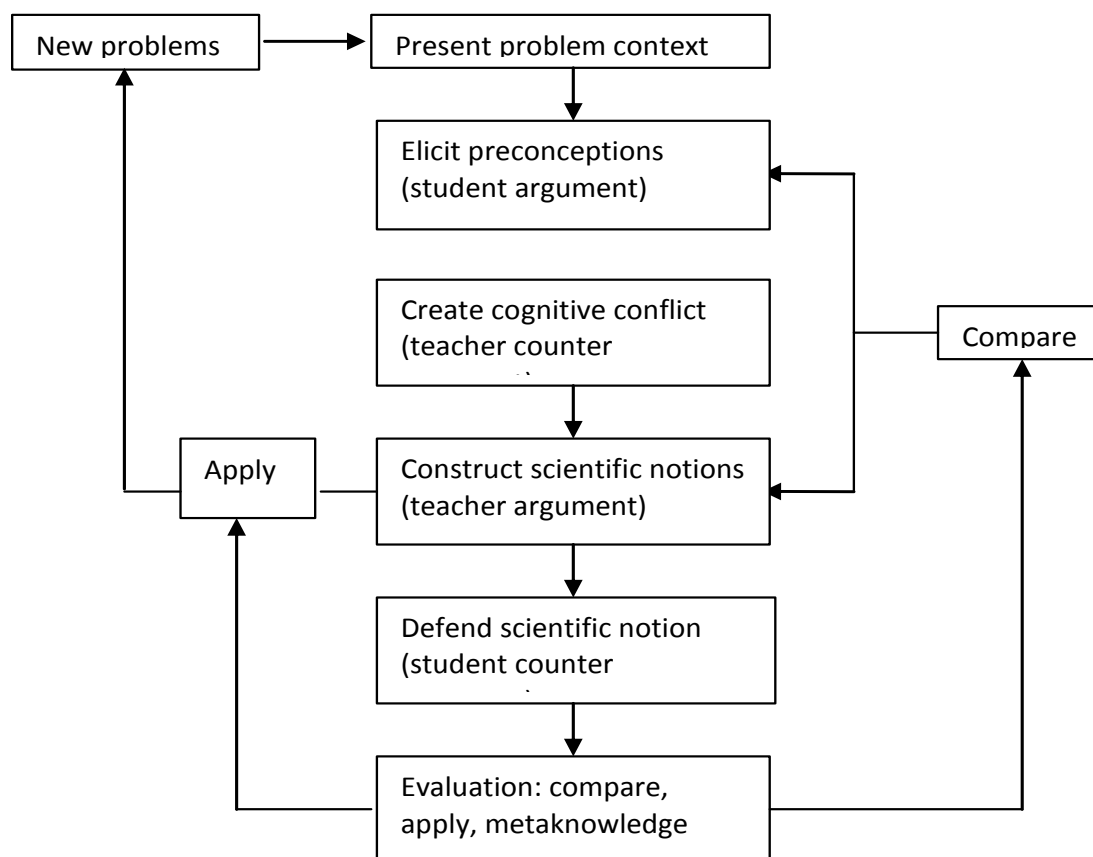


Figure 1: The argument approach to teaching science.

opportunity for arguments to occur in the classroom. An argument is a recursive journey. It takes time for arguers to understand each other's point and justification. Arguers explain, testify, defend, and convince opponents to accept their ideas, while at the same time, they should remain open minded and try to understand the stand of opponents and be always ready to modify and change their own points. Taking the norm of argument into science teaching for conceptual change, I propose the following instructional process (Figure 1).

Present problem context: An argument starts with a problem or question (Toulmin, 2003). The formats of problem can be diverse. The teacher can ask students to interpret phenomena or to watch a demonstration with their predictions in mind. The choice of this introductory activity is very important. For example, when teaching Newton's 3rd law, we used to start with a demonstration: one bar magnet and one metal bar, sitting respectively on two small wooden pieces floating on the surface of water, move toward each other. The scientific conclusion is then inferred from this demonstration, followed by an application of the law to new contexts. This kind of scientific explanation-centered curriculum sequence places students in a passive position. In contrast to this way of presenting materials, the argument approach starts the instruction from where students are. It deliberately chooses an introductory activity that will make students' preconceptions surface out, for example, a light paper clip jumps onto a bar magnet sitting still on a table.

Elicit student ideas: Students are asked to predict the result of experiments or interpret the phenomena. For the example of Newton's 3rd law, students are asked to think whether the paper clip exerts any force on the magnet. Students can work individually first, then are encouraged to share their thinking with partners. It is expected that this discussion can help students clearly recognize their predications, interpretations, and justifications. Through joining in student discussion and listening to their oral report of group discussion, the teacher gets to know the data and warrants students use for their arguments. The importance of this step has been documented by science educators (Champagne et al., 1985; Hewson & Hewson, 1988).

Create cognitive conflict: After the previous step, students become clear about their own ideas and begin to wonder about the different ideas their classmates may have. At this step well designed experiments are performed and their results are quite often different from students' predictions. For the example of the 3rd law, the abovementioned experiment (a bar magnet and a piece of metal move toward each other on the surface of water) can be used at this stage. The existing literature about conceptual change pedagogy often suggests that this is the time for the teacher to air the

scientific concept (Champagne, et al., 1985; Nussbaum & Novick, 1981). However, empirical studies have documented that students will not easily give up their arguments. They often think that something is wrong with the demonstration or experiment rather than questioning their own conceptions (Watson & Konicek, 1990). If the teacher is anxious to offer students scientific concepts for a replacement of students' concepts, he or she will fail to convince them. What the teacher needs to do is to respond to students' skepticism with new learning activities including experiments. In the case of interpreting phenomena, students' interpretations often have inconsistencies. Although their ideas work well for one phenomenon, it may not work for others. Pointing out these inconsistencies or limitation is a useful way to help students become dissatisfied with their own interpretations. Showing students that their ideas lead to obvious wrong deductions or their arguments leads to self-contradictions is a useful strategy to deal with students' unacceptable opinions.

Construct scientific notions: In this step, rather than telling students the scientific conception, as suggested by the current literature (Champagne et al., 1985; Nussbaum & Novick, 1981), the new model takes into account the recommendations from the plethora of studies on inquiry-based learning. Inquiry-based activities will be used to lead students to construct or invent scientific explanations. Quite often, the same events used to create cognitive conflicts provide a stage to construct scientific concepts as well. As a result of this engaging inquiry process, the new idea is more likely to be plausible and intelligible to students.

Defend the scientific notion: In a democratic classroom, students are likely to challenge scientific notions at this stage. For the example of the 3rd law, students may question the teacher why they did not see the magnet moved toward the paper clip if the action and reaction took place simultaneously. Or similarly, they will wonder why the truck is not damaged but the car is when these two vehicles have a head-on collision. The teacher needs to offer detailed discussion of these confusing phenomena and demonstrate how the scientific conception can apply to them. The focus of this step is to defend the scientific concept.

Evaluation: This step is a further effort to persuade students to appreciate the scientific ideas by comparing scientific notions with students' ideas and applying scientific notions to new problems where student preconceptions do not apply. Clear identification can help students to discover where they were wrong and to better understand scientific ideas. More applications can demonstrate the validity and fruitfulness of scientific ideas. Besides these, an analysis of the differences between personal knowing and scientific knowing may help students with metacognition. Generalizing the

scientific method reflected in a special case is also recommended at this stage.

Different from the current conceptual change pedagogy, the argument approach does not endorse a process of letting students choose between good and bad apples. It instead recommends a process that leads students to construct what good apples should be based on their dissatisfaction with the apple they originally had and evidence they gain from the inquiry experiences. Students become intentional learners who actively reconstruct their knowledge in a classroom-based social context, where both the new experiences and the conventions or argument criteria shared by the scientific community matter. The process of conceptual change is therefore an argument process of problem solving, with argument and counter argument taking place at each step.

As the reader may have realized, in this argument approach the teacher does two things: attempts to break down students' less acceptable ideas and establishes scientific notions among students. At first glance, the breaking down of students' conceptions appears to happen in the third step - creates cognitive conflict. In fact, this task continues through the whole process. We could not definitely say that one happens ahead of the other, just as breaking down an old theory and building a new one often happen concurrently in the history of science. The breaking down of preconceptions creates a need among students to establish new visions. The validity and fruitfulness of new ideas help students move away from their less acceptable ideas. The argument approach is a dynamic and dialectical process in terms of these two tasks. This dynamic process should be designed and organized by the teacher at a macro structural level, but be actually driven by the argument discourse between the teacher and students in terms of practical details.

Evidence from One Project

For many years, a group of science educators have been using computer applets to address students' preconceptions. One project the author participated in was called Modular Approach to Physics (MAP). The evaluation results of this project have been published elsewhere (Zhou, Brouwer, Nocente, & Martin, 2005). A summary is included here to provide support for the argument-based conceptual change pedagogy.

The MAP project featured a set of applets, each of which was developed as a small teaching and learning package to address one specific preconception in physics using the argument approach. Each applet normally included an explanation of how the argument process should take place to address the targeted preconception. Interactive computer simulations were developed to facilitate this argument process. For

example, to address students' misunderstanding of the projectile motion, the following simulation was built into one applet. The computer simulates the motion of a ball that has been shot upwards out of cannon. Students are prompted to draw a free body diagram on the screen to indicate the force(s) the ball experiences on its way up. Many students will include an upward force in their diagrams according to the literature (Clement, 1982). They believe that the initial force the cannon applied on the ball will stay with the ball and keep it moving upwards. After students input their ideas (drawing a force diagram on the screen using a



Figure 2. The darker ball represents the consequence of student's predictions and the ghost one represents the reality.

computer mouse), the computer will generate a virtual motion based on these inputs. The virtual process takes place on the screen alongside the realistic one (Figure 2). This ability for students to visually compare the consequence of their predictions with the realistic process can be helpful in creating cognitive conflict and facilitating conceptual change. Traditional laboratory experiments are unable to give students this ability to see the results of their predictions as easily because they often do not match the reality. The applet allows students individually or in groups to make a number of different choices, but only the correct choices will duplicate the realistic motion.

The project was evaluated through an experimental design. Pre and post conceptual understanding tests were administered to the control and treatment classes. Participating students and teachers were observed and interviewed to gain in-depth understanding of their use and perspectives of the applets. Test results demonstrated that the treatment classes, which used the applets, outperformed the control classes. It is even more interesting to notice the different results among the treatment classes. Some treatment classes were taught by teachers who received training in using the applets and as a result closely followed the embedded argument approach of teaching. These teachers used the applet in the stage of knowledge construction. Other treatment classes were taught by teachers who did not receive training and the applets were often used at the stage of knowledge application to verify what had been lectured to students. The treatment classes with a trained teacher did much better in the post-tests and reported much more positive experiences and perspectives with the use of applets than those treatment classes taught by an untrained teacher. In other words, we see evidence that the applets themselves have limitations in helping students change their preconceptions, and rather it is the argument-based pedagogy with technology assistance that really matters.

Concluding Remarks

This paper starts with a critique of a “cold” conceptual change model that overlooks irrational and social dimensions of learning. It then moves to a discussion about the need of “warm” models, which incorporate motivational constructs into our understanding of conceptual change as some educational psychologists suggested. It argues that argument is a central practice in the development of science. Teaching and learning science in a more authentic way, which brings argument into the classroom, has epistemological and pedagogical significance. Epistemologically speaking, the use of argument helps students to get dissatisfied with their preconception and become more open to scientific concepts. Pedagogically speaking, the use of argument will motivate students to become more engaged in the learning process and provide students with opportunities to learn how to respect and be respected in a community. Therefore, the argument model incorporates the contributions of science educators and educational psychologists to conceptual change pedagogy and has the potential to advance our understanding about this topic.

REFERENCES

- Ametller, J., Leach, J., & Scott, P. (2007). Using perspectives on subject learning to inform the design of subject teaching: An example from science education. *The Curriculum Journal*, 18(4), 479-492.
- American Association for the Advancement of Science (AAAS). (1990). *Science for all American*. NY: Oxford University Press.
- Ames, C. (1992). Classrooms: Goals, structures, and student motivation. *Journal of Education Psychology*, 84, 26-271.
- Andre, T., & Windschitl, M. (2003). Interest, epistemological belief, and intentional conceptual change, In G. M. Sinatra & P. R. Pintrich (Eds.), *Intentional conceptual change* (pp. 173-197). Mahwah, NJ: Lawrence Erlbaum.
- Bar, V., Zinn, B., & Rubin, E. (1997). Children's ideas about action at a distance. *International Journal of Science Education*, 19(10), 1137-1157.
- Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching*, 27(5), 415-427.
- Champagne, A. B., Gunstone, R. F., & Klopfer, L. E. (1985). Effecting changes in cognitive structures among physics students. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change*. Orlando, FL: Academic.
- Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics*, 50(1), 66-71.
- Dole, J. A., & Sinatra, G. M. (1998). Reconceptualizing change in the cognitive construction of knowledge. *Educational Psychologist*, 33(2/3), 109-128.
- Driver, R., & Erickson, G. (1983). Theories in action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education*, 10(1), 37-60.
- Driver, R., Guesne, E., & Tiberghien, A. (Eds.) (1985). *Children's ideas in science*. Milton Keynes: Open University Press.
- Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84, 287-312.
- Dweck, C. S., & Leggett, E. L. (1988). A social cognitive approach to motivation and personality. *Psychological Review*, 95(2), 256-273.
- Erickson, G. L. (1979). Children's conceptions of heat and temperature. *Science Education*, 63(2), 221-230.
- Erickson, G. L. (1980). Children's viewpoints of heat: A second look. *Science Education*, 64(3), 323-336.
- Frank, J. (1925). Noble Lecture: *Transformations of kinetic energy of free electrons into excitation energy of atoms by impacts*. Retrieved February 8, 2010 from <http://nobelprize.org/physics/laureates/1925/frank-lecture.pdf>
- Georghiades, P. (2000). Beyond conceptual change learning in science education: Focusing on transfer, durability and metacognition. *Educational Research*, 42(2), 119-139.
- Gilbert, J. K., & Watts, D. M. (1983). Concepts, misconceptions and alternative conceptions: Changing perspectives in science education. *Studies in Science Education*, 10(1), 61-98.
- Gregoire, M. (2003). Is it a challenge or a threat? A dual-process model of teachers' cognition and appraisal

- process during conceptual change. *Educational Psychology Review*, 15(2), 147-179.
- Helm, H. (1980). Misconceptions in physics amongst South African students. *Physics Education*, 15, 92-105.
- Hewson, P. W., & Hewson, M. G. (1988). An appropriate conception of teaching science: A view from studies of science learning. *Science Education*, 72(5), 597-614.
- Kuhn, D. (1993). Science as argument. *Science Education*, 77, 319-337.
- Kuhn, T. (1970). *The structure of scientific revolutions*. Chicago: Chicago University Press.
- Leont'ev, A. N. (1981). The problem of activity in psychology. In J. V. Wertsch (Ed.), *The concept of activity in soviet psychology* (37-71). Armonk, NY: Sharpe.
- McCloskey, M. (1983). Intuitive physics. *Scientific American*, 248, 114-122.
- Minstrell, J. (1985). Teaching for the development of ideas: Focus on moving objects. In C. W. Anderson (Ed.), *Observing science classrooms: Perspectives from research and practice. 1984 yearbook of the Association for the Education of Teachers in Science*. Columbus, OH: Eric Center for Science, Mathematics, and Environmental Education.
- National Research Council (NRC) (1996). *National science education standards*. Washington, DC: National Academy Press.
- Nolen, S. (1988). Reasons for studying: Motivational orientations and study strategies. *Cognition and Instruction*, 5, 269-287.
- Nolen, S. B. (1996). Why study? How reasons for learning influence strategy selection. *Educational Psychology Review*, 8(4), 335-355.
- Nussbaum, J., & Novick, S. (1981). Brainstorming in the classroom to invent a model: A case study. *School Science Review*, 62(221), 771-778.
- O'Donnell, A., & Dansereau, D. (1993). Learning from lectures: Effects of cooperative review. *Journal of Experimental Education*, 61(2), 116-125.
- Osborne, J. (2001). Promoting argument in the science classroom: A rhetorical perspective. *Canadian Journal of Science, Mathematics and Technology Education*, 1(3), 271-290.
- Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, 41(10), 994-1020.
- Osborne, R., & Freyberg, P. (1985). *Learning in science: The implications of children's science*. Auckland, NZ: Heinemann.
- Paris, S. G., & Winograd, P. (1990). How metacognition can promote academic learning and instruction. In B. F. Jones & L. Idol (Eds.), *Dimensions of thinking and cognitive instruction* (pp. 11-52). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Piaget, J. (1970). *Genetic epistemology*. New York: Columbia University Press.
- Piaget, J., & Inhelder, B. (1969). *The psychology of the child* (H. Weaver, Trans.). New York: Basic Books.
- Pintrich, P. R., & De Groot, E. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology*, 82, 33-40.
- 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*, 63(2): 167-99.
- 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(2), 211-227.
- Redish, E. F. & Steinberg, R. N. (1999). Teaching physics: Figuring out what works. *Physics Today*, 52, 24-30.
- Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education*, 28 (2-3), 235-260.
- Sinatra, G. M. (2005). The "warming trend" in conceptual change research: The legacy of Paul R. Pintrich. *Educational Psychologist*, 40(2), 107-115.
- Sinatra, G. M., & Pintrich, P. R. (2003). The role of intentions in conceptual change learning. In G. M. Sinatra & P. R. Pintrich (Eds.), *Intentional conceptual change* (pp. 1-18). Mahwah, NJ: Lawrence Erlbaum
- Smith, E. L., Blakeslee, T. D., & Anderson, C. W. (1993). Teaching strategies associated with conceptual change learning in science. *Journal of Research in Science Teaching*, 30(2), 111-126.
- Taber, K. S. (1998). An alternative conceptual framework from chemistry education. *International Journal of Science Education*, 20(5), 597-608.
- Tao, P-K, & Gunstone, R. F. (1999). Conceptual change in science through collaborative learning at the computer. *International Journal of Science Education*, 21(1), 39-57.
- Thagard, P. (1992). *Conceptual revolutions*. Princeton, NJ: Princeton University Press.
- Toulmin, S. E. (2003). *The uses of argument* (updated Ed.). Cambridge University Press.
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.). Cambridge, MA: Harvard University Press.
- Von Wright, J. (1992). Reflection on reflection. *Learning and Instruction*, 2, 59-68.
- Vosniadou, S. (2008). Conceptual change research: An introduction. In S. Vosniadou (Ed.) *International Handbook of Research on Conceptual Change* (pp. xiii-xxvi). Routledge.
- Vosniadou, S. (1999). Conceptual change research: State of the art and future directions. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New perspectives on conceptual change* (pp. 3-13). New York: Pergamon.
- Watson, B., & Konicek, R. (1990). Teaching for conceptual change: Confronting children's experience. *Phi Delta Kappan*, 71(9), 680-685.
- Wentzel, K. R. (1991). Social and academic goals at school: motivation and achievement in context. In M. L. Maehr & P. R. Pintrich (Eds.), *Advances in motivation and achievement* (Vol. 7, pp.185-212). Greenwich, CT: JAI.
- Zhou, G. Brouwer, W., Nocente, N., & Martin, B. (2005). Enhancing conceptual learning through computer-based applets: The effectiveness and implications. *Journal of Interactive Learning Research*, 16(1), 31-49.

