A General Overview of Conceptual Change Research

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> "If [student's] intuitions and misconceptions are ignored or dismissed out of hand, their original beliefs are likely to win out in the long run, even though they may give the test answers their teachers want." --R. A. Hodzi
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> "The student is not a *tabula rasa* (blank slate)." --Edward. F. Redish (and many others)

1. Misconceptions about Conceptual Change

It is important to understand that those who are involved in the conceptual change research domain are concerned about much more than simply altering a particular belief. If this were not the case, then it could be argued that conceptual change occurs every time someone changes his or her mind, or learns something new about a certain issue or fact. Let's say that I am walking across campus and I notice that clouds are moving overhead. It is not raining as I enter Wood Hall to go to my office. When I arrive at my office, Ozcan is there. He asks, "Is it raining outside?" I declare with bold confidence, "Not one drop of water is falling from the sky! It is completely dry!" Unbeknownst to me, however, storm clouds have begun to move over the campus even as I am speaking. Moments later, Uric arrives. I immediately notice that he is soaking wet. "What happened to you?" I ask. He responds, "It is raining so hard outside that you wouldn't believe it!" I am surprised, but I accept the evidence of his wet hair and clothing. I conclude that it is in fact raining, contrary to what I told Ozcan. My conception of current weather conditions has indeed changed, but this is not what is meant by the term *conceptual change*. Neither can it be said that conceptual change occurs every time a student learns something new in the classroom. It is fairly common, for example, for students to tell teachers that they learned something they never knew before. This can be quite exciting, and students may indeed be discovering, what to them, are new ideas. They may learn that warm air rises, that air moves from high to low pressure, that the sun's direct rays never get directly overhead in Kalamazoo, that gravity affects all objects equally, or that not all volcanoes are explosive in nature. However, simply altering a student's idea about some phenomenon is not what is meant by the term conceptual change.

One does not need to survey the literature for very long, however, before stumbling across examples of those who fail to recognize this. Bisard, *et al.* (1994), like most educators, want misconceptions about science to be reduced. They believe that altering ideas is a process that begins with instructors exposing the inadequacies of existing conceptions. Teachers, therefore, are encouraged to engage their students in a classroom discussion of science misconceptions. The incorrect concept must be "formally identified" as a common misconception before classroom discussions can be used to "… assist students in creating a state of cognitive dissonance in which students evaluate their faulty conception relative to the correct scientific concept… Through this process, students begin to construct a logical, coherent, and more important, realistic knowledge of science." Similar arguments are presented in other articles written by the co-authors (Nelson, *et. al.* 1992; Aron, *et. al.* 1994).

Phillips (1991) also believes that the exposure of misconceptions is essential to bringing about conceptual change. He suggests that providing teachers with a list of the misconceptions may help them begin this process in their students. He is concerned, however, that no such list is apparently available to help teachers know what should be addressed before presenting scientific explanations about the physical world. He therefore took it upon himself to research over ten years of material on scientific misconceptions in order to compile a list of sixty commonly held misconceptions in Earth Science. He also encouraged teachers to survey their own students for misconceptions. He argues that if teachers have adequate knowledge of the commonly held misconceptions, they will become motivated to eliminate them.

The above two examples should cause all science educators and teachers to ask several very important questions. Is it appropriate for teachers to formally identify their students' misconceptions, whether through a list or otherwise? Is this adequate? Will a state of cognitive dissonance truly be created in the minds of students when their current ideas are compared with the proper scientific conceptions? Will students begin to construct a logical, coherent, and "realistic" knowledge of science? Will they suddenly become motivated to actively confront their own misconceptions? Extensive research suggests that the answer to all of these questions is a great big resounding "No!" The next section will attempt to demonstrate this.

2. *The Tenacity of Alternative Conceptions*

It is easy to believe that the classroom is a setting where students replace naïve views of the world with scientific ones. In reality, however, instructors often fail to make even the slightest progress toward changing their students' conceptions. The tenacity of students' alternative conceptions is well documented and discussed in the literature. In fact, there is overall consensus among researchers that alternative conceptions about science are highly resistant to change (MacBeth 2000). Simply telling somebody something does not easily change his or her deep ideas (Redish 1994). One researcher went so far as to say that "…we cannot affect scientific understanding without grasping the depth and tenacity of the student's preexisting knowledge" (Cary 1986). This tenacity shows a remarkable consistency across diverse populations (Champagne 1982) and it persists even in the face of conventional instruction at both the grade school and university levels (Perkins 1991). It is frequently encountered with counter-intuitive phenomena such as those involving bodies in motion (Wandersee 1994) and with earth science phenomenon such as the shape of the earth, the earth as an object, and gravity (Klein 1982). In fact, attempts "… to 'teach to' what we thought to be student preconceptions have met with limited success" (Nersessian 1991). All of this suggests that the authors of the two articles discussed above (Bisard, *et. al.* 1994; Phillips 1991) have oversimplified the matter. While they do recognize that many misconceptions are so deeply ingrained in the minds of students that merely giving the "correct" scientific conception will not be adequate, they fail to understand that "formal identification" of misconceptions and related classroom discussions will generally not be very effective. I suggest that they, and others, have not fully realized how deeply rooted alternative conceptions are in the experiences and histories of learners. This is the topic of the next section.

3. The Origins of Alternative Conceptions

A survey of the alternative conceptions research demonstrates that the origins of misconceptions are difficult to discern. The evidence is often only inferential in nature, and the actual origins are often difficult to document, especially for those alternative conceptions that are derived from direct observation and perception where the primary data collected by researchers are self-reported statements provided by the subjects themselves (Wandersee 1994). Nonetheless, there is general evidence that pre-instructional knowledge structures have their origins in the following sources: (1) experiences and perceptions that extend as far back as early infancy, (2) a wide variety of cultural values and ideas, and (3) language factors.

Experiences and perceptions: Hawkins and Pea (1987) argue that children construct knowledge structures for scientific understanding on a "domain by domain basis" prior to formal instruction. It is therefore important to view children as active constructors of knowledge through their interactions with the physical world and their social and cultural environments. Even when they are only toddlers, children are actively engaged in asking for explanations and giving reasons about the way things are. A functional reason for developing these explanations is to gain "more predictive control" over the world. This allows the child to avoid undesirable events and to perpetuate desirable ones. The child learns what to expect by his own actions, by the actions of others, and by events in the physical world. In this way, children construct non-scientific understandings of natural phenomena as they are encountered, and they create frames for interpreting natural and social events. Further insights are provided by McClelland (1984):

> Phenomena are not the content of science but the vehicle for learning it, that is, for learning theories. Children in all societies meet a wide range of phenomena but a glance at history and anthropology is enough to remind us that interpretations in terms or reproducible, explicable, causally related events are not automatic features of human thought.

Pre-instructional understandings are therefore quite adequate to "interpret" and "guide" daily life (Driver, 1994), but may significantly hinder learning in the context of the science classroom.

Culture: Conceptions can also have their origin within the overall culture that students are participants in. Solomon (1987) states that the "social scene" makes an essential difference as to how a particular task is perceived in the learning environment. He therefore asks, "Do entirely personal ideas ever exist? When a child holds some private evaluation about a scientific happening, is it ever unaffected by culture?" Solomon argues that even if a student has a "truly eccentric" idea, this idea will probably will not survive for very long. Too different of a viewpoint from the accepted notion will generally be excluded from social intercourse, and many children may not have the ability to withstand this kind of pressure. The human desire to be accepted will cause many individual ideas to fade away. The chief effect of social interaction, therefore, is to "smooth out" differences within the culture and to produce consensus. This is not to say that change cannot take place; even majority views change with time. However, it is to say that the influence of the overall culture on students' understandings is incredibly powerful and cannot be ignored by instructors.

An example of how cultural influences can effect understanding is found in a study that examined folkbiological taxonomies among the Itzaj (a people native to the Americas) and among North American college students (Lopez 1997). Of special interest was the way that the Itzaj subjects categorized bats. While the American group tended to group bats with insectivores and rodents (thus preserving scientific formalisms to a significant degree), the Itzaj left them unaffiliated with any general category, or they classified them as birds. When asked, the Itzaj acknowledged that bats do indeed seem to more closely resemble shrews and small rodents. They did not classify them as mammals, however, because they "knew" that bats are birds! Cultural influences caused the Itzaj subjects to deem the relationship of bats to mammals as superficial. The influence of scientific understanding on the culture of the United States, however, helped the North American college students to avoid this stumbling block.

Language: Word meaning and usage can also be a significant source for alternative conceptions. An example of how this can happen is presented by Strike and Posner (1992). They describe a hypothetical learner named Fred who is asked to choose between two views of motion. Fred is asked to think about what will happen if a force is applied to a particular object. He is presented with two views:

(1) Force is transferred to the object and erodes, causing the object to gradually slow and eventually come to a rest.
(2) Application of force to the object imparts some motion to the object that continues indefinitely until it is acted upon by another force.

Fred is a baseball fan and he notes that there are numerous cases where forces are applied to baseballs. The subsequent motion of the balls leads him to accept the first view. This seems logical to Fred because he can detect no other forces being applied to the baseballs. Thus begins the "language game." Strike and Posner explain it in the following way:

> Fred may have learned to talk about force in a way that requires force to have an agent. Hitting balls with bats thus counts as applying force. Also, force-talk may be associated with fatigue. One's ability to apply force is limited by stamina. Or sometimes in ordinary speech force is associated with coercion. Normally, when people are coerced, they cease doing what they are coerced to do as soon as the coercion is withdrawn. Fred thus has ways of talking about force that lead to and reinforce a way of seeing. Fred thus decides that forces are transferred to objects and erode during motion.

This story may only be hypothetical, but it is a very realistic illustration. Indeed, studies involving both grade school and college level students have demonstrated that students often do not have the same definitions for scientific terms as those that are held by their instructors. For example, a general characterization of naïve knowledge of motion has been described as follows (Champagne 1983):

> (1) Concepts are poorly differentiated. For example, students use the terms *speed*, *velocity* and *acceleration* interchangeably. As a result, the typical student does not perceive any differences between two propositions such as these: (a) The speed of an object is proportional to the [net] force on the object; (b) The acceleration of an object is proportional to the [net] force on the object.
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> (2) Meanings physicists attribute to terms are different from the everyday meanings attributed to the terms by the students. For example, students generally define acceleration as speeding up, while physicists define acceleration as any change in velocity.

4. *The Focus of Conceptual Change Research*

In a previous section, I demonstrated why one who simply learns that it is raining outside (or that hot air rises, or that anything else happens for that matter!) has not necessarily undergone what researchers within the conceptual change domain consider to actually be *conceptual change*. It has been shown that ideas held by learners are rooted within a lifetime of experiences, perceptions, cultural influences, and language use, and cannot be easily overthrown. As such, it seems inadequate to attempt to change, idea by idea, the vast inventory of alternative conceptions. It is important to understand that conceptual change research is performed by people who are heavily involved in the science education system, and who are searching for solutions for its crucial problems and inadequacies (Anderson 1987). As such, the futile endeavor of altering the plethora of individual ideas is rejected. Instead, conceptual change researchers focus their attention on those concepts that are at the "core" of a system of concepts. It is more analogous to what Piaget calls an accommodation, or to what Kuhn calls a paradigm shift (Strike 1992). The next two paragraphs present a brief overview of both of these ideas.

Accommodation*:* Piaget's notion of an accommodation involves the replacement or reorganization of "central" concepts (Posner 1998). The easiest way to explain what is meant by this is to give a couple of examples. I will begin with a simple one (Millhoff 2002):

> Sometimes … old ways or existing schemes of dealing with the world simply don't work. Piaget used the term accommodation to describe this changing of an existing scheme to fit new objects. An example of accommodation would be the action of a young person who has always ridden a bicycle with pedal brakes but then gets on one with hand brakes. Accommodation of the existing "braking scheme" must occur for the bicyclist to be able to stop.

A more complex example from Piaget's own writings involves a four month and twenty-two day old infant named Laurent (Piaget 1952):

> Laurent … knows how to strike objects intentionally with his hand… [He] holds a stick; he does not know what to do with it and slowly passes it from hand to hand. The stick then happens to strike a toy hanging from the bassinet hood. Laurent, immediately interested by this unexpected result, keeps the stick raised in the same position, then brings it noticeably nearer to the toy. He strikes it a second time. Then he draws the stick back but moving it as little as possible as though trying to conserve the favorable position, then he brings it nearer to the toy, and so on, more and more rapidly… [The] child, intentionally and systematically, applies himself to rediscovering the conditions which lead him to this unexpected result.

Paradigm shift: Kuhn's notion of the paradigm involves concepts that are organizing in nature, and that adequately address contemporary research problems. In his book *The Structure of Scientific Revolution* (1970), Kuhn describes the history of science as a series of paradigm shifts. If the dominant paradigm of the time cannot adequately address contemporary problems, a new paradigm may arise and compete for acceptance. "Normal Science" therefore involves research that is firmly based on one or more scientific achievements that some particular scientific community acknowledges, for a time, as supplying the foundations for its future research and practices. However, even if the new paradigm proves better at problem solving, it is often met with resistance. Many scientists will adhere to the old paradigm until their deaths even if it means ignoring a tremendous amount of evidence. Copernicanism, for example, was not widely received by the scientific community until nearly a generation after Copernicus' death.

5. *Examples of Conceptual Change Research*

When a learner makes a conceptual leap that is analogous to an accommodation or paradigm shift, then one can say that *conceptual change* has finally taken place within that learner. It is around this notion that theories of conceptual change are designed. This section presents four very different, yet significant, theories involving conceptual change. I have chosen these particular theories because they are among the most significant in terms of my own understanding of conceptual change.

Posner and Strike: The theory of conceptual change presented by Posner and Strike, *et. al* (1982) is based on the accommodation of a scientific conception. Conceptual change involves the "…alternation of conceptions that are in some way central and organizing in thought and learning." Most cased of altered belief do not fall into this category. A student, for example, who successfully rejects an Aristotelian view of motion in favor of Einstein's view of motion has undergone the kind of change that is being addressed by this theory. Several conditions are necessary for conceptual change to successfully take place. First, there must be dissatisfaction with current conceptions. Students will not alter the concepts that perform a central role in their thinking until they somehow find them inadequate. Second, the new conception must be intelligible and initially plausible. Students must be able to make sense of the new concept, and the new idea must be seen as a possible candidate for resolving inconsistencies in their belief systems. Third, the new conception must suggest the possibility of a fruitful research program. It is not enough to solve current problems. The new concept must also suggest ways to "approach the world" and "open new avenues."

The conditions discussed above are based on the assumptions that genuine learning takes place within the learner's *conceptual ecology*. A conceptual ecology is the conceptual context by which concepts are "understood and appraised" in the context of the concepts that are already possessed by students. This context includes several cognitive artifacts, including anomalies, analogies, metaphors, epistemological beliefs, metaphysical beliefs, knowledge from other areas of inquiry, and knowledge from other areas of competing conceptions. Teachers must take into account the fact that their students possess all of these artifacts, and that these artifacts may be both assets and liabilities to instruction. These artifacts may also be used by teachers in their instruction for the purpose of facilitating conceptual change.

This theory was later revised and clarified. Several modifications were provided (Strike, *et. al.* 1992). First, a learner's conceptual ecology was made larger than what was suggested by the original theory to include motives and goals not related to the epistemological factors suggested by the history and philosophy of science. For example, students may view a problem to be solved in the classroom as a means of getting a good grade, or as an academic exercise; thus, they may not view it as scientific inquiry. Second, the current conceptions held by students were originally viewed as simply being the objects on which a learner's conceptual ecology acts. The revised theory suggests that current conceptions are themselves actually *part* of the learner's conceptual ecology. For example, people are inclined to view the world in ways that are consistent with their conceptions. Misconceptions, therefore may lead them to misinterpret counter-examples that go against their perceptions. In short, people tend to find ways to make the counter-examples fit their current conceptions. Third, conceptions can exist in different modes of representation and articulateness. For example, a student may be more motivated to get a good grade and to do well in class then to actually learn science. This student may therefore focus on rote learning and not understand what is being memorized. This will affect the student's ability to judge other ideas, and may even lead to a perception that physics is merely an aggregation of arbitrary facts, which may in turn reinforce the student's dependence on rote learning. It is also possible that conceptions may not exist at all but may only appear to do so because, through the classroom environment or by research, they are generated *on the spot* by other elements of the learner's conceptual ecology.

diSessa and Sherin: diSessa and Sherin (1998) begin by outlining the "standard model of conceptual change" that is commonly used by most researchers within the conceptual change domain. As an example of the model, they present a version that is found in the work of Cary (1988). Cary begins by discussing the concept of the "novice/expert shift" as it relates to physics learning. For example, the belief that "there is no motion without a force" (novice misconception) should be replaced with "there is no acceleration without a force" (expert conception). This is a *relational* change among concepts, which is to say that concepts such as *force*, *motion*, and *acceleration* may not themselves change in the "move from novice to expert," but may simply be related in new ways. Cary also discusses the possible existence of more dramatic varieties of change related to "core" concepts of theories. Here, she draws upon the work of Kuhn (1970). A contrast is therefore presented between "more" and "less" dramatic varieties of change. If the "less dramatic" notion of change is accepted, it may be adequate to perceive students as simply acquiring new beliefs, or new relations among concepts such as *force* and *mass*. However, if the "more dramatic" notion is accepted, it is likely that students and instructors are not even talking about the same things when they say "force" and "mass." Cary calls the "more dramatic" variety of change "strong restructuring." It is this variety of change that is known as *conceptual change*. Other researchers use different language than Cary, but present similar images of the standard model. For example, Gentzer, *et. al.* (1997) differentiate between *belief revision*, *theory change*, and *conceptual change*:

> Belief revision is a change in facts. Theory change is a change in the global knowledge structure. Conceptual change, in some sense the most drastic, is a change in the fundamental concepts that compose the belief structure. Conceptual change thus requires at least locally nonalignable or incommensurable beliefs.

According to the standard model, the standard answer to the question "What changes in conceptual change?" is "concepts." This is where diSessa and Sherin diverge from other researchers. They reject the notion that it is "concepts" that change, and they state that it is necessary to replace the notion of "concept" with a "variety of more carefully defined theoretical constructs," called *coordinated classes.* They argue that there are problems with deciding what should count as a *concept*. The central problem lies in the fact that just because researchers can name a particular cognitive task (such as determining whether an object is alive), this does not say anything directly about how this task is accomplished. They continue:

> The temptation to assume that words or phrases correspond to concepts has other difficulties. Notably, there are tens of thousands of words. If every such is a concept, then the concept of concept almost certainly cannot do the work we need it to. That is, conceptual change (learning a new word) cannot separate difficult, deep learning from easy learning.

The authors argue that it is likely that knowing *force* is very different from knowing *dog*. Different types of reasoning may be needed for each. It is therefore easy to see why more than one theoretical construct may be needed. The issue may be one of how to understand conceptual change in each case. Even the notion of the prototype (Smith 1989) is rejected because they do not find it reasonable to understand concepts such as *number* according to some representation of a prototype. They ask, "Are all numbers represented by one prototype, or do we need a prototype for every number?"

This, then, brings us to the second part of their paper: the presentation of the notion of *coordinated classes*. Instead of stating that one does or does not have a particular concept, diSessa and Sherin describe specific ways in which a learner's concept behaves and does not behave like that of an expert's. Their model is therefore described partly in terms of performance. *Coordinated classes* are defined as classes of concepts important in science learning, and they are what are behind the learner's ability to "see" things. They are "systematically connected ways" of getting information. For example, the primary task for "seeing" *velocity* is to determine the amount (evident by the necessity of asking questions like "Is the velocity high or low?" and "Which has the highest velocity?"), while the primary task for "seeing" *bird* it to determine whether some entity actually *is* a bird. There are two main structural components of coordinated classes. The first is a *readout strategy*. The job of a coordinated class is to "penetrate the diversity and richness of varied situations to accomplish a reliable 'readout' of a particular class of information." In other words, a learner must choose the correct features from the current context that are related to the information that is required. Two different kinds of coordination are central to a readout: (1) *integration*, which is to say multiple observations need to be coordinated, and (2) *invariance*, which is to say that observations from different contexts must determine the same information. The second structural component of coordinated classes is the *causal net*. This is the "general class of knowledge and reasoning strategies that determine where or how some observations are related to the information at issue." They use the concept of force to illustrate the causal net:

> The existence of force "causes" acceleration, which is the essence of Newton's second law, the equation $F = ma$. (F denotes force; a denotes acceleration, and m denotes the mass of the object that is accelerating and on which the force acts.) So if you want to determine force, you can sometimes look first to determine acceleration. Conversely, the same equation allows you to determine effects from preconditions. If you happen to know the force, then you can determine the acceleration.

Clement, Brown, and Zietsman: Clement, *et. al.* (1989) begin with the assertion that even though preconceptions present strong barriers to the learning of physics, some of these preconceptions are in agreement with accepted physics theory and can be used to produce conceptual change in areas that are not. This leads to their hypothesis that not all preconceptions are misconceptions; some, in fact, are useable "anchoring conceptions." An *anchoring conception* is defined as an intuitive knowledge structure that is in general agreement with accepted physics theory. By intuitive, the authors mean that the concept is self-evaluated, and that it is determined by the subjects themselves rather than by an authority. The focus of their study, therefore, is to identify such intuitions and to explore their potential for use in instruction. The authors argue that it is important to ground new material in that portion of students' intuition that is in agreement with accepted scientific theory. An example of how this can take place relates to the notion of upward force. Students often have great difficulty believing that a table exerts an upward force on a coffee cup; however, they have little trouble believing that a spring exerts an upward force on the human hand. Therefore, the authors argue that intuitions about springs can be built on as an anchor. In other words, the student should be able to transfer a central idea from an anchor, in this case "the applied force causing deformation causing a reaction force" is transferred from the "spring on the hand" to the "static object."

A diagnostic test was used to search for anchoring examples in the following areas: (1) *force from static objects*, (2) *Newton's third law in dynamic situations*, and (3) *frictional forces*. The subjects were chosen from three western Massachusetts high schools. None of the subjects had taken physics, but were enrolled in chemistry, biology, or general science. The diagnostic test contained fourteen multiple choice questions, some with multiple parts. After responding to each question, subjects were asked to indicate their confidence on a scale ranging from "0" ("just a blind guess") to "3" ("I know I'm right"). Anchors for individuals were determined if the correct answer was given by a subject who stated a confidence level of "2" or more. The authors argue, however, that these anchors are only *potential anchors* because not all anchoring examples can effectively be used in instruction "via transfer." A *usable anchor* is one in which the central idea was found to be effective in instruction; in other words, the anchoring conception could effectively be transferred to more difficult target situations. *Group anchors* are considered to be those that have strong potential for instruction, and were identified by the percentage of subjects who correctly answered a particular problem with a confidence level of "2" or higher. This percentage is referred to as a *belief score*, and a belief score of 70% or higher was considered to be a group anchor.

The authors discerned several potential anchors (such as the idea that the spring exerts an upward force on the human hand when the spring is pressed down and the hand is held still), but also discovered that some of the anchors were *brittle*. The idea of a brittle anchor can best be explained with the following example: 96% of subjects correctly stated that identical carts pushed apart by a spring would move away from each other at the same speed (the belief score was 83%), but only 32% stated that they would move away from each other at the same speed in a slightly asymmetrical situation in which the spring was attached to only one of the carts (the belief score was 23%). A small modification to the problem changed the students' intuitions about it! The authors therefore argue that "…we may not be able ontologically to extend anchoring examples such as symmetrical cart situations in attempts to help students overcome the misconceptions represented in the asymmetrical problem." The authors therefore give the following remark of caution: "The situations in this study that were predicted to be anchors, but which turned out not to be, indicate that examples which teachers and curriculum developers take for granted as 'obvious' and helpful may be seen differently by students."

Chi, Slotta, and deLeeuw: Another excellent theory is presented by Chi, *et. al* (1994) who discuss conceptual change in terms of ontological categories. Conceptual change occurs when the ontological category to which a particular concept is assigned changes. For example, when a student who has always viewed a whale as being a fish suddenly begins to see the whale as being a mammal, that student has undergone conceptual change. Entities may be viewed as belonging to different ontological categories, or *trees*. These categories include MATTER (THINGS), PROCESSES, and MENTAL STATES. There are also sub-categories embedded within the trees. For example, PROCESSES can be broken down into events, procedures, and constraint-based interactions; MATTER can be broken down into natural kinds and artifacts. The "crux" of Chi's notion of conceptual change is therefore the re-assignment of a concept from its initial tree to a different tree. Many scientific concepts belong within the constraint-based interactions sub-category of the PROCESSES tree. For example, electrical current is not MATTER, but a PROCESS. A field fills all space, but an electric current exists only when a charged particle is introduced into the field. Other examples of scientific concepts that are not MATTER-based include force, light, and heat. The reason that students have so much trouble understanding scientific concepts such as force, heat, light, and electricity is because these concepts are all perceived as being MATTER rather than PROCESSES. Students believe that force has "oomph" or that gravity is "in the earth." The key, then, to helping students gain genuine scientific understanding does not lie in simply trying to formally identify misconceptions and confront them with the "correct" scientific ideas; rather, educators and teachers must look at the ontological categories that students are using to organize their ideas.

Their theory can be illustrated using a simple example from my own experiences. My grade school and college science and physics teachers tried to present the concepts of potential and kinetic energy by using the example of a large rock sitting at the top of a hill. The rock has potential energy while it is sitting at the top of that hill, but kinetic energy when it is pushed down the hill. The potential energy becomes zero when it reaches the base of the hill. However, if the land in front of the rock were to suddenly be blasted away with explosives, and a new hill—with a similar slope to the one the rock just rolled down—were to be created, it could then be said that the rock once again has potential energy—similar, in fact, to what it had at the top of the first hill. I was never able to grasp this, even at the college level. While I would write on tests that this was the case, I mentally rejected the "existence" of potential and kinetic energy. From my point of view, teachers were telling me that potential energy had somehow mysteriously (and without explanation) "oozed" into the rock after the second hill was created by the explosives. This, of course, made no logical sense to me. I was unable to understand because I lacked the foundational ideas (whether paradigmatic or ontological) that would enable me to organize my learning in such a way that would allow me to grasp the specific concepts of potential energy and kinetic energy. I viewed energy within a paradigm that all natural phenomena could be explained in terms of matter. It was only after I understood that these concepts were PROCESSES (or, as some may prefer, "energy-based") rather than MATTER-based that I was able to make the "leap" to a proper scientific understanding. This, by the way, did not occur until my first year in a Ph.D. program!

6. Summary and Implications of Conceptual Change Research

What follows is essentially is a summary, in the context of specific questions, of how the research presented above has influenced my own point of view.

How does conceptual change take place? Conceptual change only occurs when students have begun to view the world and develop frameworks of knowledge based on "core" concepts that are scientific in nature. This position stands in opposition to the following inadequate but popular ideas about how misconceptions may be altered: (1) the extinction of old conceptions and their replacement with new conceptions, (2) the addition of new ideas, and (3) the rearrangement of ideas. Most science educators, if not all, want to see naïve conceptions exterminated and replaced with conceptions that are more scientific in nature. However, simply attempting to exterminate an old idea by replacing it with a new one is rarely effective because it fails to take into consideration the incredible tenacity of students' pre-instructional conceptions (MacBeth 2000, Cary 1986, Champagne 1982, Perkins 1991, Wandersee 1994, Klein 1982, Nersessian 1991, Redish 1994). Simply adding ideas to existing ideas is also inadequate. This was demonstrated in the opening paragraph of this paper. Knowledge that I gained from Urich may have changed my conception about current weather conditions, but it did nothing to alter my overall understanding of the atmosphere or meteorology. The simple rearrangement of ideas was also shown to be insufficient by Cary (1988) who clearly distinguished *relational change among concepts* from conceptual change. Without the emphasis on "core" concepts, one can never be sure that a student and a scientist even mean the same things when they use words such as *force*, *motion*, and *acceleration*.

What is the nature of conceptual change? Is conceptual change a "cold, rational" process, or is it "warm, irrational, and fuzzy?" The work of Posner and Strike suggests that it may be a combination of the two. On the one hand, all learners possess a conceptual context, or ecology, by which they understand and appraise concepts in the context of other concepts that they already possess. These ecologies include such artifacts as anomalies, analogies, metaphors, epistemological beliefs, metaphysical beliefs, knowledge from other areas of inquiry, and knowledge from other areas of competing conceptions. This suggests that conceptual change is very rational in nature. However, later revisions to their theory point out that there are artifacts in a learner's conceptual ecology that are not rational in nature. Some students, for example, may simply want a good grade, or they may see a particular task as an academic exercise rather than as scientific inquiry. This suggests that, when considering conceptual change, one must look beyond only taking into account rational considerations to a wider range of student motives and goals.

What role does the uniqueness of each student play? Does conceptual change follow definite pathways or multiple pathways? The evidence presented in this paper suggests that it will follow multiple pathways. Every student comes into the classroom with his/her own unique experiences and perceptions (Hawkins, *et. al.* 1987). This is not to ignore cultural influences common to most or all (McClelland 1984, Lopez 1997), but it is to say that no two students will have all of the exact same perceptions about the world. Instructors must therefore take the time to get to know their students individually. This, however, only seems possible in small classroom settings. Large college lecture halls of 100 students or more do not seem to be conducive environments for conceptual change. Instructors in this sort of setting are often, if not always, confined to merely presenting an overview of the "facts" of science and have little opportunity to deal with any of the concerns that have been addressed by this paper.

How will an emphasis on conceptual change affect content coverage? If instructors are to become involved in what this paper is advocating, a shift away from emphasizing detailed coverage is necessitated. Instructors must focus more broadly on "core" ideas related to the nature of science, or, in other words, on the paradigms that govern current scientific research. Details should be minimized in favor of a broader presentation of the "big ideas" of science. Simply memorizing numerous facts, laws, principles, formulas, and concepts does little to produce a genuine understanding of science. Science instructors often delude themselves into thinking so because students are usually able to "regurgitate" on a test what they have been told. Simply repeating information, however, should not be seen as evidence that students understand the material at a level where they can "make sense" of science. Consider, for example, "the dead leaves model" that students often use as a means for "learning" physics (Redish, 1994):

(a) Write down every equation and law the teacher puts on the board that is also in the book.
(b) Memorize them, together with the list of formulas at the end of each chapter.
(c) Do enough homework and end of chapter problems to recognize which formula is to be applied to which problem.
(d) Pass the exam by selecting the correct formulas for the problem on the exam.
(e) Erase all information from your brain after the exam to make room for the next set of material.

The use of this model allows students to pass a physics course, but it says nothing about the genuine learning of physics. If science educators want their students to gain a genuine understanding, they must be willing to sacrifice their obsession with details.

How important is conceptual change? At the risk on minimizing everything that I have argued for thus far in this paper, I will confess that I have often asked myself, "How important is conceptual change *really*? Is it actually necessary for the average person to view reality as scientists do?" This is a difficult question to answer, and it is one that I am still wrestling with. The following example illustrates why this is an important question to ask. Let's consider a factory worker and family man named Rob. Rob has a college degree and understands the basic ideas of earth science, including the notion that the earth revolves around the sun. However, on a practical level, he still views the universe from an "earth-centered" paradigm. Rob works long hours on his job. When he drives home from work, it is usually around sunset. He drives west to get home and the sun is often in his eyes. He regularly finds himself thinking, "That sun is sure bright! I wish it would hurry up and set behind the horizon!" Rob does *not* think, "I wish the earth would speed up its rotation a bit!" He may have a proper mental representation of how scientists view the solar system, but it has little bearing on his life. His scientific understanding does not significantly alter the way that he performs his job, relates to his family, or lives his life. In fact, for many people, proper scientific ideas may not be essential to their lives. I would be lying, therefore, if I did not admit that I have questions about the significance of "science literacy for all." Nevertheless, I am not willing to take this as grounds for arguing that conceptual change and science literacy are entirely unimportant. This would be the other extreme. I believe that there are few things that have had a more profound effect on our world than science. Scientists have landed men on the moon and sent probes to other planets. They have solved environmental problems and cured diseases. Medical advances have prolonged the average human life expectancy of the human being, and meteorological forecasting has saved countless lives from perishing in hurricanes and tornadoes. This is only the tip of the iceberg of all that has been accomplished! It is for this reason that I have such a passion for science! I acknowledge that many people can function "just fine" for their entire lives without proper scientific conceptions, but the tremendous effect science has had on our world demonstrates that I should not be content with students being unable or unwilling to grasp the scientific way of viewing the world. Thus, conceptual change will remain a fundamental goal in my own teaching endeavors.

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