A LIVELY ELECTRONIC COMPENDIUM OF RESEARCH, NEWS, RESOURCES, AND OPINION

Astronomy Education Review

Volume 3, Mar 2004 - Oct 2004
Issue 1

Framework for Conceptual Change

by **Esther L. Zirbel**
Tufts University, Department of Physics and Astronomy
Received: 06/03/04, Revised: 08/05/04, Posted: 09/08/04

The Astronomy Education Review, Issue 1, Volume 3:62-76, 2004

Abstract

Students often enter introductory courses lacking a consistent conceptual framework about natural sciences, and after traditional instruction, many experience little change in conceptual understanding. This article analyzes the nature and origin of misconceptions and discusses how they are formed and where they come from. It explains why it is so difficult to change students' concepts. This article also reviews Posner et al.'s (1982) conceptual change model and elaborates how and under what conditions it can be employed to modify students' preexisting concepts. Various challenges of that conceptual change model are discussed. How to teach to provoke conceptual change is discussed in a further paper.

1. INTRODUCTION

It is generally accepted that students do not enter the classroom as a "blank slate" (Pinker 2003). They come to school with already-formed ideas on many topics, including how they view and interpret the world around them. Sometimes these views may be rather strange, even elaborate, but regardless of their content, these views tend to be highly resistant to change. In fact, some researchers have found that individuals whose ideas conflict with new information might disregard or discount the new information in favor of their existing beliefs, and may even end up defending those beliefs.

Although learning the unfamiliar and conceptually understanding the subject matter already provide a formidable challenge, "unlearning" misconceptions is significantly more difficult, as will become evident in this article. If we understand how to change students' concepts, we might understand how students form concepts in the first place. This article focuses on the origin of misconceptions and suggests how to provoke conceptual change. This focus provides us with valuable clues about how students think, learn, and build ("construct") their own concepts (the main focus of Zirbel, "Learning and Concept Formation," forthcoming). How to teach to provoke conceptual change is discussed in "Teaching for Conceptual Change" (Zirbel, forthcoming).

2. THE NATURE OF CONCEPTS AND MISCONCEPTIONS

2.1 What Are Concepts?

Concepts are like mental representations that, in their simplest form, can be expressed by a single word, such as plant or animal, alive or dead, table or chair, apple or orange (e.g., Carey 2000). Concepts may also represent a set of ideas that can be described in a few words. Through the use of language, individual concepts can be connected to build more complex representational structures, such as "babies crawl" or "birds fly." At other times, two concepts can be combined to form a third representational structure. An example of the latter is density, which is the matter per volume (i.e., a concept that stands by itself but is a product of two other concepts). Through the use of language, we can thus create new concepts that stand by themselves. More complex concepts can describe a whole idea, such as the theory of natural selection. Similarly, through the use of math, we can build somewhat more abstract theories that end up representing one idea, such as the Big Bang model of the Universe. In other words, within a particular representational structure, concepts help us make deductions and explain even more complex ideas. Concepts can thus act like building blocks of more complex or even abstract representations. Outside a particular conceptual framework, concepts then seem to pick out entities in the world that fall under them, somewhat like ontological categories.

Core concepts are those building blocks of knowledge upon which we base other knowledge that we might acquire as we learn about the world around us. As such, a core concept is one that we are born with, available within our genetic fabric, so to speak. Although no real model for core concepts seems to exist, describing the nature of full-blown complex concepts is equally challenging. One possibility suggested by diSessa (1993) is that knowledge comes in the form of small fragments, which he called phenomenological primitives, or "p-prims." These p-prims combine to form individual concepts. Another view often shared by behavioral scientists is the notion of ontological categories (as suggested by Chi & Slotta 1993; Chi 1997; and Johnson & Southerland 2000). In this view, each concept is classified into individual categories of living versus dead (or alive versus object), plant versus animal, and so on, similar to the genetic tree in biology. Core concepts in Chi’s picture are the most fundamental distinctions that we learn to make at the youngest ages. P-prims, on the other hand, are the basic building blocks of more complex concepts.

2.2 What Are Misconceptions?

What are misconceptions? In its simplest form, a misconception is a concept that is not in agreement with our current understanding of natural science. Often, these can be private versions of a student’s understanding of particular concepts that have not been tested scientifically, or premature beliefs that do not stand the test of scientific analysis or that have not been exposed it.

Our current understanding of phenomena in the Universe has changed as we have learned more; thus, a concept once considered scientifically correct may become a misconception. For example, the geocentric model survived for 2,000 years. Actually, the term misconception might not be totally appropriate in this case. In the science education literature, many other terms have been proposed: naïve beliefs, preconceptions, private versions of science, personal models of reality, persistent pitfalls, preinstructional ideas, unfounded beliefs, and even mistakes (Wandersee, Mintzes, & Novak 1994). All of these words imply that there is something seriously wrong. After substantial analysis, we know of right and wrong answers in science. But there are also many contemporary debates among scientists; who is to say that one is right? Thus, it seems that the notion of goodness of fit with known data would be a better characterization. The data used to support the Earth-centered idea are not the same data that support a heliocentric concept. The geocentric model is wrong, but it is far beyond arbitrary or trivial. A model that is so elaborate and more complicated than the heliocentric model--and above all, a model that was backed by intellectual giants like Aristotle and Ptolemy--deserves a better term. It should be regarded as an alternate hypothesis to the currently accepted model; calling it an alternate conception does this model much more justice. Although, generally speaking, an alternate concept may not be in agreement with our understanding of science, it might have varying degrees of logic and truth to it--and for the student, that concept may be rather real and sometimes very complex. Thus, an alternate concept is part of the student’s private knowledge that is not consensual. On the other hand, an alternate concept could be associated with the student’s current understanding of the truth of the situation based on the facts available to the student at that time. In other words, it could be the best solution, or perhaps even a personal sophisticated model, that is available to the student at his or her current understanding of the situation. As such, it could be viewed as a yet immature understanding of a complex problem.

3. THE ROOTS OF ALTERNATE CONCEPTIONS

Where do alternate conceptions come from? Much of how we form concepts, both alternate concepts and scientifically correct ones, depends on the learner’s prior epistemology--how the learner accumulates information, organizes it, and consequently constructs personal views. Much of the alternate conception literature, therefore, is an outgrowth of constructivist thinking in which knowledge acquisition is viewed as a constructive process that involves more or less actively generating and testing alternate propositions. This section discusses how initial misconceptions, or alternate concepts, may be formed and constructed within the student’s mind.

3.1 Innate Knowledge

Where do misconceptions come from? Determining the degree to which we have learned specific concepts and the degree to which specific concepts may be innate is rather tricky (see, for example, Chomsky 1985; Carey 2004; Carey & Spelke 1996). Several studies have focused on determining what newborns can do and what they know. For example, it appears that babies have an innate ability to learn languages (e.g., Chomsky; Pinker 1998). Furthermore, some type of common sense reasoning seems to be a factor. For example, in a study about misconceptions in cosmology, Prather, Slater, & Offerdahl (2003) found that most students believed that there was preexisting matter before the Big Bang because "you can’t make something from nothing." What is the nature of a concept like this? And where does the intuition that you cannot make something out of nothing come from? Is this genetic wisdom? Is it based on experience? What is the experience of nothing? What is the most fundamental concept of this statement?

In some cases, it is clear that we have picked up these types of wisdom from more educated people or the media. For example, nowadays, children are often exposed to space pictures of the Earth and told that the Earth is round. Because they are most often told so by a trusted source, they will believe (i.e., regurgitate) that the Earth is round. However, when quizzed, primary school children will respond that the Earth they live on is flat, and the Earth in space is round. In this case, they have not yet made the connection that the Earth they live on is the same as the planet in space (e.g., Sneider & Ohadi 1998). But as they grow older, many make that connection and correct their views. The point is that some factual knowledge may be picked up through more or less trusted sources, but then one may wonder where the original flat Earth concept came from. Is that a core concept or is there another base for it, such as the baby's early "experience" of a flat floor?

What is interesting is that there are several core concepts that seem to be far more complicated than the flat Earth concepts. For example, birds know where to fly when the time is ripe. They are born with an innate mechanism by which they can tell that they need to fly, when they need to fly, and where they need to fly. Knowing where to fly is not an instinct, nor is it knowledge obtained from previous generations of birds (Carey 2004). So, what is the flat Earth concept? Could it be a core misconcept? The only argument against this is that it seems unlikely that nature infused us with innate misknowledge that is not important for human survival.

3.2 Personal Experience

Most students believe that understanding the world around them is a direct result of their observations and experiences. For example, in terms of gravity, we know that objects fall downward and do not ascend upward. One might argue, then, that concept formation depends on our perception of the external world and is coupled with personal experience and how we subsequently process that information.

In many cases, scientifically correct concepts are formed, but sometimes the observation itself might not be analyzed in enough detail. An example of a correct observation that led to an alternate conception was presented by Hynd et al. (1994). They discussed the students' concept of a projectile and claimed that when asked, some students recalled their observations of old World War II movies. The students reported seeing that a bomb dropped from a moving airplane travels backward from the point of the drop (it actually moves forward relative to the ground). However, origins of all misconceptions do not seem to be this straightforward, and often students might not even remember the origin of a particular idea.

The real process of concept formation is rather complex, but one can claim that there is a basis to the formation of concepts. It depends on what we perceive and experience, and on how we process that information. Concepts can then be viewed as a consequence of the process of observing and processing. This has the further implication that concept formation is not an isolated event, but a result of repeated observations coupled with how individuals construct their own views of the world from those observations. Although some concepts are based in personal experiences, "intuitive" responses seem to go somewhat deeper. They could be true core concepts or fabricated at a very deep level. It is well known that because of the frequency of the same observations, some people develop a type of intuitive understanding of a situation or concept. For example, most students will have driven a car and noticed that when they stop pressing the gas pedal (i.e., stop applying a force), the car slows down. Although they might know that there is friction that is responsible for slowing down the car, their personal experience is that in the absence of a force, the car will slow down. Because this experience is repeated every time a student drives, it is no surprise that the student develops an intuitive sense that a constant force results in motion.

3.3 Grounding Arguments and Dynamic Concepts

Not every observation registers consciously in a student's mind, especially if the observation is unimportant at the time. However, it is possible that some observations are remembered in retrospect. How the student proceeds to form a concept then depends on the complexity of thinking and previous conscious and unconscious observations. Premature or unfinished concepts might still be exposed to dynamic changes in the way of thinking.

Some alternate concepts are interesting, particularly if several individuals come up with comparable theories of how the Universe functions. For example, in Schneps & Sadler’s (1998) film *A Private Universe*, a substantial fraction of individuals seem to believe that the cause of the seasons is that the Sun is closer to us in summer than in winter. This might be because we all have some type of inherent common sense logic (or similar way of thinking about a concept) that leads to similar misinterpretations. After all, it does make sense that as we get closer to a heat source, it gets warmer. In this case, one of the common misconceptions about the seasons is caused by insufficient rigor in thinking through the situation from beginning to end. As such, this is a premature concept that makes sense to some degree but still requires more critical analysis. The common problem is that a half-understood concept might appear to look like a full-blown conceptual understanding of a situation, but only a fraction of it makes sense and it has not been exposed to thorough critical review. In other words, alternate conceptions may be unfinished concepts.

Alternatively (and this is dangerous from an educational perspective), an alternate concept might be grounded because of a misinterpreted instructional argument. For example, if the teacher or another trusted individual believes in an alternate conception or does not have an adequate understanding of the underlying scientific process, misconceptions might be installed easily in the students’ minds. Several studies have shown that some teachers can have inadequate understanding of the concepts of heat, temperature, force, and motion, and even about the reasons for the seasons. Many students believe that the cause of the seasons is that the Sun is closer to us in summer than in winter. Indeed, proximity and flux are correlated, and this argument makes sense if one considers that the students might have learned Kepler’s laws--specifically that the Earth’s orbit around the Sun is an ellipse with the Sun in one focus. In other words, if one is not careful, incomplete or misinterpretable instruction may support a preexisting (or maybe unfinished) misconception.

We all have our own notions of what common sense is: It is some type of thinking about the world around us that seems to be consistent with a series of observations and other concepts that we might have. When we consciously think about a concept and try to verify it in our minds, these concepts can get grounded regardless of whether they are correct. To the individual, it makes sense.

3.4 Aristotelian and Impetus Thinking

In science education literature, one often comes across the phrase *Aristotelian thinking*. Although some science educators refer to this term when specifically differentiating between Aristotelian and Newtonian physics, they more often use *Aristotelian thinking* to refer to simplistic ideas that have not been thought through sufficiently. Somehow, this does not do justice to Aristotle, whose models and arguments were sometimes rather elaborate and well thought out. In fact, if the students in class argued the way Aristotle did, they would certainly be arguing at an advanced level. The only critique that one might impose on Aristotle is that he did not use scientific methodology to experimentally prove some of his arguments. His arguments were by no means simple or naïve. To distinguish between incorrect but clever thinking and naïve, wrong, and insufficient thinking, some science educators use the phrase *impetus thinking* to refer to naïve and oversimplified ideas.

Several hundred papers have been written in the past 20 years on intuitive or Aristotelian ideas held by learners on the topic of simple mechanics alone (early, frequently cited publications are Vinnot 1979; Caramazza, McClosely, & Green 1980; Champagne, Klopfer, & Anderson 1980; Clement 1982; diSessa 1982; Gunstone & White 1981; McCloskey 1983; Watts 1983; McDermott 1984; and Halloun & Hestenes

1985). Among the propositions that students frequently embrace are the following (this is often referred to as the Force Concept Inventory): (1) when a force is applied to an object, it produces motion in the direction of the force; (2) under the influence of a constant force, objects move with constant velocity; (3) the velocity of an object is proportional to the magnitude of the force applied; and (4) in the absence of a force, objects are either at rest, or if moving, slowing down. Champagne et al. (1980) summarized this thus: "students have a rich accumulation of interrelated ideas that constitute a personal system of commonsense beliefs about motion." In fact, it turns out, as Trowbridge & McDermott (1981) found, fewer than 25% of in-service teachers and physics undergraduate students have a sufficient qualitative understanding of acceleration to be able to apply the concept to real-world situations. These problems have been summarized more recently by Wandersee et al. (1993) and McDermott & Redish (1999; see references therein).

Impetus thinking and Aristotelian thinking have one common dominator: They refer to how thinking in society as a whole has evolved. There is also an implicit assumption in this statement--namely that it is somewhat more natural to start simple and become more elaborate as we understand the world around us more completely. This argument can sometimes be taken even further. It can be hypothesized that students learn concepts in a manner similar to the way that society learns basic concepts.

It also turns out that a historical approach tends to be the least intimidating to students because they see the mistakes of humanity and of some famous individuals. This can make science less dry and more approachable, and make students more confident. For example, Duschl (1992) suggested that science instruction might benefit from a constructivist-historical approach in which students learn not only the justifications of modern scientific theories, but also how and why older theories where rejected, and how the nature of scientific inquiry changed within the discipline when the scientific community shifted from the old paradigm to the new. Other studies even went as far as to claim that the developmental stages in children (described by Piaget in 1929) can be simulated through historical parallels (e.g., Sneider & Ohadi 1977).

3.5 Astute and Bizarre Models

Another important point is that even though alternate conceptions can be erroneous and based on incomplete personal observation and inadequate analysis, they are not necessarily the result of a lack of reasoning ability. Sometimes when students present an immediate but unusual answer to a conceptual question, it becomes evident that they previously thought about that particular concept and reached an answer. Children often have interesting stories to tell. For example, my five-year-old niece claimed that the Moon is alive because its face changes shape. Sometimes it is surprising how long some children hold onto their beliefs and even refine those beliefs when inconsistencies appear at later times. However, it also appears that we lose the ability to naturally change our minds (e.g., Gardner 2004), and if some of those imaginative ideas are carried into adulthood, they may never change.

3.6 Emotionally Loaded Alternate Models

Sometimes individuals, especially when it comes to religious beliefs or very personal experiences, hold onto their beliefs no matter what. These individuals do not want to be convinced and can have emotional reasons that may be irrational. Sometimes it might even appear as if rational reasoning with these individuals has been short-circuited (see Zirbel, "Learning and Concept Formation"). Sometimes the only way that these individuals deal with inconsistencies is to disregard any other possible models, or just defend or insist on their world views. In this case, it might be a conscious choice of believing in a particular model (or faith), and it might be based on a decision made by the student at some point. Thus, changing personal belief systems, especially emotionally loaded ones, is one of the biggest challenges and most likely to fail, particularly if the student is unwilling to have an open mind about a concept.

4. THEORETICAL FRAMEWORK

4.1 The Conceptual Change Model (CCM)

4.1.1 Origin of the Conceptual Change Model

Students' conceptual ideas are based on personal experiences and require real changes in thinking and adjustments at the neural levels (see Zirbel, "Learning and Concept Formation"). Unfortunately, students often are not open to new ideas, in which case a radical approach is needed to change preexisting concepts. With this in mind, Posner et al. (1982) proposed the conceptual change theory, a combination of two theories: one from the history and sociology of science (Kuhn 1970), and one from developmental psychology (Piaget 1977). Kuhn's work, *The Structure of Scientific Revolutions*, describes how scientific discoveries by various individuals, coupled with historical crises, caused the scientific revolution that finally led to the new scientific methodologies and globally accepted world views. Posner et al. stated that they used Piaget's terms but did not borrow the concepts in total. Piaget's work, including his earlier works of 1950, 1951, and 1971, described how students learn through the assimilation and accommodation of knowledge. Posner et al. suggested that the conditions for the accommodation of new concepts are similar to Kuhn's conditions for the acceptance of a new scientific paradigm. In other words, the process of doing science that Kuhn typified as assimilation of scientific results within a paradigm is similar to the way that Piaget described how individuals acquire knowledge. Kuhn's paradigm shift caused by the scientific revolution can then be compared with the accommodation of new knowledge in an individual, which leads to a change of that individual's conceptual framework. Thus, using the words of Posner et al., assimilation refers to "the use of existing concepts to deal with new phenomena," and accommodation involves "replacing or reorganizing the learner's central conceptions." In that sense, accommodation signifies a radical change involving abandoning an existing conception and accepting a new one.

4.1.2 Conditions to Provoke a Conceptual Change

One of the common instructional strategies to foster conceptual change is to confront students with discrepant events that contradict their existing conceptions. This is intended to invoke a disequilibration (Piaget 1977), or conceptual conflict that induces students to reflect on their conceptions as they try to resolve the conflict. The students then must undergo the process of accepting, using, and integrating the new concepts into their lives and even apply them to new conditions. Posner et al. (1982) hypothesized that there are four essential conditions for conceptual change: (a) dissatisfaction with one's current conception, followed by the degree to which the new conception is deemed (b) intelligible, (c) plausible, and (d) fruitful. Although, over the past 20 years, the interpretations of these categories and the wording have changed slightly, the general framework still remains. The steps can then be summarized as follows:

1. **Dissatisfaction.** The learners must first realize that there are some inconsistencies and that their ways of thinking do not solve the problem at hand. Their concepts must be, in Kuhn's words, "awash in a sea of anomalies."

2. **Intelligibility.** Posner et al. (1982) argued that for a learner to accommodate a new conception, he or she must find it intelligible. The concept should not only make sense, but the learners should also be able to regurgitate the argument, and ideally be able to explain that concept to other classmates.
3. **Plausibility.** The new conception must be plausible for it to be accommodated. The new concept must make more sense than the old concept. It must have (or at least appear to have) the capacity to solve the problem. The learners should be able to decide on their own how this new concept fits into their ways of thinking, and recall incidences in which this concept could be applied.
4. **Fruitfulness.** For the new conception to be accommodated, the learners must find it fruitful in the sense that this concept should have the potential to be extended to other incidences and open up new areas of inquiry. In other words, the new concept should do more than merely solve the problem at hand; it should open up new areas of inquiry.

The practical side of these processes may have a variety of different facets and applications. Some refinements and varying approaches are presented in the next section.

4.1.3 Alternatives to the Original Conceptual Change Model

A decade after the publication of Posner et al.’s (1982) paper, the theory was revised because of an overemphasis on the rational aspects of learning, and effective and social issues for conceptual change were incorporated into the initial theory. Strike & Posner (1992) expanded on their theory and incorporated a wider range of factors necessary for inducing conceptual change. They introduced the notion that alternate concepts might not exist initially, but that they may be generated on the spot as a consequence of instruction. Furthermore, they pointed out that all parts of the conceptual ecology, including correct scientific conceptions and misconceptions, are "dynamic and in constant interaction and development."

Many other papers have been published since then, all of which describe and refine the conceptual change theory to some degree. Fensham, Gunstone, & White (1994) contended that conceptual change is rarely an abrupt change, but more often "an accretion of information and instances that the learner uses to sort out contexts in which it is profitable to use one form of explanation or another." They called this "conceptual addition" because old ideas are not abandoned, but revised incrementally. In a similar vein, Linder (1993) offered the idea of "conceptual fitting" and suggested that the learner has a range of conceptions that are invoked according to specific contexts. He argued that even scientists use different conceptions of the same science concept in different contexts (e.g., electric current is conceptualized as a flow of electrons in metal, ions in aqueous solutions, or holes in semiconductors), and the same could well be true for students. Maloney & Siegler (1993) extended this view and proposed the notion of conceptual competition, suggesting that competing conceptions coexist in the learner, and that after a prolonged period of learning, one achieves dominance. On the other hand, Mortimer (1995) proposed the idea of a conceptual profile, and suggested that it is important for students to become conscious of the alternative and scientific conceptions in the different zones of the profile without necessarily having to replace the former with the latter. Dykstra, Boyle, & Monarch (1992) asserted that conceptual change is a progressive process of refinement of students’ conceptions, and proposed a taxonomy of conceptual change consisting of differentiation, class extension, and reconceptualization. Similarly, Niedderer & Goldberg (1994) described conceptual change as a process of change from the learner’s prior conceptions to some intermediate conceptions, then to scientific conceptions.

4.1.4 Unsuccessful Conceptual Change

Conceptual change is only really successful if all individual stages of the initial theory are followed. However, this still does not imply that conceptual change really has to occur, even if all stages (and refined or additional stages) are followed, nor is the conceptual change model to be viewed as a teaching tool; it merely describes the process of conceptual change. In the literature, there is plenty of evidence of conceptual change failing to occur. Duit & Treagust (2003) found that students' conceptions after instruction still frequently turn out to be rather limited. Interestingly, there appears to be no study in the literature that shows that particular students' conceptions could be completely extinguished and replaced by a new scientific view (Duit 2002). Most studies show that the old ideas stay alive in particular contexts. Usually the best that can be achieved is a peripheral conceptual change (Chinn & Brewer 1993) in which parts of the initial idea merge with parts of the new idea to form a type of hybrid idea (Chinn & Brewer 1998).

Other studies have shown an even more negative approach to facilitating conceptual change. Hewson & Hewson (1983) explained that when students are confronted with conflicting data, rather than experience conceptual change, they discount the data, ignore it, or memorize it (compartmentalize it). In another study of the energy concept, Trumper (1997) found that students reacted to conceptual conflicts in several different ways that did not lead to conceptual change: (a) failure to recognize the conflict, (b) recognizing the conflict but avoiding resolution by passively relying on others, (c) resolving the conflict partially, and (d) resolving the conflict using alternative conceptions. McCloskey (1983), Maria & MacGinitie (1981), and Marshall (1989) claimed that some students disregard new information that might be in conflict with prior beliefs. Niaz (1995) found that some students "protected" their conceptions by ignoring the conceptual conflict. Chinn & Brewer (1993), in explaining what scientists themselves do with conflicting data, offered even more ways for scientists to "maintain" their existing perceptions. In other words, there are more avenues for maintaining ideas than for changing them. Often, the path of least resistance is maintenance. Tyson et al. (1997) claimed that conceptual change does not imply that initial conditions are "extinguished," and that some students might hold scientific conceptions and their old, powerful alternate conceptions concurrently. Gault (1986) and Blank (2000) found that students might even vehemently defend their previous beliefs more strongly than before.

4.1.5 Additional Condition: Openness to Conceptual Change

It seems that one of the most important aspects of the conceptual change theory involves the student--his or her willingness to listen and evaluate new ideas and methods, to let go of old beliefs, and to want to undergo conceptual change.

4.2 Beyond Conceptual Change

4.2.1 Owning versus Borrowing

Once the student has allowed himself or herself to be convinced that the new concept is intelligible and makes sense, and once he or she is convinced that the new concept provides a better solution to the problem, it does not stop there. Most educators want the student to go beyond just understanding a theory. Posner et al. (1982) suggested an additional step: that the theory has to be plausible for it to be accommodated, and that the new concept must make more sense than the old concept. It must have, or at least appear to have, the capacity to solve the problem that the previous conception could not. Posner et al. stated that the learners should be able to decide on their own how this new concept fits into their way of thinking, and to recall instances in which this concept could be applied. Afterward, the theory should be fruitful in the sense that this concept should have the potential to be extended to other instances and open up new areas of inquiry.

Here I would like to add a condition that again depends on the openness and willingness of the student to accept conceptual change. It is not sufficient to use a concept and apply it even to new situations, though it certainly requires thorough understanding of the theory. The student must make the concept his or her own. So far, the student has borrowed the theory and has been able to apply it, but even that does not mean that the student has necessarily undergone a definite shift in his or her way of thinking; he or she may still hold onto his or her prior conception while accepting and using the new one. In fact, it is very rare that a student will completely let go of his or her prior belief. The student might also have become convinced that the new theory does a better job explaining the concept and that it can be successfully applied to other situations, but the student might still not have let go of the old theory even though it does not work as well. It turns out that the prior and new theories often coexist as different entities. At this level, decisions are rather personal, and the student has to consciously decide to replace his or her old theory with the new one and discard the old theory. But even that is not enough; the student must become so familiar with the new theory that it starts to feel like his or her own theory. The student must make the transition from borrowing a theory to owning it. (This concept of borrowing versus owning was introduced by Schwarz & Fisher, 2003.)

4.2.2 Creative and Original Thinking

The final step in Posner et al.'s (1982) conceptual change theory is that the new concept must be successful in the sense that it can be applied to new situations and yield new results. Indeed, this is what we would like all of our students to be able to do; it proves a thorough understanding of the newly acquired concept. However, ideally we would like the student to go even further and apply it to new situations. Once the student owns the new theory, we would like him or her to be able to take the additional step of coming up with a new theory based on the newly acquired concept. In other words, the ultimate step is not only the transfer of knowledge, but also the ability to think creatively and to come up with new, original theories. The concept must be "chunked" and integrated into the student's knowledge database to the degree that the newly acquired concept is not the ultimate in thinking, but has become a building block for further thought. In fact, if this new building block can be used, it might, together with creative thinking, give rise to original and new theories.

5. SUMMARY AND CONCLUSION

As stated in the introduction, this article's focus is misconceptions. Understanding the origins of misconceptions provides us with valuable clues about how students think and learn, and how they build ("construct") their own concepts. Some questions were answered in this article, but many still remain. Concepts are mental representations roughly equivalent to a single word, such as plant, animal, alive, dead, heat, weight, or matter. Questions that remain are: What are the most fundamental representations of concepts? Exactly how do we construct more complicated concepts on top of the basic core concepts? What happens in our minds as we construct concepts? As we learn more about the world around us, we continually adjust our strategies and come up with new conclusions. So why is it so difficult to change one's concepts? In more general terms, how do we think and exactly how do we learn and build concepts?

Identifying the origin and the nature of concepts is rather tricky, and no clear theories of how this happens in the student's mind are available. Nevertheless, this article attempts to make a few claims about what conditions might affect the formation of more or less logically constructed concepts. Determining the origin of concepts is still a major puzzle, but there seems to be some evidence that core concepts might be inherent in human nature, in our genetic wisdom that we bring to life. We also seem to have an inherent ability to take in new information. Babies learn naturally from the day they are born. Though this is a natural process, the construction of concepts requires a complex combination and repeated evaluation of old and new observations, facts, and thoughts. This is a natural process of learning, and we do it every day.

Alternate concepts are particularly interesting to study because something in the way of constructing the arguments leads to inaccurate or insufficient knowledge. Pinpointing exactly where and under which conditions alternate concepts are formed might provide clues about how people construct concepts naturally. Looking for common dominators among classical misconceptions might shed light on this issue. It seems that alternate conceptions often parallel explanations offered by previous generations of scientists and philosophers; perhaps the historical development of concepts parallels the general learning process in students' minds. Though especially thought provoking, this is not the central issue of this article; rather, the focus is on understanding the nature and origin of concepts and how to provoke conceptual change.

We claim that there seems to be a base to alternate concepts. They are often the result of the students' personal observations and experiences. Frequent personal observations might result in "intuitive" knowledge. Concepts can become grounded in our minds when we use our own version of common sense arguing to construct what we might call "reality" (though not every prior concept has been thought through extensively, and many concepts might still be dynamic). Although alternate concepts might be built upon mistakes or due to a lack of knowledge and insufficient or inadequate thinking, they might also be the result of imaginative and very astute thinking. Changing personal belief systems, especially emotionally loaded ones, is one of the biggest challenges--and most likely doomed to fail, particularly if the student is unwilling to have an open mind about a particular concept.

Whether a student will undergo a conceptual change depends not only on the complexity of the concept itself, but also on the character and upbringing of the student--that is, it involves his or her personality, general cultural and personal belief systems, acquired and inherited intellect, ability to follow and think though arguments, and personal attitude toward undergoing conceptual change. All of these attributes contribute to each of the four (or five) distinct, continuous stages of the conceptual change model. Initially, the student must become dissatisfied with his or her own prior theory; this will involve letting go of his or her precious prior beliefs, some of which might be rather personal. The student must be able to logically follow and understand the new theory and find that it does a better job than his or her prior theory in explaining the situation in question (in the words of Posner et al., 1982, he or she needs to find the new theory "intelligible" and "plausible"). But that is not all; the student must find the new theory successful in the sense that he or she can apply it to other situations and solve new problems--and above all, the student must show a personal willingness to do so.

Acknowledgments

Thanks to Michael Beeth, Charles Whitney, Michael Connell, Candelario Saenz, and Jim Nathanson for comments that improved the quality of this article.

References

Blank, L. 2000, A Metacognitive Learning Cycle: A Better Warranty for Students' Understanding?, *Science Education*, 84(4), 486.

Caramazza, A., McClosely M., & Green B. 1980, Curvilinear Motion in the Absence of External Forces: Naïve Beliefs About the Motion of Objects, *Science*, 210, 1139.

Carey, S. 2000, Science Education as Conceptual Change, *Journal of Applied Developmental Psychology*, 21(1), 13.

Carey, S. 2004, Core Concepts [lecture title], Cognitive Development, Education, and the Brain [course title], Lecture given as part of HT100 at the Harvard Graduate School of Education, Cambridge, MA.

Carey, S., & Spelke, E. 1996, Science and Core Knowledge, *Philosophy of Science*, 63(4), 515.

Champagne, A., Klopfer, L., & Anderson J. 1980, Factors Influencing the Learning of Classical Mechanics, *American Journal of Physics*, 48, 1074.

Chi, M. T. H. 1997, Creativity: Shifting Across Ontological Categories Flexibly, in *Creative Thought: An Investigation of Conceptual Structures and Processes*, T. B. Ward, S. M. Smith, & J. Vais (Editors), Washington, DC: American Psychological Association, 209.

Chi, M. T. H., & Slotta, J. D. 1993, Ontological Coherence of Intuitive Physics, *Cognition and Instruction*, 10(2, 3), 249.

Chinn C. A., & Brewer W. F. 1998, Theories of Knowledge Acquisition, in *International Handbook of Science Education*, B. Fraser & K Tobin (Editors), Dortrecht, Netherlands: Kluwer Academic Publishers, 97.

Chinn C. A., & Brewer, W. F. 1993, The Role of Anomalous Data Knowledge Acquisition: A Theoretical Framework and Implication for Science Education, *Review of Educational Research*, 63, 1.

Chomsky, N. 1985, Knowledge of Language: Its Nature, Origins, and Use, Convergence Series, Westport, CT: Praeger.

Clement, J. 1982, Students' preconceptions in Introductory Mechanics, *American Journal of Physics*, 50, 66.

diSessa., A. A. 1982, Unlearning Aristotelian Physics: A Study of Knowledge Based Learning, *Cognitive Science*, 6, 37.

diSessa., A. A. 1993, Towards Epistemology in Physics, *Cognition and Instruction*, 10(2, 3), 105.

Duit R. 2002, Conceptual Change: Still a Powerful Frame for Improving Science Teaching and Learning?, Proceedings of the Third European Symposium on conceptual change, 26-28 June 2002, Turku, Finland, http://www.edu.utu.fi/konf/Proceedings.pdf.

Duit, R., & Treagust, D. 2003, Conceptual Change: A Powerful Framework for Improving Science Teaching and Learning, *International Journal of Science Education*, 25, 671.

Duschl, R. H. 1992, *Philosophy of Science, Cognitive Science and Educational Theory and Practice*, Albany: SUNY Press.

Dykstra, D. I., Boyle, C. F., & Monarch, I. A. 1992, Studying Conceptual Change in Learning Physics, *Science Education*, 76, 615.

Fensham, P. J., Gunstone, R. F., & White R. T. 1994, *The Content of Science: A Constructivist Approach to its Teaching and Learning*, London: Falmer.

Gardner, H. 2004, *Changing Minds*, Cambridge, MA: Harvard Business School Press.

Gault C. 1987, Student Beliefs and Cognitive Structure, *Research in Science Education*, 17, 87.

Gunstone R., & White R. 1981, Understanding Gravity, *Science Education*, 65, 291.

Halloun I. A., & Hestenes D. 1985, Common Sense Concepts about Motion, *American Journal of Physics*, 53, 1056.

Hewson M., & Hewson P. 1983, Effect of Instruction Using Students' Prior Knowledge and Conceptual Change Strategies in Science Learning, *Journal of Research in Science Teaching*, 20, 731.

Hynd, C. R., Alvermann, D. E., & Qian, G. 1994, Preservice Elementary School Teachers' Conceptual Change about Projectile Motion: Refutation Text, Demonstration, Affective Factors, and Relevance, *Science Education*, 81, 1.

Johnson, A. T., & Southerland, S. A. 2000, A Reconsideration of Science Misconceptions Using Ontological Categories, Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, April 2000, New Orleans, LA.

Kuhn, T. S. 1970, *The Structure of the Scientific Revolution* (2nd ed.), Chicago: University of Chicago Press.

Linder, C. J. 1993, A Challenge to Conceptual Change, *Science Education*, 77, 293.

Maloney, D. P., & Siegler, R. S. 1993, Conceptual Competition in Physics Learning, *International Journal of Science Education*, 15, 283.

McCloskey, M. 1983, Naïve Theories of Motion, in *Mental Models*, D. Gentner & A. Stevens (Editors), Hillsdale, NJ: Erlbaum, 299.

McDermot, L. C., & Redish E. F. 1999, Resource Letter: Physics Education Research, *American Journal of Physics*, 67, 755.

McDermott, L. 1984, Research on Conceptual Understanding in Mechanics, *Physics Today*, 37, 24.

Mortimer, E. F. 1995, Conceptual Change of Conceptual Profile Change?, *Science and Education*, 4, 267.

Niaz, M. 1995, Cognitive Conflict as a Teaching Strategy in Solving Chemistry Problems: A Dialectic-Constructivist Perspective, *Journal of Research in Science Teaching*, 32, 959.

Niedderer, H., & Goldberg F. 1994, An Individual Student's Learning Process in Electric Circuits, Paper presented at the NARST 1994 annual meeting, April 1994, Anaheim, CA.

Piaget, J. 1950, *The Psychology of Intelligence*, M. Piercy & D. Berlyne (Translators), London: Routledge & Kegan Paul (original published 1947).

Piaget, J. 1951, *The Origin of Intelligence in Children*, M. Cook (Translator), New York: International Universities Press.

Piaget, J. 1971, *Biology and Knowledge*, B. Walsch (Translator), Chicago: University of Chicago Press (original published 1967).

Piaget, J. 1977, *Equilibration of Cognitive Structures*, New York: Viking Press.

Pinker, S. 1998, *The Language Instinct: How the Mind Creates Language*, New York: Harper.

Pinker, S. 2003, *The Blank Slate: Modern Denial of Human Nature*, New York: Penguin.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. 1982, Accommodation of Scientific Conception: Towards a Theory of Conceptual Change, *Science Education*, 66, 211.

Prather, E. E., Slater, T. F., & Offerdahl, E. G. 2002, Hints of a Fundamental Misconception is Cosmology, *Astronomy Education Review*, 1(2), 28.
http://aer.noao.edu/AERArticle.php?issue=2&section=2&article=3.

Schneps, M., & Sadler, P. 1998, *A Private Universe*, CD produced by the Harvard Smithsonian Center for Astrophysics, funded by the National Science Foundation and Annenberg/CPB.

Schwarz, M., & Fisher, K. W. Building General Knowledge and Skill: Cognition and Microdevelopment in Science Learning, in *Cognitive Developmental Change: Theories, Models and Measurement*, A. Demetriou & A. Raftopoulos (Editors), Cambridge, England: Cambridge University Press. In press, to be published 2004.

Sneider, C. I., & Ohadi M. M. 1998, Unraveling Students' Misconceptions about the Earth's Shape and Gravity, *Science Education*, 82(2), 265.

Strike K. A., & Posner G. J. 1992, A Revisionist Theory of Conceptual Change, in *Philosophy of Science, Cognitive Science and Educational Theory and Practice*, R. Duschl & R. Hamilton (Editors), Albany: SUNY Press.

Trowbridge, D. E., & McDermott L. 1981, Investigation of Student Understanding of the Concept of Acceleration in One Dimension, *American Journal of Physics*, 49, 242.

Trumper, R. 1997, Applying Conceptual Conflict Strategies in the Learning of the Energy Concept, *Research in Science Education and Technology Education*, 15, 5.

Tyson, L. M., Vanville, G. J., Harrison, A. H., & Treagust, D. F. 1997, A Multidimensional Framework for Interpreting Conceptual Change Events in the Classroom, *Science Education*, 81, 387.

Vinnot, L. 1979, Spontaneous Reasoning in Science: A Pragmatic View of Theoretical Problems, *European Journal of Science Education*, 1, 205.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. 1994, Research on Alternate Conceptions in Science, in *Handbook of Research on Science Teaching and Learning*, D. Gabel (Editor), New York: Macmillan, 177.

Watts, D. M. 1983, Students' Conceptions of Light: A Case Study, *Physics Education*, 20, 183.

Zirbel, E. L. Learning and Concept Formation, forthcoming.

Zirbel, E. L. Teaching for Conceptual Change, forthcoming.

ÆR
62 - 76