Framework for Conceptual Change

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ABSTRACT

Students often enter introductory courses lacking a consistent conceptual framework about natural sciences, and after traditional instruction, oftentimes undergo little change in conceptual understanding. This paper 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 paper also reviews Posner et al's conceptual change model and elaborates how and under which 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 what Pinker 2003 called) a "blank slate". They come to school with already formed ideas on many topics, including on how they view and interpret the world around themselves. 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.

While "learning the unfamiliar" and "conceptually understanding" the subject-matter already provides a large challenge, unlearning misconceptions is significantly more difficult as will become evident in this paper. If we understand how to change students' concepts, we might understand how students form concepts in the first place. This paper (paper I) focuses on the origin of misconceptions and suggests how to provoke conceptual change. This provides us with valuable clues to how students think, learn, and how they build ("construct") their own concepts (which the main focus of paper II). How to teach to provoke conceptual change is discussed in paper III.

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 by a few words. Through the use of language individual concepts can be connected to build more complex representational structures, like for example "babies crawl" or "birds fly". At other times two concepts can be combined to form a third representational structure. An example of the latter could be "density", which is the "matter" per "volume", i.e., a concept that stands in itself but is a product of two other concepts. Through the use of language, we can thus create new concepts that can stand by themselves. More complex concepts can describe a whole idea, like for example "the theory of natural selection". Similarly, though the use of math, we can build somewhat more abstract theories that in the end up representing one idea, like for example " 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. Concept can thus act like building blocks of more complex or even abstract representations. Outside of 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 any other knowledge that we might acquire as we learn about the world around us. As such a core concept is an innate concept that we are born with that is available within our genetic fabric so-to speak. While no real model for core concepts seems to exist, describing the nature of fullblown complex concepts is equally challenging. One possibility is that of DiSessa (1993), where he suggests that knowledge comes in the forms of small fragments of knowledge that he called phenomenological primitives – or in short "p-prims". These p-prims then combine to form individual concepts. Another view, often shared by behavioral scientists is the notion of ontological categories (e.g. as suggested by Chi & Slotta, 1993, Chi 1997, or Johnson & Southerland 2000). Here each concept is classified into individual categories of alive versus dead (or alive versus object) and into plant versus animal, etc, similarly as the genetic tree in biology. Core concepts in Chi's picture are then the most fundamental distinctions we learn to make at the earliest ages. P-prims, on the other hand, are the basic building blocks of more complex concepts as is seen more from the perspective of the final most complex concept.

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. Oftentimes these can be private versions of student's understanding of particular concepts that have not been tested extensively via scientific methodology. Misconceptions then could be premature beliefs that do not stand the test of scientific analysis or that might have never been exposed to a rigorous scientific analysis.

In many situations our "current" understanding of phenomena in the universe has changed as we have learned more, thus a previously scientifically correct concept may then be regarded as a misconception. For example, the Geocentric Model survived for 2000 years throughout history. In fact, the word misconception might not be totally appropriate in this case. In the science education literature many other terms have been proposed, like for example "naïve beliefs", "pre-conceptions", "private versions of science", "personal models of reality", "persistent pitfalls", "pre-instructional ideas", "unfounded beliefs" and even "mistakes" (see for example Wandersee, Mintzes, and Novak, 1994). All of these words imply that there is something seriously wrong. So, 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. Maybe 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 believed by intellectual Giants from Aristotle to Copernicus deserves a better term. It should be regarded as an alternate hypotheses to the currently believed model, thus 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 nevertheless 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 that were 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 students at his current understanding of the situation. As such, it could be viewed as a yet "immature understanding" of a complex problem.

3. The Roots 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 his or her personal views. Much of the alternate conception literature is therefore 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 originally come from? Determining to what degree we have learned specific concepts and to what degree specific concepts may be innate is rather tricky (see for example Chomsky 1985 or Carey & Spelke 2000, Carey 2003). Several studies have focused around determining what newborns can do and what they know. For example, it seems that babies have an inborn disposition to learn languages (e.g. Chomsky 1985, Pinker 1998). Furthermore, here seems to be some type of common sense arguing that we seem to have. For example, in a study about misconceptions in Cosmology, Praher, Slater and Offendahl (2003) found that most students believed that "there was preexisting matter before the big bang", because "you cannot make something out of nothing". What is the nature of a concept like this one? And where does the intuition that you cannot make something out of nothing originally come from? Is this genetic wisdom? Is it based on experience? What is the experience of nothing? What is the most fundamental core concept of this statement?

In some cases (but not all) it is clear that we have picked up these types of wisdom from more educated people or the media. For example, nowadays kids are oftentimes exposed to space pictures of the Earth and told 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 & Ohnadi 1998), but as they grow older, many (but not all) will 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 comes 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 concepts that are core concepts that seem to be far more complicated that the flat Earth concepts – for example birds just know where to fly when the time is ripe (i.e. 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, e.g., Carey 2004). So then – what is the flat Earth concept – could it be a core-mis-concept? The only argument against this is that somehow it seems unlikely that nature infused us with this type of innate mis-knowledge that is in fact trivial to the human survival. Nevertheless it is a curious notion that may never to resolved.

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 downwards and do not ascend upwards. One might argue then, that concept formation depends on our perception of the external world and is coupled with personal experience, and with how we subsequently process that information.

In many cases scientifically correct concepts will be formed, but sometimes the observation itself might not be analyzed and thought through in enough detail. An example of a correct observation that has lead to an alternate conception is 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 backwards from the point of the drop (it actually moves forward relative to the ground). However not all origins of all misconceptions seem to be this straight forward to determine, and oftentimes students might not even remember the origin of a particular idea.

The real process of concept formation is a rather complex, but nevertheless one can claim that there is a basis to the formation of concepts. It depends on what we perceive, 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 rather a result of repeated observations coupled with how individuals construct their own view of the world from those observations. While some concepts might be based in personal experiences, "intuitive" responses seem to go even somewhat deeper. Either they could be a true core-concept, or they might be fabricated at a very deep level. It is well known that due to the frequency of the same observations some people might develop some type of "intuitive understanding" about a situation or a concept. For example, most students will have driven a car and noticed that when they cease to press the gas pedal (i.e. apply a force) the car will slow down. Although they might know that there is friction that might be responsible to slowing down the car, their personal experience is that in the absence of a force the car will slow down. Since this experience is repeated every time the students drive, it is no surprise that the student will develop and intuitive sense that a constant force results in motion.

3.3. Grounding Arguments and Dynamic Concepts

Not every observation will get registered consciously in the students' mind, especially if the observation is unimportant at that time. However sometimes it is possible that some observations are remembered in retrospect. Whether a concept is formed then depends on how the student thinks about that concept at that particular moment. It then depends on the complexity of thinking and previous conscious and unconscious observations how the student will proceed to form a concept. 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 some reason groups of people may come up with the similar pitfalls to a theory. For example, in Schweps & Sadler's (1998) movie, the "Private Universe" a substantial fraction of individuals seem to believe that the cause of the seasons is due to the fact 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 ways of thinking about concepts) 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 for the reasons of the seasons is caused by insufficient rigor in thinking through the situation from beginning to end. As such this then is a premature concept that makes sense to some degree, but still requires more critical analysis. The common problem then is that a half-understood concept might appear to look like a full blown conceptual understanding of a situation when only a fraction of it makes sense and has not yet been exposed to thorough critical review. So then, alternate conceptions may thus also be “unfinished” concepts.

Alternatively, and this is dangerous from an educational perspective, an alternate concept might be grounded due to misinterpreting an instructional argument. For example, if the teacher or any other trusted individual believes in an alternate conceptions or does not have an adequate understanding of the underlying scientific process, misconceptions might be installed easily in the students mind. For example, several studies have shown that some teachers can have inadequate understandings of the concepts heat and temperatures of force and motions and even about the reasons for the seasons. Many students believe that the reason for the season is that the Sun is closer to us in the summer than in the 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 notion 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. The point is that 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 or not. To the individual it makes sense.

3.4. Aristotelian & Impetus Thinking

In science education literature one often finds the term “Aristotelian Thinking”. Although some science educators refer to this term when specifically differentiating between Aristotelian and Newtonian Physics, they more often use the term “Aristotelian Thinking” to refer to simplistic ideas that have not been thought through sufficiently. However somehow this does not do justice to Aristotle whose models and arguments were sometimes rather elaborate and well thought through. In fact, if the students in class argued the way Aristotle argued, they would definitely argue at a rather advanced level and this is actually a quite desired way of arguing. The only critique 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 even naïve. To distinguish between incorrect but clever and naïve, wrong and insufficient thinking some science educators use the term “Impetus thinking” whenever referring to naïve and oversimplified ideas.

Several hundred papers have been written in the past 20 years on intuitive or “Aristotelian” ideas held by learners in the topic of simple mechanics alone (early, frequently cited publications in the area are Vinnot 1979, Caramazza, McClosely & Green 1980, Champagne, Klopfer & Anderson 1980, Clement 1982, diSessa 1982, Gunstone & White 1981, McCloskey 1983, Watts 1983, McDermott 1984, 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, (4) in the absence of a force, objects are either at rest, or if moving, slowing down. Champagne et al (1980) summarized this as “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, that 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, Mintzes & Novak (1993) and more recently again by McDermott & Redish (1999) and 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 better and better. This argument can sometimes be taken even further. It can be hypothesized that students learn concepts in a similar manner as it took society to learn basic concepts.

It also turns out that this approach tends to be the least intimidating to students because they see the mistakes of humanity and of some famous individuals, and this oftentimes will make science less dry and more approachable, thus making them feel better and encourage their self confidence. For example, Duschl et al (1992) suggest that science instruction might benefit from a constructivist-historical approach in which students do not only learn 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 to the new paradigm. (Other studies even go as far as claiming that the developmental stages in children (described by Piaget in 1929) can also be simulated through historical parallels – e.g. Sneider & Ohadi 1977).

3.5. Astute and Bizarre Models

Another important point to make is that even though alternate conceptions can sometimes be rather erroneous understandings and based on incomplete personal observations and inadequate analysis, they are not necessarily the result of a lack of reasoning ability. Sometimes when students present an immediate but rather strange answer to a conceptual question, it becomes evident that they previously had thought about that particular concept and had reached an answer. Kids may often have some interesting stories to tell, like for example my 5 year old niece who claimed that the moon is watching and alive since its face changes shapes. Sometimes it is surprising for how long some kids may hold on to 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 astute and imaginative ideas get 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 will hold onto their beliefs no matter what, even when common sense arguing is no longer possible. These individuals do not want to be convinced and can have emotional reasons that might even be irrational. Sometimes it might even appear as if rational reasoning with these individuals has been short-circuited (see paper II). Sometimes the only way that these individuals deal with inconsistencies is to disregard any other possible models, or to just defend or insist on their world views. In this case, it might be a conscious choice of believing in a particular model (or a faith) and it might be based on a decision the student made at some point. Thus changing personal believe 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 that 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). Unfortunately oftentimes the students are not open to new ideas. In that case a rather radical approach is needed to change pre-existing concepts. With this in mind Posner, Strike, Hewson, and Gertzog (1982) proposed the conceptual change theory which is 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 do make the statement that they are using Piaget's terms but not borrowing the concepts in total. Piaget's work (including his earlier works of 1950, 1951 and 1971) describes how learners learn through the "assimilation" and "accommodation" of knowledge. Posner et al. (1982) 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 paradigms shift caused by the scientific revolution can then be compared to the accommodation of new knowledge in an individual that 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 the abandonment of the existing conception and the acceptance of a new conception.

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. Following that the students have to 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) hypothesize that there are four essential conditions for conceptual change. These include: (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 sometimes the wording has changed slightly, the general framework still remains. The steps can then be summarized:

1) **Dissatisfaction** The learners must first realize that there are some inconsistencies and that their way of thinking does 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 learner to accommodate a new conception, they 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 where this concept could be applied.
4) **Fruitfulness** For the new conception to be accommodated, the learners need to 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 and 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. Alternations to the Original Conceptual Change Model

A decade later the theory was revised due to an overemphasis on the rational aspects of learning and affective and social issues for conceptual change were incorporated into the initial theory. They (Strike and Posner 1992) expanded on their theory and incorporated a wider range of factors that are needed to induce conceptual change. They also introduced the notion that alternate concepts might not pre-exist initially, but that 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 were also published since then, all describing and refining the conceptual change theory to some degree. Fensham, Gunstone, and 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," since 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 which 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 and Siegler (1993) extended this view and proposed the notion of conceptual competition, suggesting that different competing conceptions coexist in the learner, and that after a prolonged period of learning one of these achieves dominance. On the other hand, Mortimer (1995) proposed the idea of 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, and Monarch (1992) asserted that conceptual change is a progressive process of refinement of students' conceptions and propose a taxonomy of conceptual change consisting of differentiation, class extension, and reconceptualization. Similarly, Niedderer and Goldberg (1994) described conceptual change as a process of change from the learner's prior conceptions to some intermediate conceptions and then to scientific conceptions.

4.1.4. Unsuccessful Conceptual Change

Conceptual change is only really successful if all those individual stages of the initial theory are followed. But 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 frequently turns out to be still rather limited. Interestingly there appears to be no study in the literature, which shows that particular student's conceptions could be completely extinguished and replaced by the 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 that parts of the initial idea merge with parts of the new idea to form some type of hybrid idea (Chinn & Brewer 1998).

Other studies show an even yet more negative approach to facilitating conceptual change. Hewson and Hewson (1983) explain that, when students are confronted with conflicting data, rather than undergo 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" any 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 and Brewer (1993), in explaining what scientists themselves do with conflicting data, offer even more ways for scientists to "maintain" their existing perceptions. In other words, there are more avenues for maintaining ideas than there are for changing them. Often, the path of least resistance is maintenance. Tyson et al (1997) claim that conceptual change does not imply that initial conditions are "extinguished". The claim that some students might hold scientific 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 himself – his willingness to listen and evaluate new ideas and methods, his willingness to let go of his old beliefs, and his willingness to want to undergo conceptual change.

4.2. Beyond Conceptual Change

4.2.1. Owning versus Borrowing

Once the student has let himself be convinced of that the new concept is intelligible and makes sense and once he is convinced that the new concept provides a better solution to the problem, it does not stop there. Most educators will 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 the previous conception could not. They furthermore quote that the learners should be able to decide on their own how this new concept fits into their ways of thinking and recall incidences where this concept could be applied. Following that, the theory should be fruitful in the sense that this concept should have the potential to be extended to other incidences, and open up new areas of inquiry.

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

4.2.2. Creative and Original Thinking

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

5. Summary and Conclusion

As stated in the introduction this paper focuses on misconceptions because understanding the origin of misconceptions provides us with valuable clues to how students think, learn, and how they build ("construct") their own concepts. Some questions were answered in this paper, but many questions 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 upon the basic core concepts? What happens in our minds as we construct concepts? As we lean more about the world around us we continually adjust our strategies and cone up with new conclusions – so then, 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 paper tries to make a few claims on 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 mixing 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 led to inaccurate or insufficient knowledge. Pinpointing exactly where and under which conditions alternate concepts were formed might provide clues to 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 was not the central issue of this paper, rather the focus was on understanding the nature and origin of concepts and on how to provoke conceptual change.

We claim that: There seems to be a base alternate concepts – they are oftentimes 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 caused by a lack of knowledge and insufficient or inadequate thinking, they might also be the result of imaginative and very astute thinking. Changing personal believe 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 that concept.

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

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