# Students' Misconceptions in Science, Technology, and Engineering.

**Tatiana Goris**
PhD student
Department of Electrical and Computer Engineering Technology (ECET)
College of Technology
Purdue University
tgoris@purdue.edu
Phone: (765)-586-6450

**Dr. Michael Dyrenfurth**
Professor
Department of Industrial Technology (IT)
College of Technology
Purdue University
mdyrenfu@purdue.edu
Phone: (765)-496-6160

## Abstract

There is some evidence that suggests that when students learn a new material, many of them already have some kind of understanding of the problem. They also may have pre-conceptions or naïve theories in their mind about the new or experienced concept. These pre-conceptions are also called alternative conceptions or misconceptions. Misconceptions also can be identified as students' prior knowledge, which are embedded in a system of logic and justification, albeit it may be incompatible with accepted scientific understanding (Tomita, 2008, p.10). Usually misconceptions are robust, very resistant to change, and deeply rooted in everyday experience. Often new information, presented by instructor, comes to conflict with already existing student's mental models. Therefore, to overcome existing misconceptions, some kind of conceptual change has to occur in the student's mind. For the successful conceptual change, a new concept has to be "(a) *intelligible* - the new conception must be obvious to make sense to the learner; (b) *plausible* - the new conception must be seen as reasonably true; (c) *fruitful* - the new conception must appear potentially productive to a learner for solving current problems. The major goal of teaching methods is to create a cognitive conflict to make a learner dissatisfied with his or her existing conception" (Posner et al., 1982, p.352). "The goal of conceptual change theories is to understand and propose a way to overcome…stubborn resistance to change" (Ohlsson, 2009, p.68). In general, the research on misconceptions and the research on conceptual change are intertwined very closely. There are many theories that explain mechanisms of conceptual change in different ways; therefore, depending on definitions of "what misconceptions are," each theory offers particular ways for removing (or at least clarifying) misconceptions. During last two decades, a significant amount of research was conducted to investigate students' misconceiving in science. Most of the literature is related to correct/incorrect explanations of physical phenomena (like heat, force, energy, etc). But research about misconceiving in technology and engineering is very limited.

According to constructivist theory, which states that humans generate knowledge and meaning from their previous experiences, the same concept might be recognized differently by people who have a core focus in their education on scientific fundamental knowledge, comparing to people, which education is more orientated to technological needs and development of procedural knowledge as well. In short, scientists and technologists might perceive the same task, concept or phenomenon in different ways. It follows that, "science" and "technology" students also might have different misconceptions about the same phenomena.

**Introduction**

This paper describes the work in progress (which is part of the dissertation research) on diversity of students' misconceptions in science, technology, and engineering. The main goal of this research is to compare if there are any significant differences in the perception of the phenomenon (and misconceptions about phenomenon as well) by "scientists" and "technologists" . This paper presents the overview of the literature on different approaches to students' misconceptions. At the beginning of the paper, the definitions for science, technology and engineering are presented. Then, the phenomenon of "misconceiving" is described according to various theories of conceptual change. In the conclusion section, three possible directions for the future research were identified. The final decision in which direction to go is not made yet. At the present time, each of these questions is under deep consideration to choose the most beneficial way for the future research.

**What is Science?**

The terms of *Science* and *Technology* (as well as terms of *Culture* or *Art*) can be defined in many different ways. Literature gives hundreds of various definitions and meanings for the word *science*. In general, science is a human search about the truth; it is an investigation of the nature and the world around us. Krebs (1999) referring to the *Webster's II New Riverside University Dictionary* (1994) presented a few definitions of the term s*cience*:

Science is:

1. The observation, identification, description, experimental investigation, and theoretical explanation of natural phenomena.
    - Such activity restricted to a class of natural phenomena;
    - Such activity applied to any class of phenomena;
2. Methodological activity, discipline, or study.
3. An activity that appears to require study and method.
4. Knowledge especially that is gained through experience (p. 6).

The other meaning of s*cience* was made by Kuhn (1962). He introduced a new term, which had never been used before - *Normal science* - an activity in which most scientists inevitably spend almost all their time, routine everyday work.

> *Normal science* means research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice. These achievements must be sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity and sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners (and their students) to resolve, i.e. research. These achievements can be called – *paradigms* (Pajares, n.d. online).

Simply said, *normal science* is a daily-routine research life; *paradigms* also can be called scientific models of the world perception. "Men whose research is based on shared paradigms are committed to the same rules and standards for scientific practice…unfortunately; *normal science* often suppresses fundamental novelties because they are necessarily subversive of its basic commitments" (Kuhn, 1962, p.10).

**What is Technology?**

Asked to explain the term *technology,* Pitt (1999) answered that *technology* is humanity at work. From this perspective, technology always exists as long as humanity exists. Pitt opposed the popular opinion that science is pure knowledge, and technology is applied knowledge. He argued that many times in human history, technology is ahead of science.

> Now technology includes many more factors that were not considered technology in the past (including social structures and bureaucracy systems as controls on what scientists can and cannot do), but on the other hand, the definition of technology cannot be used too broadly because it would be concept without content (Olsen, 2007, online).

Many authors argue that the notion of technology might be used in very different senses. For example, Mitcham (1994) distinguished between four different manifestations of technology, namely technology as object, as knowledge, as activity and as volition. Kroes & Van de Poel (2009) described two meanings of technology:

1. *Technology as a process (activity):* is a collection of processes of designing, developing, producing, maintaining and disposing of technical artifacts;
2. *Technology as a product (object)*: is a collection of technical artifacts, that is, what comes out of technology as a process in so far the latter is restricted to the design, making and maintenance of technical artifacts (p.62).

The authors argued that "technology as process may be taken broadly in the sense of all processes, scientific, social, economic, cultural etc., that concern the evolution and development of technology, more in particular processes that concern the creation, production, maintenance of technical artifacts"(p.64). Therefore, technology (as a process) and engineering (as a human activity) are two integral components of one process of the development of new technical artifact or/and new technical procedures.

**The Link between Science, Technology, and Engineering**

Discussing the correlation between science and technology, Bunge (1985) distinguished human knowledge about the world and nature in two big categories:

- *Science* - in general consists of *Formal* and *Factual* Science, where *Formal* science is studying artifacts (logic and mathematics). *Factual* can be separated in two groups: *Natural* and *Social Sciences*.
- *Technology* - consists of many independent fields: Engineering, Biotechnology, Socio-technology, Information Technology, and General Technology.

Mario Bunge, one of the most known philosophers of science in the twentieth century, in one of his interviews argued:

> Whereas scientists study the world, technologists help alter it -- for better or worse. In short, science is about truth, and technology is about utility…There is a popular belief that science and technology are the same thing: that there are no differences between physics and engineering, biology and medicine, psychology and psychiatry, and so on. This confusion has recently been given an academic name: *techno-science* (Olsen, 2007, online).

Lavelle (2009) discussed a strong unbreakable link between technology and engineering. He defined technology as a dynamic process of "design, production and use of technical artifacts for which engineering appears as a core activity. Engineering design is largely about working with constraints, many or most of which can be described in quantitative terms" (p.29). Engineering was identified as "an activity that is shaped during whole technological process, from requirements gathering to design and on to the use of technical artifacts, by a set of external social factors" (p.30). The literature presents many broad definitions of engineering as a human activity. Jamison (2009) explained that "one of the main difficulties in discussing the context of engineering is that engineering like science and art and other forms of human creativity, has had a range of different meanings and functions: commercial, economic, social, professional, cultural, and human " (p.49-50). Newberry (2009) argued:

The activity of engineering cannot be easily excised and examined in isolation from the larger ecology of human action. Like all ecological elements, it is inextricably coupled with its surroundings. At a very high level we might be able to create serviceable definitions of what it means to be an engineer, or to describe the products of engineering and the reasons for their creation. Such definitions for engineering are abstractions that we use to aggregate particular aspects of human activity for purposes of conceptual manipulation. But as we begin to dig to deeper levels of understanding, we get the feelings that the more we learn about engineering the less plainly we can demarcate it (p.34).

Defining Engineering (as a practice), Streveler et al. (2008) clarified that this process consists of three main components:

- Engineering as problem solving (consisting of the systematic processes that engineers use to define and solve problems).
- Engineering as knowledge (consisting of the specialized knowledge that enables and fuels the problem solving process).
- Engineering as integration of process and knowledge. Thus knowledge, including conceptual knowledge, is central to the practice of engineering (p.280).

**Different approaches to misconceptions**

Literature describes misconceiving as a phenomenon very differently. There are many definitions for the term *students' misconceptions.* Tomita (2008) proposed:

When students enter science classrooms, they often hold deeply rooted prior knowledge or conceptions about the natural world. These conceptions will influence how they come to understand their formal science experiences in school. Some of this prior knowledge provides a good foundation for further, formal schooling, while other conceptions may be incompatible with currently accepted scientific knowledge. The importance of prior knowledge and the struggle to replace that knowledge with or help that knowledge evolve into scientifically-sound knowledge has spurred a large tradition of research in developmental and instructional psychology and science education (p.9).

Despite the fact that the term *students' misconceptions* is widely used in scientific literature, not all researchers agreed to define students' prior knowledge as misconceptions. The term *misconception* has many synonyms. Discussing definitions for misconceptions, Tomita (2008) noticed:

Initially referred to as *misconceptions* (Wandersee, Mintzes, & Novak, 1994), these conceptions are also known as naive conceptions (Champagne & Klopfer, 1984), nonscientific beliefs (Lawson & Weser, 1990), pre-instructional beliefs (Chinn & Brewer, 1993), intuitive knowledge (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001), phenomenological primitives or p-prims (diSessa, 1993), facets (Minstrell, 1992), or alternative frameworks (Carey, Evans, Honda, Jay, & Unger, 1989). Regardless of terminology, the point is to recognize that a students' prior knowledge is embedded in a system of logic and justification, albeit one that may be incompatible with accepted scientific understanding (p.10).

Smith, diSessa, and Roschelle (1993) observed that novices' interpretations of scientific concepts and experts' perceptions of scientific knowledge are very different. Researchers argued that clarification of the terms *misconceptions*, *alternative beliefs*, and *preconceptions* is necessary:

The prefix to the most common term - *misconception* - emphasizes the mistaken quality of students' ideas. Terms that include the qualifier – *alternative* - indicate a more relativist epistemological perspective. Students' prior ideas are not always criticized as mistaken notions that need repair or replacement but are understood as understandings that are simply different from the views of experts…Students' *alternative conceptions* are incommensurable with expert concepts in a manner parallel to scientific theories from different historical periods…*Preconceptions* and *naïve beliefs* emphasize the existence of student ideas prior to instruction without any clear indication of their validity or usefulness in learning expert concepts. However, researchers who have used them have tended to emphasize their negative aspects. This epistemological dimension emphasizes differences in content. The content of student conceptions (whether mistaken, preexisting, or alternative) is judged in contrast to the content of expert concepts (p 159).

In 1993 Smith et al. made an overview of seven widespread assertions, which represent a traditional theoretical position in the misconception research.

**Assertion 1: Students have misconceptions**. Coming to the class, students already have got some understanding of the problem. "Before they are taught expert concepts, students have conceptions that explain some scientific phenomena that expert concepts explain, but these conceptions are *different* from the currently accepted disciplinary concepts presented in instruction" (p.119).

**Assertion 2: Misconceptions originate in prior learning.** It is another common opinion that "misconceptions arise from students' prior learning, either in the classroom or from their interaction with the physical and social world…for example, the persistence of the "motion implies a force" misconception is rooted in everyday perceptual-motor experiences with pushing and pulling objects" (p.120).

**Assertion 3: Misconceptions can be stable and widespread among students. Misconceptions can be strongly held and resistant to change**. Referring to Clement (1982a), Smith et al. (1993) argued that sometimes misconceptions even coexist alongside the correct approach:

> Perhaps most troubling is that students can doggedly hold onto mistaken ideas even after receiving instructions designed to dislodge them…It does not necessarily mean that instruction has failed completely. It can succeed in imparting the correct concept that then *competes with* the prior misconception (p.121).

**Assertion 4: Misconceptions interfere with learning.** Describing this meddling, the authors referred to the studies of Clement (1982b) and Resnick (1983). They argued that "researchers in physics have reported that misconceptions even cause students to misperceive laboratory events and classroom demonstrations" (Smith, 1993, p.121).

**Assertion 5: Misconceptions must be replaced**. The opinion that the learning of science is a replacement (or removing) of novices' misconceptions by expert concept is the central idea of misconception research. "Learning involves the acquisition of expert concepts and the dispelling of misconceptions. The assumption that removing misconceptions has no negative consequences because they play no productive role in expertise is implicit in the replacement view" (p.122).

**Assertion 6: Instruction should confront misconceptions.** "Confrontation begins as an external, social interaction in the classroom, but for confrontation to succeed, the competition between misconception and expert concept must be internalized by students. Confrontation and replacement are therefore inextricably linked. Successful instructional confrontation leads to learning by replacement" (p.122).

**Assertion 7: Research should identify misconceptions**. During the last three decades many works have been done in one straight direction -- to identify as much as possible misconceptions in different scientific domains:

> Much less emphasis was given to modeling the learning of successful students in those domains, to characterizing how misconceptions evolve, or to describing the nature of instruction that successfully promotes such learning…When we consider the corpus of misconception research, the major research effort has been to identify more misconceptions (p.123).

Some researchers identify *misconceiving* as misunderstanding, but this point of view is not always correct. Maznichenko (2002) argued that misconceiving and misunderstanding have a common feature: both of them lead to an inadequate perception of the reality, but there are a few distinctions between them:

- Mistakes and misunderstanding are caused only by personal insight and sensitivity of the learner;
- Misunderstanding is casual, but misconceiving is not; the occurrence of misconceptions obeys some rules, which will be discussed further.

- Misunderstanding may happen according to any particular and specific case, but misconceiving is total; it influences all world-perception of the learner.
- When a person realizes that he/she has misunderstood or made a mistake, he can correct it easily. A person usually does not have any resistance to changing his ideas and thoughts; he does not follow his misunderstandings anymore. A misconception, on the other hand, is very resistant to any change. The big issues are that once a misconception has been formed, it is extremely difficult to change, and that possessing misconceptions can have serious impacts on learning.
- Misconceiving can be a reason for misunderstanding.

**Correlation between "misconceiving" and conceptual change**

In general, the research on misconceptions and the research on conceptual change are intertwined very closely. Many scientists argued that to overcome existing misconceptions, some kind of conceptual change has to occur in the student's mind. Each theory of conceptual change explains misconceptions in different ways; therefore, depending on definitions of "what misconceptions are," each theory offers particular ways for removing (or at least clarifying) misconceptions. A consequence of that is the fact that each theory usually presents its own approach to the curriculum. Thus, initial students' knowledge about to-be-learned material has to be evaluated very carefully. Halloun and Hestenes (1985) took an attempt to explain the importance of this evaluation. They argued that if misconceptions are not recognized early in the course "the student will not only fail to understand much of the new material, but worse, he is likely to dress up his misconceptions in scientific jargon, giving the false impression that he has learned something about science"( p.1048).

**Overview of Contemporary Theories of Conceptual Change**

Ohlsson (2009) noticed that "the goal of conceptual change theories is to understand and propose a way to overcome…stubborn resistance to change" (p.68). Before describing the most known theories of conceptual change, which are overviewed in this chapter, it is necessary to present the approach of Chi (2008). The researcher distinguished three types of learning:

1. *Missing and Adding* – when a student has no prior knowledge, in this case prior knowledge is missing, and the learning process consists of adding new knowledge.
2. *Gap filling* – a learner may have some correct prior knowledge, but that knowledge is incomplete. In both *missing* and *gap filling* conditions, knowledge acquisition is of the *enriching* kind (Carey, 1991).
3. *Conflict* -- a student may have acquired ideas, either in school or from everyday experience, that are 'in conflict with' to- be-learned concepts (Vosniadou, 2004). Under this condition, the knowledge acquisition is of the *conceptual change* kind. (Chi, 2008, p. 61)

Tomita (2008) referring to Duit (1999), defines a conceptual change as the pathway from pre-instructional or prior conceptions to post-instructional, desired conceptions. In the present time, various theories of conceptual change exist. Many of them have common features and disagreements, but all those theories are agreed on one point: the conceptual change process is a function of time. There is no consensus among scientists on how and why conceptual change occurs. Most known theories of conceptual change are:

- Kuhn's theory of paradigms' shifts. Kuhn (1962)
- Theory of Gradual Transformations of Naïve Theories. Carey (1999).
- Theories of Mental models and beliefs' revision. Ioannides and Vosniadou (2002); Linder (1993); McCloskey (1983); Smith, Blakeslee, and Anderson (1993); Vosniadou (1994); Vosniadou and Brewer (1992).
- Jean Piaget's theory of learning (Assimilation & accommodation) Posner, Strike, Hewson and Gertzog (1982); Ozdemir and Clark (2007)

- Chi's ontological mis-categorization theory. Chi, Slotta, & DeLeeuw (1994); Chi (2008).
- DiSessa's perspectives on misconceptions. Phenomenological primitives (p-primes). Smith, E. L., Blakeslee, T. D., & Anderson, C. W. (1993); Smith, J.P., diSessa, A. A., & Roschelle, J. (1993).

All presented theories of conceptual change are not described in this paper because of the space limitation. Focus is made on two of them: Jean Piaget's theory of learning (Assimilation & accommodation) and Chi's ontological mis-categorizations,

Jean Piaget's theory of learning had the enormous impact on the educational psychology of the twentieth century. Piaget considers a conceptual change from two perspectives: *assimilation* and *accommodation*. Discussing some aspects of Piagetian theory, Posner, Strike, Hewson and Gertzog (1982) clarified:

> Sometimes students use existing concepts to deal with new phenomena. This variant of the first phase of the conceptual change we call *assimilation.* Often, however, the student's current concepts are inadequate to allow him to grasp some new phenomenon successfully. Then, the student must replace or reorganize his central concepts. This more radical form of conceptual change we call *accommodation* (p. 212).

In 1982, talking about assimilation-accommodation theory, Posner et al. noticed that for successful conceptual change, a new concept has to be:

- Intelligible -- the new conception must be obvious to make sense to the learner;
- Plausible -- the new conception must be seen as reasonably true;
- Fruitful -- the new conception must appear potentially productive to a learner for solving current problems.

Researchers argued "the major goal is to create a cognitive conflict to make a learner dissatisfied with his or her existing conception" (p.352). Then, a new idea as intelligible, plausible, and fruitful may be accepted.

Another understanding of conceptual change comes from "the building of mental models" perspective: Ioannides and Vosniadou (2002); Linder (1993); McCloskey (1983); Smith, Blakeslee, and Anderson (1993); Vosniadou (1994); Vosniadou and Brewer (1992). Discussing mental models, Chi (2008) argued that knowledge might be misconceived at three hierarchically different "grain- size" levels:

- Beliefs;
- Mental models;
- Ontological Categories.

Individual *Beliefs* is at the lowest level, and *Categories* is at the highest. According to Chi (2008), to achieve a conceptual change, teaching instructions should be different depending on the level to which misconceiving knowledge belongs. The author defines *beliefs* as "students' prior knowledge, which on the grain-size can be called single ideas, corresponding more or less to information specified in a single sentence or statement" (p.66). As a described earlier, students' prior beliefs can be missing or incomplete. For example, a student might not know that the atom's core consists of neutrons and protons, and telling the student this piece of information would be *adding* to his prior beliefs. Chi (2008) proposed that "conceptual change can sometimes be readily achieved as a belief revision through explicit or implicit refutation of prior false beliefs. But such beliefs revision can be achieved only when misconceived knowledge conflicts in the contradictory sense" (p.67). In other words, the conceptual change occurs when old beliefs contradict new information. The researcher argued that *mental models* as well as *beliefs* can be "in conflict with" the correct scientific model to varying degrees, such as a *missing* or non-existing mental model or an *incomplete* mental model. By Chi's definition, "learning would begin by *adding* and *gap filling* in missing components. ***Adding* and *gap-filling* a mental model would not constitute conceptual change**" (Chi, 2008, p.67). A good example of mental models has been described by Vosnidadou, Vamvakoussi and Skopeliti (2008). The majority of young children believe that the Earth is flat:

Mom: Do you know what the shape of the Earth is?
Child: Square.
Mom: No, it is round.
….
Mom: So, what is the Earth's shape, honey?
Child: Like a pancake.

This conversation about the shape of the Earth was described by Yin (2005) referring to Vosniadou & Brewer (1992) presents an interaction between a child's previous knowledge and upcoming new information. Learning in school that the Earth has a spherical form and is an astronomical object, they do not refuse their previous ideas, but they form new synthetic mental models about the Earth.

Some children formed the interesting model of dual earth, according to which there are two earths: a flat one on which people live and a spherical one, which is up in the sky, and which is a planet. Another common mis-representation of the earth was that of a hollow sphere. According to that model, the earth is spherical but hollow inside. People live on flat ground inside the bottom part of the hollow sphere. Alternatively, the earth was conceptualized like a flattened sphere or truncated sphere with people living on its flat top, covered by the dome of the sky above its top (Vosnidadou et al., 2008, p.7).

Chi (2008) argued that students' knowledge consists often of an inter-relative system of false and correct beliefs. This system is coherent, but sometimes it is a flawed mental model. As a consequence, a mental model is in conflict with a scientific model. Therefore, it leads to unscientific predictions and explanations. When a student learns new information from a teacher, two outcomes are possible.

1. In the first case, when a student understands that his initial concept was wrong, his flawed concept usually is changed to the correct concept. A conceptual change would happen.
2. In the other situation, when a student does not recognize through instructions that his initial concept was wrong, new information is assimilated into the flawed mental model. The conceptual change would not occur.

Figure 1. shows the mechanism of conceptual change in the terms of mental models.

Chi (2008) proposed that "many misconceptions are not only 'in conflict' with the correct scientific conceptions, but moreover, they are robust; therefore, the misconceptions are difficult to revise, so conceptual change is not achieved" (p.72). The researcher proposes that certain misconceptions are robust because they have been mistakenly assigned to an appropriate ontological category:

Our claim, then, is that some false beliefs and flawed mental models are robustly resistant to change because they have been laterally or ontologically miscategorized. That is, if a misconception belongs to one category and the correct conception belongs to another ontological category, then they conflict by definition of *kind* and/or *ontology*. It means that conceptual change requires a shift across ontological categories" (p.72).

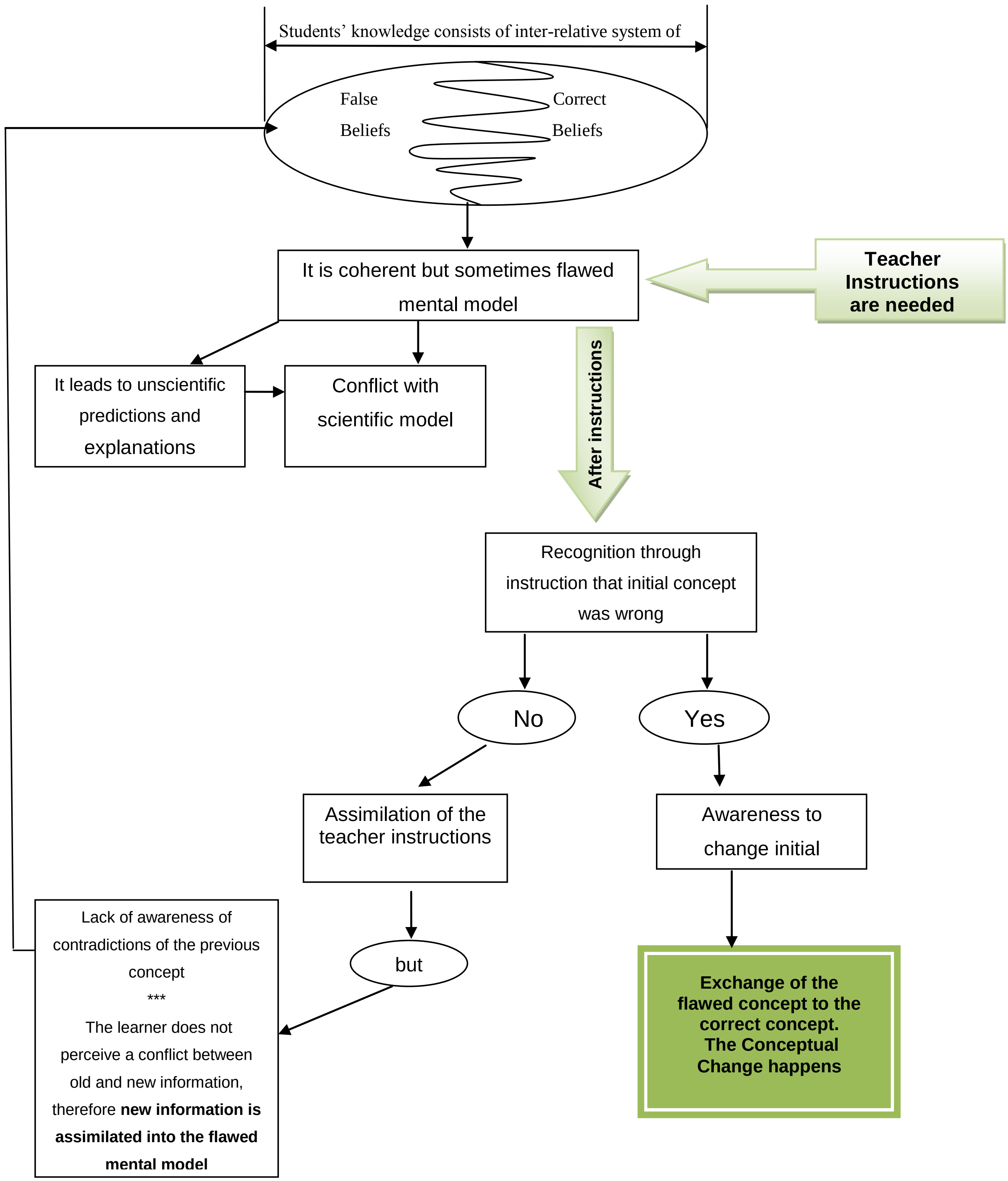


Figure 1. The mechanism of conceptual change for mental models (adapted from Chi, 2008).

A good example of re-assigning a concept from one category to another was presented by Chi, Slotta, & DeLeeuw (1994). They argued that re-assigning a whale from the category of "fish" to the category of "mammal," changes the fundamental essence or ontology of the concept "whale."
In summary, Chi's supposition states that any concept can be ontologically classified under three primary categories of MATTER (or THINGS), PROCESSES and MENTAL STATES:

Categories within a given tree differ ontologically from any category on another tree, because they do not share any ontological attributes. For example, any category of MATTER, such as Living Things or Solids, is ontologically different from any category of PROCESSES, such as Naturally Occurring Events. An ontological attribute, as distinct from either defining attributes or characteristic features, is a property that an entity may *potentially* possess as a consequence of belonging to that ontological category; whereas defining attributes are those an entity *must have,* and a characteristic feature is one that an entity *most frequently* has (Chi, 1994, p.28).

Figure 2 schematically represents Chi's theory of ontological categories.

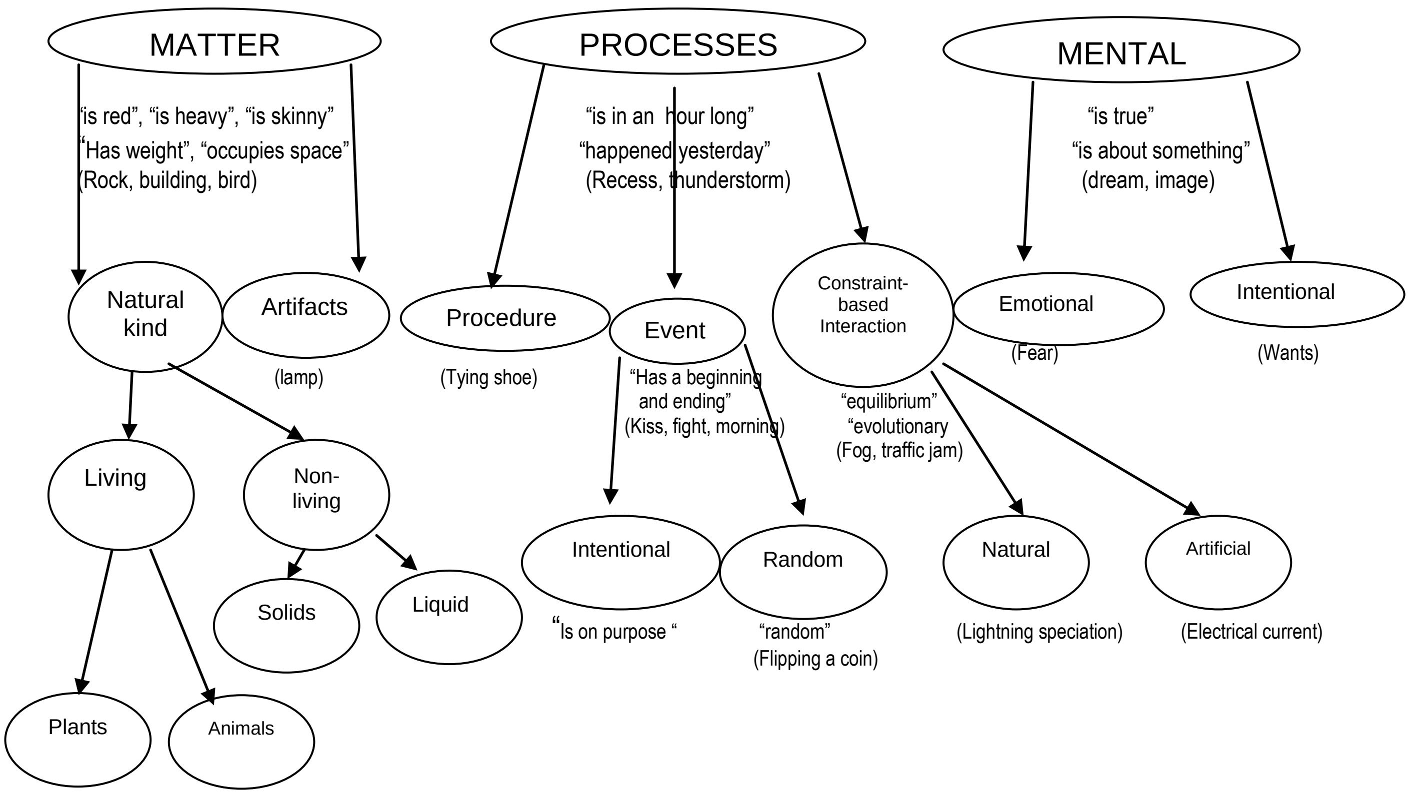


Figure 2. An epistemological supposition of the nature of our conceptions about the entities in the world. The three primary categories of MATTER, PROCESSES, and MENTAL STATES are ontologically distinct, and other subcategories on each tree, may be as well. (Chi et al. 1994, p.29)

Observing various studies, Ozdemir & Clark (2007) concluded that time is an important component in the conceptual change process:

Radical changes do not take place suddenly. Rather, they involve gradual and time-consuming processes because the student must revise and restructure an entire network of beliefs and presuppositions. While Chi's argument focuses specifically on changing ontological categories, Vosniadou and Ioannides (1998) suggest that ontological change is only one of the changes required in the process of changing theories. As students slowly revise their initial conceptual system over time by adding the elements of scientific explanation, students should be guided through instruction to create larger theoretical constructions with greater explanatory power (p.354).

In the traditional approach, many researchers agree that learning is a process of removing students' misconceptions from cognitive structures and inserting appropriate scientific (or experts') concepts (Smith et al. 1993). But some scientists disagree with this evaluation. DiSessa is the most well known opponent of the traditional approach to students' naïve concepts. He argued that a big contradiction exists in the evaluation of learners' misconceptions. From one side, for the successful conceptual change, a traditional approach requires a conflict between novices' concepts and experts' concepts. From the other side, "if we accept a mistaken character of misconceptions, they cannot serve as resources" (Smith et al, 1993, p.125). DiSessa and colleagues argued that "confrontation essentially denies the validity of students' ideas. It communicates to students that their specific conceptions and their general efforts to understand are fundamentally flawed" (Smith et al., 1993, p.126). Researchers proposed that misconceptions do not always have a mistaken character. Conceptions that lead to erroneous conclusions in one context can be quite useful in others. "Motion implies a force," although inadequate in many mechanical situations, provides a reasonable explanation of why electrical current flows in proportion to voltage (Smith et al., 1993, p.152).

In 2007 Ozdemir and Clark evaluated students' initial knowledge and separated it in two different categories: (a) *Knowledge-as-theory perspectives,* (b) *Knowledge-as-elements perspectives*.
In the first category, students' naïve conceptions of about to-be-learned concepts somehow are already organized in a system (a traditional approach). In the second category, students' preconceptions are considered as ecology of quasi-independent elements:

Knowledge-as-elements perspectives propose that naive knowledge is a collection of quasi-independent simple elements within a larger conceptual ecology that are loosely connected into larger conceptual networks without an overarching structure. Knowledge-as-elements perspectives also predict that individuals may simultaneously maintain multiple conflicting ideas on a regular basis (p.356).

Ozdemir & Clark (2007) compared most important similarities and differences between knowledge-as-theory and knowledge-as-elements perspectives. Table 1 provides a summary of these similarities and differences.

| **Agreements** | |
|---|---|
| 1. Learners acquire knowledge from their daily experiences.<br>2. Learners' naïve knowledge influences their formal learning.<br>3. Much naïve knowledge is highly resistant to change. Thus, conceptual change is a time consuming process. | |
| **Disagreements** | |
| **Knowledge-as-Theory Perspectives** | **Knowledge-as-Elements Perspectives** |
| Naïve knowledge is highly organized in theory, schema, or frame forms. | Naïve knowledge is a collection of quasi-independent knowledge elements. |
| Naïve knowledge in a coherent form has explanatory power to consistently interpret the situations across broad domains. | Consistent application over time for individual contexts, and systematicities will be present, but high contextual sensitivity. |
| More focus on revolutionary replacement of naïve knowledge in a manner similar to Kuhn's perspectives on paradigms in science. Significant coherence between ideas at any given point in time. | More focus on conceptual change involving evolutionary revision, refinement, and reorganization. Multiple conflicting ideas may coexist simultaneously at any given point in time. |
| Explanations involve the creation of mental models constrained through the overarching framework theories or ontological categories. | Explanations involve the p-prims and other elements within the learner's conceptual ecology that are most strongly cued by the context. |

Table 1. [Summary Comparison of Knowledge-as-theory and Knowledge-as-elements Perspectives (Ozdomir & Clark, 2007, p.355)].

**Different approaches to students' misconceptions in Science, Technology, and Engineering.**

Research on misconceptions in science is more expanded and more deeply developed than similar research in technology or engineering. Table 2. shows major differences in approaches (which were found analyzing related literature) to misconceptions in science, technology, and engineering.

| Literature about misconceptions in Science | Literature about misconceptions in Technology | Literature about misconceptions in Engineering |
|---|---|---|
| Almost always related to the explanation of physical phenomena. | Often repeated statement: that research on misconceptions in technology is less expanded and developed than research on misconceptions in science. | Content of the literature devoted to misconceiving in engineering is more clearly defined comparing to the literature about misconceptions in technology. |
| Describes correct-incorrect perceptions and understandings of phenomena by students (for example, force, temperature, light) | The literature mentions absolutely different aspects and themes depending on definition "what is technology". | Literature defines various complications, which are related to "the problem solving process". |
| In general, it can be presented in a few stages:<br>• Describe a phenomenon;<br>• Ask students what they think about this phenomenon. "In physics education research, it is common to gain insight into conceptual knowledge by showing the student a physical situation and asking what will happen and why." (Streveler, Litzinger, Miller, & Steif , 2008, p. 281)<br>• Analyze the answers (correct and incorrect perceptions of this phenomenon)<br>• Make an attempt to understand how the incorrect meaning of the phenomenon occurs;<br>• Discuss a robustness of students' misconceptions.<br>• Almost all literature about misconceptions in science (and in physics) is connected in many ways to the psychological literature about conceptual change theories. Every theory of conceptual change has its own explanation for students' misconceptions and offers its own mechanism for overcoming these misconceptions. | Examples of the most often discussed themes:<br>• Teachers' misconceptions about technology education and educational technology;<br>• Gender differences in interaction with technology (misunderstandings, confusions and misconceptions)<br>• Technology in relation to innovations. Misconceptions about technology presented as misconceptions about innovations;<br>• Perceptions and misconceptions about technology (as a tool) by business management, and managers' resistance to new technologies.<br>• Conceptual misunderstandings in biotechnologies or others technologies (for example: nano-, computer-, or medical-) that are closely related to sciences. In this type of literature the approach to misconceptions in technology is usually the same as in the research on misconceptions in science. Big attention is paid to (a) clear understanding of scientific concepts by students; (b) conceptual change theories as an instrument to overcome students' misconceptions.<br>• Misconceptions about the use of technology in K-12.<br>• Misunderstandings and technical misconceptions about distance learning, online-education and multimedia.<br>• Almost all literature about "misconceptions in engineering" somehow includes the term *technology*.<br>• Describes a strong link between engineering (as a problem solving process) and technology (as a tool or product, which is made by engineers). Therefore, literature paid close attention to clear understanding of scientific concepts by engineers. | Examples of various themes that are mentioned in research about misconceptions in engineering:<br>• Evidence that many engineering students (including seniors who have completed science courses) still do not understand key relationships between scientific concepts .<br>• Attempts to explain misconceptions in engineering by already existed theories of conceptual change.<br>• Refer to cognitive psychology literature. "Issues include the basic organization of students' conceptual knowledge and explanations about why some misconceptions tend to be more difficult to correct than others" (Streveler et al., 2008, p.280).<br>• Complaints on rigor curriculum and math requirements for engineering- major students.<br>• Misconceptions related to engineering education. Discussions about what curriculum changes have to be made to make engineering profession more popular.<br>• Various gender misconceptions about engineering and discussions of women roles in engineering.<br>• Discussion of robustness of misconceptions and resistance to overcome.<br>• Many authors agreed that research on misconceptions in engineering is undeveloped; there are more questions than answers. This field needs more investigations. |

Table 2. Different approaches in literature about misconceptions in science, technology, and engineering.

**Conclusion and possible directions for the future research**

The contemporary literature on research about students' misconceptions is widely presented and consists of many various topics and themes. As it is said above, this literature review is a work in progress and the part of the dissertation research. At that moment, four possible research questions are being considered:

- What are the differences in misconceptions (e.g., about electronics) between freshman-level and senior-level engineering-major students? Stated another way, do misconceptions about electronics change during students' progression from freshmen-level to senior-level?

- How strong is correlation between students' *theoretical* misconceptions and *practical confusions and misunderstandings* during lab-sessions, when students have to apply their procedural knowledge and practical skills?

- What are the differences (if any) in misconceptions about electricity between senior-level "science" students (e.g., from the Physics department) and senior-level "technology" students (e.g., from the Electrical and Engineering Technology department)?

- If there is any correlation between the student grade-level and the conceptual understanding of the phenomenon? How realistically grade-level (e.g., GPA) represent knowledge of freshmen and senior students?

The final decision in which direction to go is not made yet. At the present time each of these questions is under deep consideration to choose the most beneficial way for the future research. Methodology and possible procedures for collecting the data may include:

- Clinical interviews of students, open-ended questions;
- Qualitative or mixed method;
- Phenomenology or Ground Theory.
- Correlational research.
- Concept inventory as an assessment tool to evaluate students' conceptual understanding in electronics.

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