AC 2010-1157: EFFECT OF PEDAGOGY ON CONCEPTUAL CHANGE IN REPAIRING MISCONCEPTIONS OF DIFFERING ORIGINS IN AN INTRODUCTORY MATERIALS COURSE

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Effect of Pedagogy on Conceptual Change in Repairing Misconceptions of Differing Origins in an Introductory Materials Course

Abstract

Different pedagogies will affect how conceptual change and repair of misconceptions occurs. Taber has developed a categorization scheme for classifying origins of misconceptions which he refers to as "impediments". In particular, he states that there are two general types, each with subtypes. Null impediments refer to missing information (necessary for learning new material) due to students: 1) not having prior knowledge (deficiency) or; 2) not recognizing links between new material and their prior existing knowledge (transfer). Substantive impediments refer to faulty conceptual models which originate from: 1) observations or personal experience or (experiential); 2) prior courses and teaching (pedagogic) or; 3) bending or misinterpreting of new concepts to fit prior knowledge (misinterpretive). Knowledge of the origin of different types of misconceptions can be useful in selecting more effective pedagogical techniques for repairing of the misconceptions. Thus, in this paper we address the research question of, "What is the effect of different pedagogies on misconception repair as classified by Taber's five categories of misconception origin?" Conceptual change in an introductory materials course was measured by the Materials Concept Inventory (MCI) for five differing pedagogies used by the same instructor in 2002, 2003, 2007, Spring 2009, and Fall 2009. Conceptual change theory framed the study which used results of Hake gains from specific MCI questions to generate misconceptions that fit each of Taber's five categories. Conceptual change differed for the various pedagogies. Overall, however, there was a trend in the effectiveness of differing pedagogies in achieving conceptual change. Ranked from highest to lowest, the order of pedagogy effectiveness, as measured by increases in conceptual change, was found to be: 1) team discussions with hands-on activities and concept sketching in 2007; 2) team discussions with contextualized concept mini-lectures and activities in the Spring of 2009; 3) team discussions, contextualized concept lectures and activities, plus pre-post topic assessments and daily reflections in Fall 2009; 4) lecture with some discussions in 2003 and; 5) lecture only with no team discussions or activities in 2002. It was found that all pedagogies using student engagement achieved greater conceptual change compared to passive learning and lecture-only pedagogies. Another interesting effect for the two pedagogies in Fall and Spring 2009, which used contextualized concept mini-lectures and activities, was that course dropout rate was lowered and course retention improved to 95%. This was an increase from 89% in 2002, 86% in 2003 and 82% in 2007. While all active learning pedagogies were better than passive lecturing for achieving conceptual change, different categories of Taber's misconception origins were more effectively addressed by different active learning pedagogies. It was found that an awareness of Taber's misconception origin categorization scheme, as used in conjunction with frequent formative assessment and feedback, has proven effective in uncovering new and diverse misconceptions in materials engineering. The usefulness of Taber's classifications with frequent formative feedback for improving teaching and learning is discussed and assessed in the paper.

Introduction

In introductory materials science and engineering (MSE) courses students come from various engineering disciplines and have taken many physical science classes through their K-13 education, including one or two college level chemistry classes. The goal of the K-13 classes is for students to be able to understand and explain nature, including the characteristics and chemistry of materials. As such, there may be limited exposure to important engineering materials, such as metals and polymers, in students' K-13 education. However, since the goal of engineering is to use science and mathematics to create new entities to benefit society, the focus of the introductory MSE class is to learn the approach that materials science and engineering uses for the processing and properties of materials for real world applications in the engineering design of components, devices, and systems. As a result, the conceptual framework of students must shift from an understanding of physical science and the chemistry of materials towards a framework of an understanding of the processing and properties of materials for engineering applications. It is therefore particularly important to understand students' prior knowledge and personal experience for each of the eight to ten topics studied in an introductory MSE course. Thus, it is critical to use both formative (such as clicker questions) as well as summative (such as the Materials Concept Inventory (MCI)[1]) assessment tools to characterize misconceptions and the effectiveness of pedagogy in addressing those misconceptions.

For instructors to create an effective learning experience they must be aware of and acknowledge students' *conceptual frameworks* and *mental models*[2]. Each student's framework and collection of mental models have been developed from *prior knowledge* acquired from academic settings of earlier physical science and chemistry classes and from everyday *previous personal experience,* where information might be acquired from sources such as personal observation, the television, and the internet. The *mental models* that do not align with scientifically correct consensus models of the scientific community, such as the ductile copper atom[3], are *misconceptions*. These scientifically inaccurate interpretations of the world can neither explain nor predict characteristics and behavior of systems and phenomena of interest. In order for an instructor to facilitate more effective student construction of new knowledge, students' misconceptions need to be characterized and addressed. There are various approaches and tools available to do this.

Much research has been done on uncovering and repairing misconceptions. For example, Hestenes created the Force Concept Inventory to identify misconceptions students hold about Newtonian physics[4]. Many other concept inventories have been created for other science, math, and engineering disciplines, including the MCI for use in introductory MSE classes[5]. Likewise, various pedagogies that use active learning have been developed based on the findings of Hake[6] and many others that report that in order to achieve significant conceptual gain in a given subject, students must be actively engaged in their own learning. However, some concepts are still difficult to teach and learn even with active learning pedagogies because there are present misconceptions which are persistent and difficult to repair. These have been referred as "robust" misconceptions by Chi[7], Streveler[8] and others. One approach to better address such robust misconceptions has recently been proposed by Taber, who has devised a schema for categorizing the origins of the misconceptions[9]. Chi has also suggested a method to classify effectiveness of different active learning activities by hypothesizing the underlying cognitive processes[10].

Background

Characteristics of Effective Learners. Significant findings for cognition of teaching and learning have been summarized by the book, *How People Learn*: *Brain, Mind, Experience, and School*[11]. One important finding is that students have prior knowledge about how the world works, consisting of preconceptions (if incorrect, misconceptions) and, if their initial understanding is not engaged, they may fail to grasp new concepts and information and revert to their preconceptions outside the classroom. A second finding is that novice learners are unlike expert learners in that experts have developed the learning skills to build a deep content understanding of their subject and have facts and ideas organized into a conceptual framework that facilitates retrieval and transfer to new and different applications. A third finding is that experts are metacognitive learners who develop their own expertise by defining learning goals and monitoring their progress. In this study we are focused on the first finding. In particular, since all learning involves transfer from prior knowledge and previous experiences, an awareness and understanding of a learner's initial *conceptual framework* and/or topic can be used to formulate more effective teaching strategies. If this idea is taken a step further, it could be said that, since misconceptions comprise part of a conceptual framework, then understanding origins of misconceptions would further facilitate development of effective teaching strategies. MSE is an applied field which has, as a major goal of the discipline, educating students of other engineering disciplines on how to control a material's macroscale properties based on the understanding of its nanoscale structure. But, achieving this goal is a significant intellectual challenge to learners who must develop their own *mental models*[2] that effectively link the concrete "macroworld" of everyday objects and phenomena to the abstract "nanoworld" of atoms, molecules and microstructure. Students enter introductory MSE classes with a *conceptual framework* comprised of *mental models.* These arise from *prior knowledge* acquired in an academic setting of earlier chemistry classes or from everyday *previous experience* where information might be acquired from sources such as personal observation, the television, and the internet. When students' *mental models* fail to align with scientifically correct models, they are often referred to as *misconceptions*. These are scientifically inaccurate interpretations of the world that can neither explain nor predict the characteristics and behavior of the systems and phenomena of interest. Some examples include the explanation that copper metal is malleable because "individual copper atoms are malleable[3] or that the metal nickel can only exist as a solid[12]." Such misconceptions inhibit or impede conceptual change.

Conceptual Change and Mental Models. Learning can be defined as *conceptual change* with students learning most effectively by constructing their own knowledge through modification of their *conceptual framework*. The framework is comprised of *mental models*, which are simplified, conceptual representations that are personalized interpretations of *target systems or phenomena* in the world around us. Useful *mental models* allow a learner to understand, explain, and predict behavior of systems and phenomena, whereas faulty *mental models* that lead to misconceptions do not. Thus, characterizing a learner's initial *conceptual framework* is useful since prior knowledge and previous experiences may facilitate or impede learning. Learning can be facilitated by activating prior knowledge from an earlier class or with a familiar context for new material to provide a linkage to a learner's previous experiences. Conversely, learning can be impeded by misconceptions that originate from personal experience, previous classes, or misapplication of prior knowledge to new content.

Conceptual change is sometimes difficult and may be impeded by robust misconceptions resistant to change because of students' arguments, contradictions, and obstinacy[13]. Thus, the general strategies of assimilation or accommodation have been used to promote conceptual change[14]. The strategy of assimilation is to build on existing *mental models* and associated concepts of a conceptual framework. In contrast is accommodation, change occurs by revision or replacement of an existing misconception and associated *mental model*[15]. Misconceptions must be identified before they can be analyzed and addressed. They may be revealed by various methods such as pre-class, in-class, or two-tiered questions (multiple choice plus open-ended explanation), student interviews, focus groups, classroom talking, writing, or sketching. Here, conceptual change and innovative teaching strategies were assessed with the MCI.

Conceptual Change Theories. There are several conceptual change theories commonly used by science and engineering education researchers[16]. Posner, Strike, and Gertzong's[17] theory of conceptual change requires four conditions for conceptual change to occur: 1) there must be dissatisfaction with the students' existing concept, 2) the new concept must be intelligible, 3) the new concept must be plausible, and 4) the new concept should be fruitful. Discrepant events have been used in the light of this theory. An example that shows the buoyancy of a large and a heavy object, such as wood in water, forces students to reconsider the misconception that heavy objects always sink. More recently, new theories have emerged that focus more on understanding why some science concepts are so difficult to learn. For example, Vosniadou and Ioannides's "theory-theory" states that students form their own theories of science concepts which are sometimes in conflict with scientific theories[18]. An example of such a faulty theory is the impetus theory that all moving objects have to have a force that acts in the direction the object is moving. diSessa[19], on the other hand, argues that students have partial and fragmented understanding of concepts that he calls "knowledge in pieces." According to this conceptual change theory, a child can have a normative understanding of a concept such as thermal equilibrium in room temperature in one context (e.g., for wood) but not in another (e.g., for metals). diSessa would argue that this occurs because the student pulls together pieces of knowledge to form a conception to answer a question. However, the pieces that are chosen may differ depending on the situation. Chi's[20] "ontological theory of conceptual change" is a theory that sheds light on causes of robust misconceptions. Chi says concepts such as electric current and heat are difficult because they miscategorize these concepts as "things" rather than "processes." A challenge for engineering and science educators is to decide which framework to use to study conceptual change.

Taber's Impediment Classification Scheme. Regardless of which theoretical framework is used to describe conceptual change, engineering and science educators remain concerned with student misconceptions. To facilitate misconception repair, Taber created a classification system based on misconception origin as a type of "impediment" to learning. He specifies two general types, both with subtypes[9]. *Null impediment* refers to missing information (necessary for learning new material) due to students: 1) not having prior knowledge (*deficiency*) or; 2) not recognizing links between new material and their prior existing knowledge (*transfer*). *Substantive impediment* refers to faulty concept models students hold from: 1) personal experience or observations (*experiential*); 2) prior courses and teaching (*pedagogic*) and; 3) bending or misinterpreting of new concepts to fit prior knowledge (*misinterpretive*). These categories are summarized in Table 1 shown below.

Table 1. Taber's Classification Scheme Describing Impediment Types and Definitions[1]

Type of Impediment	Definition of Impediment
1. null deficiency impediment	missing information necessary for learning new material due to students not having prior knowledge
2. null transfer impediment	missing information necessary for learning new material due to students not recognizing the links between new material and their prior existing knowledge

1. substantive experiential impediment	faulty concept models students hold from personal experience or observations
2. substantive pedagogic impediment	faulty concept models students hold from prior courses and teaching
3. substantive misinterpretive impediment	faulty concept models students hold from bending or misinterpreting of new concepts to fit prior knowledge

We are using Taber's classification method, in conjunction with results of the MCI, to assess the effectiveness of different pedagogies and associated learning strategies for repairing misconceptions of different origins in MSE courses. Overall, the research question we are investigating in this paper is, "What is the effect of different pedagogies on repair of misconceptions that have been classified by aligning them with Taber's five categories of misconception origin?"

Methods

In this paper we report on applying the previously discussed theoretical approaches for conceptual change to better explain and understand results of the MCI when used to assess conceptual gain for the classroom practice of an introductory MSE course which used five different pedagogies. These included: lecture only in 2002; lecture with some discussions in 2003; team discussions with hands-on activities (concept sketching) in 2007; team discussions with contextualized concept lectures and activities in Spring 2009; and team discussions, contextualized concept mini-lectures and activities, plus pre-post topic assessments and daily reflections in Fall 2009.

Summative assessment was done with the MCI which has been shown to be a valid and reliable instrument, with factor analysis giving a Cronbach's alpha of 0.71[5]. In this work the MCI has been used to measure conceptual change over a semester for four introductory MSE courses taught by the same instructor who employed four different pedagogies in the years 2002, 2003, 2007, and Spring and Fall 2009. The student percentage gains over a semester have been calculated using the Hake method[6]. The calculation Hake used is given by the equation:

$$\% \text{ gain} = ((\text{post-score} - \text{pre-score}) / (100 - \text{pre-score})) \times 100.$$

The sections described here were one of three taught every fall and spring term at Fulton School of Engineering at Arizona State University. The course is required by some other engineering disciplines and was populated mainly by sophomore and junior mechanical engineering undergraduates who comprise two-thirds of the class. The remaining one-third were students from other disciplines who were taking the course either as an elective or because it was required. The MCI was administered during the first and last weeks of class in paper form in 2002 and 2003 and via computer outside class in 2007 and 2009 Spring and Fall. Students took the test voluntarily for all classes as handouts at the beginning and the end of the semester, except the entering and exiting Spring and Fall 2009 MCI in which case they took the test via computer and received an incentive of a 2 point bonus in the 80 point maximum scale for the semester. Focus groups were held twice a semester during the 2002 and 2003 courses and were also held biweekly in the Spring 2009 course. The questions selected from the MCI are shown in Figure 1 and the MCI results for all years for those questions are shown in Table 2.

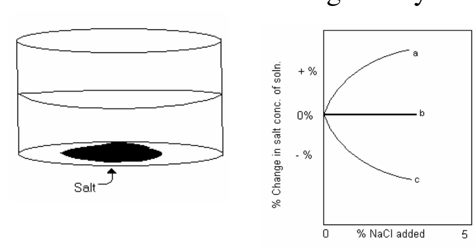
Figure 1. Materials Concept Inventory Questions Numbers 1, 5, 4, 16, and 15

1. Atoms in a solid:
a) Cannot move, only electrons can
b) May move through vacancies in a crystal lattice
c) May move in the spaces between atoms in a crystal lattice
d) Can move through both vacancies and in the spaces between atoms in a crystal lattice
e) None of the above

5. The melting points of most plastics are lower than most metals because:
a) covalent bonds are weaker than metallic bonds
b) ionic bonds are weaker than metallic bonds
c) Van der Waals bonds are weaker than metallic bonds
d) covalent and Van der Waals bonds are weaker than metallic bonds
e) ionic and Van der Waals bonds are weaker than metallic bonds

4. Nickel can exist as:
a) solid only
b) liquid only
c) gas only
d) liquid or solid only
e) gas or liquid or solid

16. When three tablespoons of salt are mixed into a glass of water and stirred, about a teaspoon of water-saturated salt remains on the bottom. If a small % of salt is slowly added to the glass while stirring the solution, the change in concentration of the salt in the solution is given by curve:



15. If a small amount of copper is added to iron the electrical conductivity will change as shown:

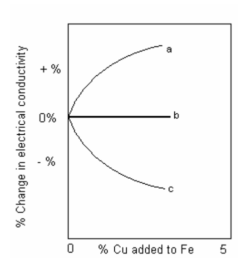


Table 2. MCI Pre-Class, Post-Class & Gain Scores for 2002, 2003, 2007, Spring and Fall 2009

	2002			2003			2007			Spr 2009			Fall 2009		
MCI Abbreviated Question	pre	post	gain	pre	post	gain	pre	post	gain	pre	post	gain	pre	post	gain
Participation: n = number of participants % = 100 (n / total enrolled at time of MCI)	n=51 85%	n=49 91%	-	n=43 84%	n=38 79%	-	n=33 83%	n=31 94%	-	n=34 85%	n=34 84%	-	n=34 85%	n=26 68%	-
1. Can atoms move in a solid?	29%	65%	51%	24%	68%	58%	16%	100%	100%	0%	63%	63%	22%	8%	69
5. Why is Tmelt of polymers lower than metals?	24%	31%	9%	6%	13%	7%	32%	30%	-3%	0%	5%	5%	11%	30%	21%
4. Can Ni exist in solid, liquid & gas phases?	45%	51%	11%	47%	53%	11%	55%	93%	84%	50%	73%	46%	60%	92%	80%
16. What is effect of NaCl added to saturated solution?	39%	65%	43%	49%	82%	65%	42%	96%	93%	27%	81%	74%	46%	75%	54%
15. What is effect of Cu added to Fe on conductivity?	20%	75%	69%	12%	61%	56%	13%	75%	71%	14%	45%	36%	11%	63%	58%

After summative conceptual gain measures were found, misconceptions that were found to be relatively robust over the various terms were collected. The origin of each of these misconceptions was then determined by use of Taber's Classification Scheme of impediments. Once misconceptions were classified, different pedagogies were compared to establish which pedagogical approaches resulted in greatest effectiveness for repair of different types of misconceptions.

Results and Discussion

Null-impediment Based Misconceptions

The first type of null impediment (missing information necessary for learning new material), a *null deficiency impediment,* refers to a lack of prior knowledge. An example of this is the diffusion of atoms in a solid, as shown from Question #1 located in Figure 1. In K-12 and college chemistry students learn atoms in liquids and solids are in "motion" but oscillate about a point in a solid and have 3-D translations in a liquid. However, MCI pretest scores shown in Table 2, which range between 0% and 29%, show most students entering MSE classes unaware that solid state diffusion can occur at higher temperatures, typically Tm/2 (k). Since there is "missing information", this is a *null deficiency impediment* which students would not be expected to understand. However, MSE instructors assume students have some familiarity with diffusion and may fail to define or explain the concept of solid state diffusion, thus increasing the difficulty of understanding the topic. This is evident from post test scores, which range from 63% to 78%, except for 2007 when there was 100% gain. The content in this question is important because students who fail to understand diffusion will have their learning impeded for topics such as annealing and isothermal transformation of steels. Thus, for students to better understand atomic motion and diffusion it is suggested that instructors devise team based creative learning activities. For example, one such activity is to use coins to trace diffusion of an atom.

The second type of null impediment is missing information, or a *null transfer impediment,* which is due to students not recognizing the links between new material and their prior existing knowledge. An example of this is, the effect of bond strength on relative melting points of 3 materials families (metals, polymers, and ceramics). This misconception is identified by MCI question #5 shown in Figure 1. In K-12 and college chemistry students supposedly learn about the three types of primary bonding, metallic, ionic, and covalent, as well as weaker secondary bonding, but the types of interatomic bonding may not be explored much. Although the bonding along the polymer chain is covalent, information may not be given or discussed about van der Waals bonds between chains which significantly affects properties such as Tm and tensile strength. So it is not a surprise that MCI pretest scores in Table 2 range between 0% and 32% which indicates less than a third of the students may not have transferred bonding concepts from earlier courses. Most MSE instructors assume students are familiar with the different bonding types, and associated melting points, for the three families of materials. Thus, they may fail to define, explain, or review the concepts of bonding between or within the three families of materials, likely increasing difficulty of understanding the topic. This may be so, as seen from gain scores, which are quite low, ranging from -3% to 10%, except for the most recent section in Fall 2009 where the gain was 21%. Although this represents only a moderate gain, the pre-topic assessment revealed the lack of any knowledge at all about metallic and van der Waals bonding by a significant majority of all students in class. The modest 21% gain was only achieved with the addition of supplemental material and an activity for which students were able to define, understand and use the concepts of metallic and van der Waals bonding in discussions, homework problems, and tests. Students who fail to effectively understand polymer bonding will have learning impeded for a wide variety of subsequent topics related to processing and properties of polymers.

Substantive-impediment Based Misconceptions

The first type of substantive impediment, a *substantive experiential impediment,* refers to faulty concept models students hold from personal experience or observations. An example of this is with respect to phases of a material is given by MCI question #4 in Figure 1. This example considers importance of materials phases, since metals, ceramics and polymers can be processed from all phases. MCI results and focus group talk showed students believe metals exist only in the solid phase or only in the liquid and solid phases for this misconception. Personal experience from focus groups gave wrong answers like: “I have never heard of Ni gas”, “I have never seen Ni gas”, and “I have only seen Ni as a solid”. MCI pretest showed only half of the students understood that elements can exist in three phases with scores ranging from 45% to 60%. The post-test MCI scores show an interesting result. The pedagogies of lecture (2002) and lecture + discussion (2003) both showed minimal gains of 11%. The other three classes based on team discussions showed better gains of 84% (2007), 46% (Spring 2009) and 80% (Fall 2009). Well-engaged students constructing their own knowledge showed this approach to be most effective for conceptual change. This may be a situation where students are not connecting this question to other materials such as water as ice, liquid, or gas. Thus, discussion and concept sketching achieves higher conceptual gains in the MCI indicating that a combination of these activities is more effective for conceptual change and learning.

A second type of substantive impediment, a *substantive pedagogic impediment,* refers to faulty concept models students hold from prior courses and teaching. An example of this is with respect to solutions and solubility limits is given by MCI question #16 in Figure 1 above. Concepts of saturation and supersaturation are used in phase diagrams in MSE (e.g. precipitation hardening). Research shows that in K-13, misconceptions on saturation and supersaturation are robust and persistent[12]. The MCI pre-class results support this idea with scores of 27% to 49%. More than half of the students bring solution-related misconceptions with them to their MSE classes, making this a *substantive pedagogical misconception*. The post-class MCI scores show gains of 42% in 2002, 49% in 2003, 65% in 2007, 93% in 2007, and 74% in Spring 2009, and 46% in Fall 2009. The gains increase as pedagogy goes from lecturing, to team discussion and concept-context problem solving pedagogies, but the highest again is team discussions with concept sketching. Thus, when students engage in discussion while constructing something, like a visual model of a phenomenon, their learning is greatest. From focus groups and concept questions it appears that saturation is misunderstood by students who do not understand the concept of solubility and solubility limit. Thus they have a framework which does not incorporate equilibrium in solution based processes. The topics of solutions and solubility play a critical role in many MSE topics related to phase diagrams, microstructures, and non-equilibrium thermal processing so it will be important for instructors to utilize the most effective pedagogy to prepare students for future classes.

A third type of substantive impediment refers to faulty concept models students hold from bending or misinterpreting of new concepts to fit prior knowledge and is referred to as a *substantive misinterpretive impediment.* An example of this, with respect to calculating the properties from the macroscopic "rule of mixtures" as given in MCI question #15 is shown in

Figure 1. Incorrect prediction of macroscale properties can occur by use of the macroscopic "rule of mixtures". This means properties of a mixture of two or more materials are proportional to the volume fraction of the individual component materials' properties. Thus, if 1% Cu (which has three times the electrical conductivity of Zn) is alloyed with Zn, "rule-of-mixtures" reasoning predicts a 3% increase in conductivity (3X conductivity x 1%). Actually, there is a 6% *decrease* in conductivity. The reason is that, at the nanoscale, there are many more atomic level sites for impurity scattering of electrons that reduce conductivity. This shows the counterintuitive nature of materials' properties and how students create substantive impediment misconceptions when using an already existing model of *rule of mixtures* to predict the effect on electrical conductivity of one element added to another. For a similar question on the MCI, less than 20% of students were correct with pre-MCI scores ranging from 12% to 20%. The post test results show good gains for all four pedagogies on the posttest but the best again was for the 2007 discussion with concept sketching. A possible macroscopic view could be an inappropriate analogy like electrons flowing through a wire like water flowing through a hose which could lead to this misconception.

The results are summarized in Table 3 which relates the MCI questions to the impediment type and the relative effectiveness of the different pedagogies in addressing misconceptions. It can be seen that for four out of the five questions the 2007 TD1 (team discussion + concept sketching) had the highest gains. The higher gains were particularly dramatic for the first and third selected questions about atomic motion in solids and existence of three phases of materials. It may be possible that discussion and concept sketching can provide a pathway to link macroscopic and microscopic behavior with more concrete expressed models than discussion can alone. On the other hand, the second and fifth questions, which may be ontologically related misconceptions, concept sketching had a more limited impact on repairing misconceptions.

Overall, Table 3 shows that there was a trend in the average effectiveness of differing pedagogies in achieving conceptual change. Ranked from highest to lowest, the order was found to be: 1) team discussions with hands-on activities and concept sketching in 2007; 2) team discussions with contextualized concept mini-lectures and activities in the Spring of 2009; 3) team discussions, contextualized concept lectures and activities, plus pre-post topic assessments and daily reflections in Fall 2009; 4) lecture with some discussions in 2003 and; 5) lecture only with no team discussions or activities in 2002. It was found that all pedagogies using student engagement achieved greater conceptual change compared to passive learning with lecture-only pedagogy. Another interesting effect for the two pedagogies in Fall and Spring 2009 that used contextualized concept mini-lectures and activities was that course dropout rate was substantially lowered and course retention increased to 95% compared to 89% for 2002, 86% for 2003 and 82% for 2007 classes. Overall, all active learning pedagogies were better than passive lecturing for achieving conceptual change. However, different categories of Taber's misconception origins were more effectively addressed by different active learning pedagogies. An awareness of Taber's misconception origin categorization scheme used in conjunction with frequent formative assessment and feedback has also proven effective in uncovering new and diverse misconceptions in materials engineering.

MCI Abbreviated Question	Impediment Type	Highest % Gain
1. Can atoms move in a solid?	null deficiency	TD1, TD3, TD2, LD, P
5. Why is Tmelt of polymers lower than metals?	null transfer	TD3, P, LD. TD2, TD1
4. Can Ni exist in solid, liquid & gas phases?	substantive experiential	TD1, TD3, TD2, LD, P
16. What is effect of NaCl added to saturated solution?	substantive pedagogic	TD1, TD2, LD, TD3, P
15. What is effect of Cu added to Fe on conductivity?	substantive misinterpretive	TD1, P, TD3, LD, TD2

Legend: P = Passive lecture 2002; LD = Lecture + discussion 2003; TD1 = Team discussion + sketching 2007; TD2 = Team discussion + sorting Spring 2009; TD3 = Team discussion + sorting + supplement Fall 2009

Table 3. Summary of results relating selected MCI questions to Taber's impediment type [9]

Summary and Conclusions

Overall, we have used conceptual change theory to frame the study to suggest possible effectiveness of different pedagogies in achieving conceptual gain (as measured by the MCI) and repairing misconceptions. This was done by using results of misconceptions associated with particular MCI questions as prototypes that fit Taber's five categories of impediments that underlie the origins of different types of misconceptions[9]. It turns out that the team discussion + concept sketching pedagogy in 2007 had the highest MCI gains for four out of the five questions based on Taber's five categories of impediments for misconception origins[9]. Of course this is a small data set, but these early findings are worthwhile pursuing by incorporating more concept sketching or other activities. This would allow students to put a concept model to use in a new situation by incorporating a sketch or 3-D model which demonstrates the application of a concept to a particular situation. This might correspond to a situation of far transfer according to where the concept is understood at a deeper level. This will be explored further in the upcoming spring 2010 semester. Summarizing the results for higher conceptual gain and possible effectiveness of the five pedagogies, they were ranked from high to low as follows: 1) team discussions with hands-on activities and concept sketching in 2007; 2) team discussions with contextualized concept mini-lectures and activities in Spring 2009; 3) team discussions, contextualized concept lectures and activities, plus pre-post topic assessments and daily reflections in Fall 2009; 4) lecture with some discussions in 2003 and; 5) lecture only with no team discussions or activities in 2002. It was found that all pedagogies using student engagement achieved greater conceptual change compared to passive learning with lecture-only pedagogy. The results indicate that it might be possible to use these principles to design and create instructional materials and activities that result in repairing misconceptions and fostering conceptual change for greater conceptual gain in materials science and engineering and possibly also other engineering disciplines. As such, there may the potential for improving student learning, attitude, and retention by employing the approaches to learning and assessment described in this paper.

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