Origins of Misconceptions in a Materials Concept Inventory From Student Focus Groups

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ABSTRACT

A Materials Concept Inventory (MCI) that measures conceptual change in introductory materials engineering classes uses student misconceptions as question responses, or "distracters", in the multiple-choice MCI test. In order to understand the origin of the misconceptions, selected sets of questions on particular topics from the MCI were discussed and evaluated with student focus groups. The groups were composed of six to ten students who met for two hours at the beginning of a semester with two "new" groups that had not taken the introductory materials course and two "prior" groups of students that had taken the course. Two examples of questions from one of the sets of topics that were discussed are presented from two areas of the thermal properties of metals. It was found that the logic and rationale for selection of given answers which were misconceptions arose from a variety of sources. These included personal observation, prior teaching, and television shows, as well as other sources. Some discussions led to suggestions of possible interventions for improving student learning and conceptual knowledge of a topic. Implications of the results and suggestions for possible improvements in teaching of introductory materials classes are discussed.

INTRODUCTION

In the past few years a number of engineering-science concept inventories (ESCIs) have been under development under the sponsorship of the NSF Foundation Coalition[1]. An ESCI is intended to provide a benchmark of conceptual knowledge for the general subject areas of a given course. An ESCI can then be used to assess the effectiveness of innovations used in the delivery of the course. This is particularly relevant since new theories of teaching and learning in engineering education have been emerging over the last decade. Such innovations include Internet courses, virtual experiments, computer classrooms, and team-based active learning.

The ESCI approach parallels that which the general physics community has been using which is called the Force Concept Inventory (FCI). It was created by Hestenes et al.[2, 3] and tested broadly by Hake[4] for students in high school and college physics classes. The FCI questionnaire utilizes a series of multiple-choice questions based on qualitative, concept-oriented problems on a particular topic, which is the approach that the ESCIs have followed. The FCI measures deep understanding and conceptual knowledge of a topic rather than the memorization of facts or the ability to carry out routine algorithmic equation solving. Thus, the FCI results are being used to measure the performance of students in physics classes with different teaching methods. The FCI has become a standard that has initiated changes in teaching methodology and stimulated healthy debate on best teaching practices.

Under the sponsorship of the NSF Foundation Coalition, a Materials Concept Inventory (MCI), which is one of the ESCIs, has been developed. The 30-question, multiple-choice MCI test was developed from a literature survey of assessment research in science and engineering in conjunction with extensive student interactions. It focuses on the subject areas such as atomic bonding, thermal properties, deformation of materials, and phase diagrams and solubility. It has been, and is being tested, on introductory materials engineering classes at Arizona State University (ASU) and Texas A & M University (TAMU). A key aspect of the MCI was discovering the student misconceptions that can be used as the incorrect answers for each question. Hestenes et al.[2] refers to these appealing, but incorrect, choices as "distracters", a term which has been adapted in the literature. The character of the distracters is discussed in the body of this paper. Also, an overall description of the development of the MCI and early results is given in earlier papers[5, 6].

The subject of this paper is on two aspects of the use of student focus groups in evaluating the MCI. One aspect is on the nature, organization, and activities of the student focus groups themselves. The other aspect is on the results of discussions on the origin of misconceptions for two example questions from the area of thermal properties of materials. They are the relationship of bonding strength to melting point of metals and on the phase state of metals. Additionally, implications of the results and some suggestions for possible improvements in teaching of introductory materials classes will be presented.

COMPOSITION, CONDUCT AND ACTIVITIES OF STUDENT FOCUS GROUPS

In prior work on the MCI, one method used to identify misconceptions was weekly interviews in which students from class would discuss current content, prior content, and the nature of misconceptions. This approach had limited usefulness because of two major problems. The first was the lack of focus for discussion with verbal dialogue only. The second problem was that the two or three students were hesitant to talk, possibly because they felt self-conscious or because they had little experience with reflective thinking. Both of these problems were solved with the approach described here. First, using selected sets of questions from the MCI gave students a focal point with specifics that led to directed dialogue. Second, the presence of six to ten students made them feel at ease in discussing their thoughts and viewpoints with their instructor. The composition, conduct and activities are described below.

There were four sets of two-hour focus groups with six to ten students. They met at the beginning of a semester with two "new" groups that had not taken the introductory materials course and two "prior" groups of students that had taken the course. The students were recruited with a free pizza lunch and a small stipend. The students first answered a selected set of ten to twelve of the 30 questions on the MCI, after which they could get their pizza. The number of students selecting each response for each of the questions was recorded. This was done to avoid changes in the explanations of given responses in the latter part of the test. The responses on each question were then discussed, with each student queried as to why he/she had selected that response. No indications of whether an answer was correct or not were given to the students until all of the questions had been completed.

There were a number of interesting aspects of the discussions on the questions. One aspect was that, in the discussion of a given question, a student or students sometimes realized that that they had chosen an incorrect answer and said they would change their response if given the question again. There was also an important and valuable aspect of the discussions with respect to student learning. This was that, although some students said that they had selected the correct response on a given question, they did not really understand the reason for their choice. This also means that responses on classroom exams to multiple choice questions, fill-in-the-blanks, and similar questions may not accurately reflect a student's knowledge on the topic. Occasionally, a given student's explanation was much clearer to other students than had been the content from the book or the lecture.

After discussions on all questions had been completed, the correct response was revealed and discussed. For the majority of the questions, the students were already aware of the correct answer, often from the prior discussion. However, on some questions there was uncertainty. The discussions here were quite valuable, both to the students and to instructor. It was felt that uncertainty of the correct answer meant that the question involved a topic that could be more difficult to understand, which was often the case. Different approaches to developing a solid understanding of a topic were brought forward by the students and the instructor. They were discussed and modified until all students developed an understanding for the correct answer. The discussions also led into the area of how each of the students study and learn new material and what their strengths and weaknesses in learning. Upon exiting the focus group, the students commented that, not only did they acquire an improved understanding of the subject matter, but also an improved knowledge of how they learn and how to improve their learning abilities. The instructor also learned, not only about origins of misconceptions, but also of student learning styles and difficulties and approaches to better teaching new material.

NATURE OF MCI QUESTIONS AND DISTRACTERS

The concept areas chosen for the MCI were atomic bonding, electronic structure and electrical properties, reactions and units, atomic arrangement and crystal structure, defects and microstructure, phase diagrams and solubility, and macroscopic mechanical properties. Within each of the subject areas, the questions were developed which were characteristic of its important concepts. Questions that were generated fell under both categories of what are referred to as Tier I and Tier II questions[6]. Tier I and Tier II can be thought of, in a given situation, as "what happens" (Tier I) and "why does it happen" (Tier II). Linking Tier II to Tier I responses is important in order to understand if the concept underlying the response in Tier I is understood, which can be revealed by the response in Tier II. In developing questions, one approach is to list a set of responses in a Tier I question and follow that with a line underneath the question to explain the response to the Tier I question. An example that is related to the MCI might be as follows.

When a cold worked material is heated and then cooled, its strength:

a) increases
b) decreases
c) stays the same

While the correct answer, b), may be given, it does not reveal if the concept underlying the phenomenon is understood. The associated Tier II question from the MCI with student generated distracters is as follows.

After a piece of Cu wire from a hardware store is heated it becomes softer. This is because:

a) the bonds have been weakened
b) it has fewer atomic level defects
c) it has more atomic level defects
d) the density is lower
e) there is more space inside the crystal lattice

The correct answer is b), and the three student-generated distracters of a), d), and e) were created during class using a Tier I statement followed by a fill in the blank line as shown below. This question was one of those used for the student focus groups.

When a piece of copper wire from a hardware store is heated it becomes softer.
This is because: ____

In introductory materials engineering classes the overall goal is to analytically link relationships of scientific concepts to macroscopic materials behavior. In particular this refers to linking relationships of atomic structure and bonding, band structure, crystal geometry, defects, microstructure, and phase diagrams to the properties of materials. The properties include, mechanical, thermal, electrical, optical chemical and others, but the focus will be on thermal and mechanical here. The families of materials include metals, polymers, ceramics, and semiconductors. In this paper, we have focused on two example questions on thermal characteristics of metals as the context to discuss the results of the focus groups. These examples will be supplemented by results of pre and post testing three sections of introductory materials engineering courses.

CORRELATION OF BOND STRENGTH TO MELTING POINT OF METALS

The effect of bond strength and thermal characteristics of materials is an early and important topic in introductory materials engineering courses. One question presented to focus groups relating the bond strength to the melting point of metals is shown below.

If atomic bonding in metal A is weaker than metal B, then metal A has:

a) lower melting point
b) lower brittleness
c) lower electrical conductivity
d) lower thermal expansion coefficient
e) lower density

The correct answer, a), was selected by five out of six students in one focus group and seven out of seven in another. This correlates well in comparison with the results of this question on the MCI given to classes of students. Those results showed that 80% of the students gave the correct answer in the pre test and 78% gave the correct answer in the posttest. The 2% decrease is probably not statistically significant.

The results on this question for the focus groups and for the question on the classroom MCI tests seem very positive at first glance, but a few questions need to be raised regarding the results. In the focus group a majority of students gave explanations that were minor variations on the correct answer of "in weaker bonds, there is less energy required to break the bonds". There were other interesting responses for students who gave the correct answer. In one focus group these include: "guessed between b) and c)"; "crossed off d), e), and f)"; and "eliminate and then boil down to a few". Thus, it can be seen that half of the students selected the correct answer with some knowledge of the topic in conjunction with variations on the technique of process of elimination. The one focus group student who gave the incorrect answer said that it was "just a guess" as to which property correlated to bond strength.

It is likely that good "test taking technique" was also used by some fraction of the 80% of students who selected the correct answer to the question on larger scale MCI classroom tests. The problem is that this is a Tier I question, which did not require an explanation for the answer. Additional work is necessary to develop a Tier II question for this topic, which would better reveal the student's conceptual knowledge on the topic. This assertion is reinforced by the focus group and classroom results of another related question to be discussed in the next section.

Another issue of the MCI classroom tests is that there was virtually no gain in knowledge between the pre and posttest results on this question. The relationship between bond strength is presented and discussed explicitly in most texts and lectures in introductory materials engineering courses. Yet there are no real world problems in most texts, which require a student to utilize the underlying principle to solve the problem. The instructor suggested, and the students agreed, that contextualizing the basic concept in a team-based learning environment may improve performance on posttest versus pretest results. The students also suggested that providing more schematic figures or diagrams would help in understanding the concept.

PHASE STATES OF METALS

Understanding and using the knowledge of the effect of thermal energy on properties is an extension of the previously discussed question. The focus of the following question is related to the phase state of metals, which is implicitly tied to the effect of thermal energy on phase behavior of materials. The question below queries students on which phases metals occur.

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

The correct answer, e), was selected only by three out of six students in one focus group and four out of seven in another. As in the previous question, this result correlates well in comparison with the results of this question on the MCI given to classes of students. Those results showed that 46% of the students gave the correct answer in the pretest and 52% gave the correct answer in the posttest. The 7% increase is small and may not be statistically significant.

The performance of this question on MCI classroom testing was surprised three instructors of the sections, but results of focus group discussions provided some interesting insights. In the focus groups, students who selected the correct answer gave variations on the explanation of "theoretically, if you heat a metal enough, it will become a gas". Although this reason is correct, it did not go down to the atomic level with regard to thermal energy breaking primary bonds in a solid (to form a liquid) or breaking secondary bonds in a liquid (to form a gas). Thus, students were still thinking on a macroscopic scale and not on an atomic scale. Another problem is that this is a Tier I question, which does not reveal student understanding in a way that a Tier II question would. There were even problems with the correct answers.

Unfortunately, some other correct responses were not even selected for an appropriate macroscopic reason. Other explanations for the correct answer included "my fifth grade teacher told me that all elements can exist as solids, liquids, and gases" (which is generally, but not completely true) and "I heard in a PBS special that iron was vaporized in the Hiroshima atomic blast". The students who gave the incorrect answer did so with variations on the statements of "I have never heard of Ni gas", "I have never seen Ni gas", and "I have only seen Ni as a solid". Thus, we see that students are giving answers based on personal observation, from watching television, and from a fact remembered from a fifth grade class. Overall, none of the focus group students gave the desired explanation for the question and even half of those with correct answer did not have a good reason.

With regard to the MCI classroom testing, it is likely that the results of the focus groups apply in a similar way. This may be why there was, at most, only a slight increase in correct answers from pre to posttest. The existence of most elements in three phases and the underlying explanations are not generally discussed explicitly in texts and lectures in introductory materials engineering courses. However, metal deposition from the gas phase is usually presented in conjunction with content on semiconductor processing. However, the existence of the gas phase of the metal is not a focal point of the discussion. It seems unlikely that that this is not discussed in college chemistry courses either. It may be that content and delivery on topics such as this need to be reconsidered. The problem might be ameliorated if there were opportunities for students to solve real world problems which require utilization of the underlying principle to solve the problem.

SUMMARY AND CONCLUSIONS

This paper discussed the procedures and activities for using student focus groups to understand responses and misconceptions from the Materials Concept Inventory. The focus groups provide a window on student knowledge and how students learn, which differs drastically from assumptions and experience of faculty. Examples of two questions from one set of topics from the MCI were discussed on the bond strength-melting point relationship and on the phase state of metals. It was found that the logic and rationale for selection of given misconceptions arose from a variety of sources including personal observation, prior teaching, and television observation, as well as other sources. It was found that even when students selected the correct answer; it may not have been for the correct and/or desired reason.

The discussions also pointed toward possible interventions for certain misconceptions that could improve student learning and conceptual knowledge of a topic. It is clear that the state of knowledge of students needs to be considered in content delivery. Additionally, contextualizing content, applying it to real world problems, improving content delivery through visualization, and team-based learning were other suggested improvements. In general, development of alternative approaches to teaching methodologies, prior course preparation, knowledge transfer, teaching effectiveness, and textbook development will offer opportunities for research in materials engineering education and to the engineering education community as a whole. The ultimate hope is that, in the future, broader participation in development and use of engineering science concept inventories will lead to healthy debate and change in teaching in the education community in the same way that the FCI has done for the physics education community.

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