Developing and Assessing Conceptual Understanding in Materials Engineering Using Written Research Papers and Oral Poster Presentations

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Abstract - Introduction to Materials Engineering at Western Washington University has been transformed from a traditional lecture course to a conceptual knowledge-centered course using several different teaching strategies. This paper focuses on the development and assessment of conceptual understanding using written research papers and oral poster presentations. Pre- and post-class concept questionnaires, paper and poster rubrics, and scores on traditional exam and design questions were used to evaluate improvements in conceptual knowledge. The pre-class questionnaires revealed several significant deficiencies. The questionnaires also revealed how robust student misperceptions can be and that it is important to build several appropriate scaffolds to new knowledge during the term so the students can reconstruct their conceptual understanding. Written research papers and oral poster presentations were also used to help the students articulate their own understanding of material properties. The process of explaining to themselves and to others develops and constructs conceptual knowledge. The assessment benchmarks indicate enhanced development in some conceptual areas. However, only limited progress was made in other important areas. Faculty time needed to complete the necessary assessments is definitely a limiting factor. Future directions conclude the paper.

Index Terms - Developing Conceptual Understanding, Oral Presentations in Materials Engineering, Understanding Student Learning, Writing about Materials Engineering.

INTRODUCTION

Introduction to Materials Engineering at Western Washington University has been transformed from a traditional lecture course to a conceptual knowledge-centered course using several different teaching strategies. The development and implementation of several of these strategies have been described elsewhere [1]-[4]. The fundamental principles guiding the changes in the course have been shaped from what is currently understood about the “best practices” in engineering education. For example, the National Resource Council (NRC) has identified the following characteristics and issues related to effective teaching for faculty in Science, Technology, Engineering and Mathematics (STEM) disciplines: “1) deep knowledge of subject matter by teachers (to encourage probing, questioning, skepticism, and integration of information and ideas); 2) skill, experience, and creativity with a range of appropriate pedagogies and technologies; 3) understanding of and skill in using appropriate assessment practices; 4) professional interactions with students within and beyond the classroom; 5) involvement with and contributions to one’s profession in enhancing teaching and learning; 6) improving the assessment of learning outcomes; 7) teaching a broad range and large numbers of students; 8) providing engaging laboratory and field experiences; 9) engaging students in original research; and 9) (understanding) limiting factors with regard to faculty knowledge of research on effective teaching” [5]. It is also well understood that diverse groups of students learn in many different ways.

Felder and Brent make the case that students have “different levels of motivation and different responses to specific instructional practices and the more thoroughly instructors understand the differences, the better chance instructors have of meeting the needs of diverse learners” [6]. In the Felder-Silverman Model, a student’s learning style may be defined by four questions: “1) What type of information does the student preferentially perceive (sensory or intuitive)? 2) What type of sensory information is most effectively perceived (visual or verbal)? 3) How does the student process information (actively or reflectively)? 4) How does the student characteristically progress towards understanding (sequentially or globally)?” [6]. More importantly, Felder and Brent also identified several mismatches between the learning styles of most current engineering students and the traditional lecture style of many engineering educators (based upon the Index of Learning Style surveys). Although most undergraduates were sensors, traditional engineering educators are likely oriented toward intuitors as traditional lectures often emphasize theory and mathematical modeling over practical application and experimentation. They also found that most of the learners in the study were visual learners, but again...
the traditional lecture style emphasized verbal skills. Most of these students were also active learners [6]. Several frameworks for learning style indicators are available and include: VARK Learning Styles (Fleming and Mills), Index of Learning Styles (ILS, Felder and Solomon), and the Myers-Brigg Type Indicators [7]–[8]. Similarly, there have been several studies examining future directions for more effective engineering education. Smith and Waller have identified several new paradigms for engineering education [9]. These new paradigms are based upon the following: “knowledge is jointly constructed by students and faculty; students are active constructors, discoverers and transformers of knowledge; narrative is a way of knowing, assessment is criterion-referenced and continual; students’ competencies and talents are developed; there is cooperative learning; and there is problem solving, collaboration, information access and expression, meaning that teaching is complex and requires considerable training” [9]. According to Felder, “the “best” method of teaching at the undergraduate level is induction which is problem-based learning, discovery learning, inquiry learning or some variation on those themes” [10]. Many other researchers have published studies that support these same basic ideas to improve engineering education [11]–[19]. Also, research studies in several STEM disciplines have shown that students understand more about what they are studying if the course environment also includes conceptual learning opportunities [20]–[24]. However, implementing these “best” strategies in your own course in the most productive way is challenging and understanding how effective the methods are for your own students is even more demanding.

This paper focuses particularly on the development and assessment of conceptual understanding using written research papers and oral poster presentations. Pre- and post-class concept questionnaires, paper and poster assessment rubrics, and scores on traditional exam and design questions were used to evaluate the improvements in the students’ conceptual knowledge. The pre-class concept questionnaires revealed several significant and somewhat surprising learning deficiencies and misperceptions of key concepts after required pre-requisite courses. Thus, the pre-concept questionnaires revealed to us precisely how important it is to know what the students bring to our classrooms (i.e. the commonly known adage “students are not blank slates”). A report from the NRC confirms the importance of knowing what students understand and don’t understand before a course begins [19]. “A logical extension of the view that new knowledge must be constructed from existing knowledge is that teachers need to pay attention to the incomplete understandings, the false beliefs, and the naive renditions of concepts that learners bring with them to a given subject. Teachers must help students change their original conceptions rather than simply use the misconceptions as a basis for further understanding or leaving new material unconnected to current understanding” [19]. The post-class questionnaires and the oral presentations of the students revealed, at times, how robust student misperceptions can be and how important it is to build several appropriate scaffolds to new knowledge during the term so the students can reconstruct their conceptual understanding. We gained an in-depth comprehension of why students understand what they do and why they think the way do regarding certain concepts from the information gleaned from both the pre- and post-class questionnaires. These questionnaires will undoubtedly help us to construct new and more productive ways to facilitate their active learning of key concepts in materials engineering.

The Writing Assignment

To facilitate improved student conceptual knowledge, written research papers and oral poster presentations were assigned to help the students articulate their own understanding of materials engineering and material properties. Oral poster presentations were used so the students could practice explaining to their peers why one material was chosen over another for a particular application, what three material properties were most important to the product design and what the limiting factors for the design were. The process of explaining to themselves and to others develops and constructs conceptual knowledge. Forming questions for others in the language of materials engineering similarly advances scaffolding.

This academic year, the written research paper was replaced with a reformulated written assignment. In the new written assignment the students were to use at least three material properties to answer a question that interested them in materials engineering and science, focusing on the use of specific materials for a certain design application. This assignment replaced a traditional research paper assignment in the course [4]. The basic idea for this modification came from Robert Frank’s book, “The Economic Naturalist” [26]. This book contains several essays which were written by students in response to an interesting assignment in his economic course. Frank’s “economic naturalist” assignment was “to use a principle or principles, discussed in the course to pose and answer an interesting question about some pattern of events or behavior that you personally have observed” [26]. In his book, he argues for the use of narrative in economics rather than only graphs, equations and mathematics because “student process equations and graphs with difficulty. … virtually everyone finds it easy to absorb the corresponding information in narrative form” [26]. Several narrative learning theorists and research results in engineering education agree with Frank’s basic assertions [27]–[31]. “The fact that writing is a uniquely valuable learning process is the central reason writing is vital in any educational setting” [32]. Also, the basic ideas correlate well with active and problem based learning strategies. In order to explain to others in the technical language of a discipline why one material is chosen over another helps students construct their own understanding as they build or perhaps reconstruct their understanding using new scaffolds.
to key concepts [27]-[31]. In addition to completing the 5 to 10 page writing assignment, the students were expected to create their own technical posters to assist them in their oral presentations to their peers. The students had to explain to each other the technical reasons why one material was chosen over another for a design. The students gave five minute presentations to six groups of their peers. All the students present their posters to their peers during the last two days of the quarter. Overall, the students are able to hear about 35 of the 5 minute presentations. The students are asked to assess each others’ presentations and posters based on the following rubric: 1) the poster contains all the required components; 2) the presenter easily answers the materials question; 3) connections are made to the appropriate material properties; 4) the poster stands alone to answer the question; and 5) the poster is of professional quality. The assessment of the writing assignment was based upon the technical content of the five required parts: the introduction, the discussion, the future, the technical conclusion, and the references. Points are deducted for misspelled words, grammatical issues, not labeling figures, graphs and tables appropriately, not citing figures or sources per assignment specifications, not have supporting figures or graphs, flow/coherence or structure issues, having insufficient depth and complexity, or failing to answer the original question. Students do not assess each others’ written work.

### Pre- and Post-Class Concept Questionnaires

During this academic year, pre- and post-class concept questionnaires were given in our introductory materials science and engineering course not only to understand the conceptual gains within the course, but to gain a much better understanding of what the students did and did not bring with them to the course. The questionnaires also asked the students to explain their reasons for their answers rather than just asking for a quick response. The sample size was approximately 100 over two quarters. Concept questions were used as much as possible. The questionnaires contain 22 questions and take about an hour to administer. The questionnaires are administered during the first course period and the last instructional period of the term. The following topics were used in the questionnaires: the nature of bonds, properties and structures, crystalline materials, conceptual understanding of the modulus of elasticity, understanding of the term “strong”, differences between materials effects and geometry effects, basic engineering design principles, conceptual understanding of wear, fatigue, creep and thermal conductivity, conceptual understanding of nanomaterials, smart materials, and composite materials. The students were also asked about what they hope to learn about in class and to write about something interesting they already knew about materials in the pre-course questionnaire. Many of the questions were posed to better understand why students had a difficult time on previously identified conceptual problems. In other words, we knew the students were having difficulties, but we did not fully understand the reasons for these difficulties. Most often, we gained more understanding as the students tried to explain why they gave the answer they did. The students were instructed to answer don’t know or never heard of this if one of those answers best fit their situation.

One of the most surprising findings gleaned from the pre-course questionnaire concerned a simple conceptual question designed to find out why students traditionally had a difficult time on the first day of class listing and describing the three types of primary chemical bonds, even though they have all completed a general chemistry course as pre-requisite to the class. Before this assessment was completed, our assumption was that the students who quickly identified covalent and ionic bonds simply forgot about the more obvious metallic bond. However, the repeating pattern of the same response from a number of students over multiple quarters made us curious enough to include this question on the pre-course questionnaire. What type of bond would you expect between two copper atoms?

![Figure 1. Student Responses to Metallic Bond Question](image)

The results were, at first, somewhat surprising (see Figure 1) in that only about 8% of the students had the right response for the right reason. Obviously then, their not responding previously was much more deeply rooted than simply forgetting. Most students thought that metals would be bonded with either covalent (24%) or ionic bonds (23%) or didn’t remember bonding enough to answer (19%). A short list of the reasons they gave for believing they had made the right choice revealed robust misconceptions. The most common reasons included:

- Metals are bonded with covalent bonds;
- Metals are bonded with ionic bonds;
- Ionic because copper atoms are positively charged, because copper gives up electrons, because copper has free electrons;
- Covalent because they share electrons, share electrons with itself, metals share electrons
- Ionic because it is metal to metal;
- Copper is a transition metal so it has ionic bonds;
- Wouldn’t bond with each other because they are charged;
- Can only remember covalent or ionic, or guessing.
Twenty-seven percent of the students said they had no idea what the students can glean from the polymers chapter in materials engineering texts seem also to be in question. The students (at our institution, at least) need more fundamentals of organic chemistry before they can really construct an appropriate understanding of the complex behaviors of polymers, especially those in service or under load.

The results from another pre-class concept question showed that our assumptions about what the students knew about advanced materials like nanomaterials were equally wrong. Thirty-three percent of the students knew what a nanomaterial was or at least that it was something small, but fully 66% of the students said they really didn’t know what a nanomaterial was and 25% claimed they had never heard of the term. Of the 33% of the students that thought they knew what a nanomaterial was, only about half of them could give a specific example (most cited carbon nanotubes). About 65% of the students could give a good description of a composite material and understood their properties would have something to do with the properties of both materials. Perhaps the difference here is that composites in the new Boeing 787 are often mentioned in local stories.

Finally, the students didn’t really come to the class knowing much about specific material properties, like hardness or creep. The pre-class concept question about the modulus of elasticity confirmed something we long knew about our students [4]. Ninety-percent of the students knew that a material should get less stiff as the temperature of the material increased, and about 80% of the students gave a correct answer as to why this is so. Unfortunately, 90% of the students then think the modulus of elasticity then should go up with increasing temperature. The word elastic is confusing to students since their pre-course conceptual knowledge is centered on elastic meaning flexible. We have given considerable attention to this misconception in our course, but have found it to be robust. The notion of an elastic band being flexible and easy to stretch is reinforced to them in everyday life more times, perhaps, than we can imagine.

Reformulating the writing assignment from a formal research paper to an assignment where the students answer a materials question that was interesting to them and having them focus on three or more material properties was done so the students could concentrate on their conceptual understanding of material properties. The purpose of having them construct a poster and orally present their work to their peers was for the identical reason. We previously identified working knowledge of several basic material properties as important learning objectives for the course and also identified lingering misconceptions and basic knowledge problems with several properties [1]-[4]. Overall, the grades on this project rose 7% from our previous experience, perhaps because the project was more focused,
and perhaps because the students found the assignment more interesting. Clarifying specific learning objectives and finding appropriate measurable outcomes has been ongoing in this course. These strategies, of course, are consistent with the “best” practices in engineering education that have been outline above. Most of the focus on our course has been on mechanical properties rather than on electrical, optical or thermal properties because they serve the needs of our students the best. However, the strategies outlined here would work for any set of properties.

In a previous paper, we outlined a specific concern that was revealed in previous experiences with our students’ research papers [4]. We found that the students were still using the word “strong” to describe a wide variety of material properties in their research papers and were not using the language of materials engineering or engineering in their description section of their papers. Thus, we examined their understanding of the word strong in the pre-class concept questionnaire. The students’ answers revealed the same misconceptions we saw in earlier research papers. The students did not distinguish between tensile or compressive strength, bending strength, stiffness, hardness, fatigue strength or corrosion resistance. They also thought that materials do not change shape unless there are extreme temperature or pressure variations (thus, their difficulty, at times, understanding elastic deformation). We did not expect that the students would be able to distinguish between materials effects and geometry effects before they complete the course. Seventy percent of the students believe that changing the material will change the stress in a design problem and about the same percentage (75%) did not consider the material properties had anything to do with a particular fracture in a similar design question. Thus, this academic year, the students had to use at least three material properties to answer a very specific materials question and they had to explain to their peers why these three material properties were important to providing the “why” of their answers; they had to use the specific language of materials engineering properties to do so.

The students answered a number of interesting materials questions; their informal assessments and comments about the poster sessions were generally positive, although they universally thought the whole assignment was too much work. The faculty workload for this comprehensive assignment is high. However, the conceptual gains for the students appear to be good, especially with regard to their abilities to use yield strengths, safety factors, elastic constants, fatigue or endurance limits, Poisson’s ratios, densities, specific strengths or specific elastic constants, and cost factors to perform materials selection for basic engineering designs. Overall, the students had a 27% increase in their scores on a difficult design problem involving various mechanical properties and constraints on the second exam! None of the students conceptually misused safety factors on the second exam this academic year. Additionally, approximately, 85% of the students had the correct conceptual understanding of fatigue, creep and hardness in the post-class concept questionnaire [range 67%-91%]. Next academic year, the difficulty of the design problem on the second exam will move to the next level in difficulty to further test the conceptual gain theory.

Listening to the students explain to their peers why one material is used over another material can also provide interesting insights into how the students construct new knowledge and build their own bridges and scaffolding. Students are eager to prove their assertions, but their peers are also eager catch errors. Unfortunately, many students (about the same 15% as before this assignment) were still confused about the modulus of elasticity and temperature (does it go up or down with increasing temperature) and whether adding fibers to a polymer should make the elastic constant go up or down. They are not confused about when a material is stiffer, but the robustness of their misconceptions about any term that contains the word elastic is problematic. Apparently, the paper/poster assignment made no real difference at all for the students who could not rebuild their understanding of the term. About 28% of the students still used the word “strong” to describe a wide variety of material properties in their written assignments and about 60% of them did so in their oral presentations to their peers. This, of course, was a disappointing result. Thus, most of the conceptual gains seem to have been made with regard to the students’ abilities to use the information correctly in design equations, rather than in reformulating their language. It appears that the students were able to make more gains in their written work than in their spoken words. Additional oral practice where we specifically draw attention to the use of generic terms (like strong) rather than engineering terms will be used next academic year with the hope that with more practice, real gains can also be made in oral presentations.

To enhance our understanding of our various new strategies we used fewer active activities in the beginning of one term and not in the other term this academic year. The result was that the scores on the first exam dropped a full 6.5% and the students seemed much less engaged. Nonetheless, both sections experienced the same conceptual gains on the design problem. This result may point to the effect being from the paper and oral poster presentations, but it is too early to draw that conclusion. It is also much too early to draw the specific conclusion that the different learning styles of the students might be influencing the results we see in conceptual gains. Only a closer examination of learning styles will provide insights to answer these questions. The next step in our process, thus, will be to use a learning style assessment and see if we can find links/connections to specific conceptual gains.

**Conclusions**

It is clear from the results of our pre- and post-class concept questionnaires that many of our previous assumptions about what students already know about materials, materials engineering or chemistry should be questioned. The results also point out how important it is for us to know what the
students know and how they constructed their own knowledge before we can truly understand how to facilitate their being active participants in their own learning experiences. Because we analyzed how the students write about materials and how they orally explained materials and material properties to their peers, we can better assess their conceptual understanding gains. We better understand the methods students use to construct their own understanding of how and why engineers choose materials for particular design applications. We believe also that the students demonstrated conceptual gains by increasing scores on both the writing assessment and better scores on a challenging design problem. Since we have started using “best” practices in this course, the students have gone from not being able to complete the comprehensive design problem, to needing the next level of challenge in an already demanding final design problem. But, did the increase in conceptual understanding for the design problem originate in their increased understanding of material properties gained from their written work and oral poster presentations? Our results seem to indicate this and that different strategies in the course are having different effects on students with different learning styles, but it is too early to draw conclusions. Thus, the next step in our process is to evaluate and understand more about the learning styles of the students and try to measure the links among strategies, styles and conceptual gains. The effects of the oral poster presentation should be investigated separately (the more visual experience) from the writing assignment (the more verbal experience). Since the investment of faculty time to complete the necessary assessments for this strategy is relatively large, a larger evidence base is needed to support the assertion that there are meaningful conceptual gains.

REFERENCES


Session F4A

October 22 – 25, 2008, Saratoga Springs, NY
38th ASEE/IEEE Frontiers in Education Conference
F4A-6

978-1-4244-1970-8/08/$25.00 ©2008 IEEE