AC 2011-576: SPECIAL SESSION: EDUCATIONAL METHODS AND TOOLS TO ENCOURAGE CONCEPTUAL LEARNING

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SPECIAL SESSION: Educational Methods and Tools to Encourage Conceptual Learning in Chemical Engineering

Overview

The goal of this special session is to provide educators with an overview of specific educational methods and tools that they can bring back to the classroom to encourage their students to think deeply about the concepts central to core chemical engineering and materials science courses. Presentations will focus on the use of concept inventories, peer instruction and ConcepTests, repair of misconceptions, and technology-based tools to facilitate active pedagogies. The session will culminate in a panel discussion to address barriers to implementing these methods. The intent of this session is to create a dialog amongst educators and expand the community of instructors interested in increasing engagement of their students in learning core concepts in the classroom.

This session contains five papers that are followed by a panel discussion. Two uses of concept-based questions are presented – one summative, one formative. With traditional instruction and testing methods, students are better rewarded by rote learning than by conceptual understanding.[1] However, requiring students to solve problems by routine does not prepare them well to solve different types of problems based on the same concepts. Alternatively, *learning with understanding* makes new learning easier, and leads to the development of expertise.[2] Two seminal works from the physics education research community have dramatically reshaped how conceptual teaching and learning is viewed in college-level physics courses. First, through the Force Concept Inventory (FCI), Halloun and Hestenes provided an instrument to measure students' fundamental conceptual understanding of Newtonian mechanics.[3,4] Second, Eric Mazur published his book Peer Instruction, which describes the use of ConcepTests to engage students in conceptual learning during lecture.[5] Both tools require that well-crafted conceptual questions be available for key concepts in a discipline.

What makes a high quality concept question? Such a question is designed to be conceptually challenging and typically requires no computation so that students cannot rely on equations to obtain the answer. It focuses on the most important concepts in a subject. Concept questions can be designed towards several objectives: to elicit or reveal pre-existing thinking in students, to have students apply ideas in new contexts, to ask students to qualitatively predict what will happen, to relate concepts to examples from everyday life, or to have students relate graphical and mathematical representations.[6] The use of concept questions assists students in obtaining a deeper learning experience, improves their understanding and ability to apply learning to new situations, enhances their critical thinking, and increases their enthusiasm for science and learning. Concept questions extend assessment beyond "What does a student remember?" and

"What can a student do?" to "What does a student understand?"[7] Effective concept questions challenge students with qualitative questions that cannot be answered by memorization.

There is interest in applying these methods to engineering education. For example, a search of ASEE conference proceedings over the past 15 years shows 24 papers with a title including concept inventory or concept inventories and 17 papers with peer instruction, clickers or response systems in the title. This special session combines speakers who have developed conceptual questions and applied them to Concept Inventories or to Peer Instruction in chemical engineering and materials science. The objectives of this special session are (1) to develop a richer understanding of conceptual learning by comparing and contrasting these approaches, and (2) to make faculty aware of resources for well-crafted conceptual questions. The following short presentations form the basis for the panel discussion:

1. Update on the Thermal and Transport Concept Inventory

In this panel discussion, a status report is provided on the development of the Thermal and Transport Concept Inventory (TTCI) for use in engineering classrooms to detect important student misconceptions in fluid mechanics, heat transfer, and thermodynamics. Development and testing of the TTCI has been reported.[8,9]

We will quickly review the methodology used to identify important and difficult thermal and transport concepts that are included in the TTCI. Then we will discuss the methodology and procedures used to generate TTCI items beginning with open-ended questions followed by beta testing of multiple-choice items. As part of the development, student responses were used to create plausible but wrong answers (known as distractors) for each item. Beta test data from ~15 engineering schools have been used to calculate traditional measures of reliability. Current work with the inventory includes developing a statistical model of knowledge "attributes" in heat transfer so that results from the inventory can be presented in diagnostic form – that is, each student's inventory answers will be used to predict underlying understanding of foundational concepts in heat transfer (e.g. temperature, heat, etc.). The ultimate goal is to use TTCI data to help instructors adapt their teaching methods according to students' knowledge level in their thermal and transport science courses.

Items in the TTCI focus on important but often misunderstood concepts in the thermal science and engineering. Ideally, each item clearly focuses on only one concept. An example item is shown below focusing on students' understanding of the difference between the actual temperature of an object and the perceived temperature when the object is touched with bare feet. Although this item seems to be straightforward, data from ~800 students shows that only about 72% of students answer the question correctly (answer c). The most common incorrect response is answer d, indicating that an significant minority of the students is incorrectly searching for a plausible reason why the tile and carpet are in fact at different temperatures.

Sample TTCI Item

An engineering student walking barefoot (without shoes or socks) from a tile floor onto a carpeted floor notices that the tile feels cooler than the carpet.

Which of the following explanations seems like the most plausible way to explain this observation?

a. The carpet has a slightly higher temperature because air trapped in the carpet retains energy from the room better
b. The carpet has more surface area in contact with the student's foot than the tile does, so the carpet is heated faster and feels hotter.
c. The tile conducts energy better than the carpet, so energy moves away from the student's foot faster on tile than carpet.
d. The rate of heat transfer into the room by convection (air movement) is different for tile and carpet surfaces
e. The carpet has a slightly higher temperature because air trapped in the carpet slows down the rate of energy transfer through the carpet into the floor

2. ConcepTests in Chemical Engineering Courses

McDermott[10] reported that few students in an introductory physics course developed a functional understanding of the material. That is, they don't develop the ability to interpret and use knowledge in situations different from those in which it was originally acquired. Students started the class with misconceptions, and lectures did not change these misconceptions. McDermott found that when students are allowed to apply their own ideas, they are more likely to learn the correct concepts. This process can be done effectively by challenging students with qualitative questions that cannot be answered through memorization. Such qualitative questions, which are referred to as ConcepTests,[5] have been developed at the University of Colorado for six core chemical engineering courses, and made available to instructors on a password-protected web site.[11] These ConcepTests are made available so as to minimize the effort required for instructors to introduce ConcepTests with student response systems (clickers) and peer instruction into their classes. Some effort is required to develop ConcepTests that are at the right level and have good incorrect answers to choose from. In addition, improving conceptual understanding requires that the important concepts be reinforced in assignments and that students are tested on the ConcepTests in exams. Thus, a sufficiently large bank of ConcepTests is required for a course to make their implementation practical, and that is the goal of the website. That is, if a large enough inventory of questions is not available, students can memorize answers instead of using understanding. Instructors need to be able to change the questions they use in class and on exams and homework assignment.

The type of clicker questions can make a significant difference in students' learning and motivation. The key concepts need to be identified in a course in order to make efficient use of class time. Effective ConcepTests are not numerical calculations, but qualitative questions. The questions must not be too easy, and around 30% correct initially is believed to be optimal. If 80-90% of the students correctly answer a question, then that topic is probably not a good use of class time, and one of the mistakes make when faculty first start using ConcepTests is to make the questions too easy. The quality of the wrong answers is as important as the quality of the questions. Good wrong answers (distracters), meaning wrong answers that bring out student misconceptions, can be obtained when a conceptual question (without multiple choice answers) is placed on an exam. ConcepTests that have slight variations on a ConcepTest that students have already seen can be difficult to answer if the students do not understand the concept. Such variations include plotting a process on a graph with different variables (e.g., on an internal energy versus volume plot instead of pressure versus volume in thermodynamics), applying the same concept to a flow system instead of a closed system, holding a different variable constant, changing the same variable by a different method, or increasing instead of decreasing a variable. Multiple choice solutions that consist of different graphical representations of a process are particularly effective ConcepTests.

Using ConcepTests and clicker questions with peer instruction dramatically increases the participation of students in class, and the number and quality of questions asked by the students also increase significantly. Thus, significant class time is devoted to peer instruction, students explaining why a given answer is correct or is wrong, and answering student's questions. As a result, not much time is devoted to mathematical manipulations and solving problems that require a numerical answer. To compensate for this, since many students like to see example problems worked out, we have also developed screencasts that present solutions of such problems. Screencasts are screen captures of the solution of an example problem on a tablet PC, including narration. The resulting videos, which are typically about 10 minutes in length, are posted on line for students to watch outside class [9]. Students can than watch on their schedule, and they can replay the sections that are confusing, or they can stop the screencast and think about what the next step is before continuing. Most students in classes where they have been made available have found the useful. Indeed, end of the semester feedback has indicated these are one of the most useful aspects of the courses, and students request that more be made. In one week, which was the week before midterm exams, the screencasts were played more than 1,500 times.

The types of ConcepTests that have been used effectively are indicated by the following example from chemical engineering thermodynamics. This example tests student understanding of vapor pressure:

> *Liquid water is in equilibrium with air at 50^{o}C in a piston/cylinder system at 1 atm pressure. The total pressure is raised to 2 atm by pushing on the piston at constant temperature. At equilibrium, the <u>partial pressure</u> of the water:*

A. Decreased
B. Increased
C. Remained the same

3. The Use of Inquiry-Based Activities to Repair Student Misconceptions Related to Heat, Energy and Temperature

This study examines the use of inquiry-based activities to repair student misconceptions related to heat, energy and temperature. Extensive research demonstrates that children, students and adults have a number of prevalent and persistent misconceptions in these concept areas.[12-14] Evidence is presented to demonstrate that engineering students similarly have related misconceptions. Specifically, the study examines misconceptions related to four targeted concept areas that have been identified by educators as both important and difficult for students to master: (1) temperature vs. energy, (2) factors that affect the rate vs. the amount of energy transferred, (3) temperature vs. perceptions of hot and cold and (4) the effect of surface properties on thermal radiation.

Students' conceptual understanding was assessed using the newly developed Heat and Energy Concept Inventory (HECI), an instrument that was developed over several years of testing and which has demonstrated high levels of internal reliability (KR20=0.85) and high content validity as assessed by engineering faculty. Baseline data on student performance on the HECI both prior to and after normal instruction in undergraduate heat transfer courses was collected from approximately 350 engineering students over11 course offerings of undergraduate heat transfer classes at 10 institutions. Analysis of pre/post performance for these students demonstrated that student performance on the HECI improved from a mean score of 49.2% correct prior to instruction to a post-instruction performance of 54.5% correct. The improvement was statistically significant, but modest. Improvements on each of the 4 subcategories of the HECI went from 52.8% to 54.7% correct for temperature vs. energy, from 61.2% to 69.4% for temperature vs. perceptions of hot and cold, from 36.9% to 42.6% for rate vs. amount and from 44.4% to 49.5% for thermal radiation.

Inquiry-based activities, modeled after those used for Workshop Physics,[15-16] were developed in an attempt to improve students' conceptual understanding in each of these 4 concept areas. The activities were both inductive and collaborative, with an emphasis on generating productive cognitive dissonance as well as providing a supportive team environment for helping students revise their thinking as a result of their observations during the activities. Initial results from the first semester of testing are encouraging. Looking at 116 students over the course of a semester's instruction in heat transfer at three diverse institutions, the mean performance on the HECI improved from 46.6% correct prior to instruction to a post-performance score of 70.1% when inquiry-based activities were employed. In terms of normalized gains, these results show an improvement from a normalized gain of 10% without the use of activities to a normalized gain of

46% with activities. There was also a statistically significant improvement on each of the 4 subcategories of the HECI with the adoption of the inquiry-based activities.

The study suggests that inquiry-based activities can be effective to help repair prevalent student misconceptions that are resistant to change through normal instruction.

4. Uncovering, Addressing and Assessing Misconceptions and Their Repair in a Materials Course

Assessing and addressing student prior knowledge is necessary for effective teaching and student learning and is a critical aspect of developing instructor pedagogical content knowledge. In an introductory materials course, summative conceptual knowledge is tested with a pre-post course Materials Concept Inventory.[17] Formative assessment of student prior knowledge for a given topical area is obtained with a short, Pre-post Topic Concept Quiz. The multimodal quiz requests both a brief description and an associated sketch about about a few important concepts to reveal misconceptions and knowledge gaps for topics such as atomic bonding or crystal structure. The pre-test informs instructional design for addressing knowledge gaps and misconceptions while the post-test assesses the effectiveness of instruction. The post –test will also reveal robust misconceptions that might be resistant to conceptual change even with informed instruction. An Atomic Bonding Pre Topic Quiz revealed that the majority of students were unfamiliar with weak van der Waals bonding between covalently bonded chains in polymers. As such, students were unable to explain reasons for easy processing of polymers due to low melting points, as well as easy orientation of strong covalent bonds in chains to make very high strength fibers. Pre and Post Topic Concept Quizzes on Metal Deformation showed that students had strongly held beliefs that bond strength was changed by deformation or heating of metals which is a major misconception. The scientific reason is actually the effect of density of defects in the crystal structure. A number of approaches have been devised to address such issues as knowledge gaps and robust misconceptions in order to foster conceptual change and student learning.

One recently developed instructional method to both assess and enhance conceptual change is being developed by Chi based on differing degrees of effectiveness of student engagement activities.[18] She classifies the different modes of student engagement as active, constructive, and interactive based upon hypothesized underlying cognitive processes occurring during learning. As such, she has demonstrated that Facilitator Structured Question Sets in which a student team facilitator leads and records individual and team consensus responses to probing questions about important topical concepts leads to large conceptual changes. Such results that indicate that greater conceptual change may be possible with this technique by careful design of activities can contribute both to student learning as well as enhancing instructor pedagogical content knowledge. The types of tools and techniques described represent an approach that could be generalized and applicable to other engineering disciplines. Thus, the ability to uncover and assess the nature of knowledge gaps and misconceptions can be linked to the design of better approaches to address them utilizing the knowledge and understanding of underlying cognitive processes that occur during student conceptual change and learning.

5. Clickers and Beyond: Innovative uses of Technology to Promote Conceptual Learning

The scope of technology use in the classroom is rapidly increasing. Wireless laptops,[19] tablet PCs,[20] and clickers[21] promote active learning environments and can increase student achievement. Additionally, modern studio classroom architectures, such as the SCALE-UP classroom[22] integrate the use of technological features such as computers. This paper discusses the use of these technologies to simultaneously engage the entire class in the learning process.

Clickers can be an enabling technology to deliver conceptual questions in the classroom and to provide instantaneous feedback to students and instructors. Typically, clickers are remote control devices making use of either infrared or radio frequency information transfer. Each clicker unit has a unique signal so that the answer from each individual student can be identified and recorded. In the typical clicker usage, a conceptual question is posed to the class which each student answers individually. When polling is complete from individual students, they are then asked to discuss their answers in small groups (peer instruction) and given the opportunity to change their answer. Then the answers from the entire class are displayed on the projection screen, usually in the form of a histogram. Based on the results, the instructor can appropriately modify instruction to reinforce learning or address misconceptions, and, thereby, guide students where to direct their learning efforts.

Alternatively, experience with development and implementation of an interactive, web-based technology will be presented. Like clickers, the Web-based Interactive Science and Engineering (WISE) Learning Tool facilitates active learning in the classroom and metacognition and allows formative assessment of student learning (formative assessment). However, WISE allows an instructor to pose to the class a wider variety of types of questions including: multiple choice answers, multiple choice with short answer follow-up, ranking exercises, automatically graded numerical answers, drawing exercises, short answers, and Likert-scale survey. For example, WISE allows short-answer written explanations to follow multiple choice questions. The short answers allow instructors to identify misconceptions directly from students, rather than inferring through distracters, as discussed above. A brief summary of the experience with WISE and the challenges of integrating this technology into the classroom are presented.

Finally, an ongoing software development project, which is collaboration between several of the panelists, is discussed. The *AIChE Concept Warehouse* will provide instructors access to conceptual questions, both as Concept Inventories and ConcepTests. Questions for the core ChE curriculum (Material and Energy Balances, Thermodynamics, Transport Phenomena, Kinetics and Reactor Design, and Materials Science) will be available through an interactive website hosted by the *Education Division* of AIChE. It will use a database - a flexible, query-driven information storage system - that is designed to be versatile so that conceptual learning can be deployed by programs and instructors as it best fits into their curriculum and culture. The software is designed to make concept questions available in different formats to facilitate widespread use. The database structure allows faculty to contribute new questions. The overall objective is to lower the activation barrier for using conceptual instruction and assessment so that many more chemical engineering faculty can incorporate concept-based learning into their classes.

Interactive Panel Discussion

Questions to consider include:

1. What factors are currently inhibiting faculty from adopting these methods now? What are the barriers to concept tests, clickers, inquiry-based activities? What is the biggest barrier to getting more faculty to change their teaching and not lecture?
2. What are the key elements of effective interventions for repairing misconceptions and promoting deep, lasting and transferable conceptual knowledge?
3. How do we reach the faculty who do not attend the ASEE meetings or the educational talks at AIChE meeting? Is the key to just get one faculty member in a dept to do this and then the others will learn from him or her and be convinced by him or her?
4. Are you convinced this is a better way to teach?
5. How do you address the concerns of faculty who say “If I do these conceptests in class, then when will I have any time to teach (i.e.,, lecture, go over example problems)?
6. How much need is there for more educational research if most faculty do not take advantage of all the current research? Should our efforts be for implementation instead of more research?
7. Why do faculty continue to only lecture when the data says it does not work? In other words, why do the same faculty who do research and use the data to make their decisions and use the data to reach their conclusions not use the same approach to their teaching- i.e.,, why do these faculty ignore the educational literature?
8. What is a reasonable proportion of lecture to active learning activities? How can such activities best be integrated into lecture?
9. Once a knowledge gap or misconception or robust misconception has been uncovered, what types of approaches could be used to address the issues and what is the difference in effectiveness of different approaches?

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