

## **ConocoPhillips Lecture 2012**

### **Education Research – Does it Really Have Anything To Offer Classroom Instructors?**

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#### **Overview**

In this lecture, I recap the process beginning in the mid 1990's by which engineering education research has moved from its Edisonian beginnings to a more rigorous research discipline. But has this increased focus on research rigor produced results that can be used by engineering educators to improve learning in our students? I'll try to answer this question via a series of short case studies, some of which show research success, some failure, and some for which the jury is still out. I'll close by proposing some themes that future engineering education research should address to make meaningful improvements in the process of educating our students.

#### **Introductory Remarks**

Before I begin this lecture, I want to thank everyone at Oklahoma State University and ConocoPhillips for unexpectedly being selected as the 2012 ConocoPhillips Lecturer in Chemical Engineering Education. Long ago at the beginning of my teaching career, I distinctly remember receiving in my mailbox each year, a professionally designed pamphlet containing a paper about chemical engineering education by one of the giants in our field – Felder, Fogler, Wankat, Prausnitz, Bird and others. These were names I recognized because I'd studied using their textbooks. The lecture topics were always interesting and often thought provoking—but I never dreamed I would be giving the Conoco Phillips lecture some 30 years later. I'm honored and more than a bit humbled.

I would not have been able to accomplish what I have in engineering education research (or even be working in the field) without many mentors and role models and I wish to acknowledge them here. Among those who most influenced my early career are chemical engineers Rich Felder, Jim Stice, and Don Woods who showed me that focusing on teaching scholarship and research was possible for a chemical engineering professor. My mentors at Colorado School of Mines have included Dendy Sloan (also a chemical engineer), Mike Pavelich, Barbara Olds, and Ruth Streveler. I'm grateful to all of them.

### **The Genesis of Rigorous Engineering Education Research**

After a few years teaching at the University of Wyoming at the beginning of my academic career, I moved to Colorado School of Mines and quickly learned from Dendy Sloan that teaching scholarship was a valued and encouraged activity in my department and at the school. I soon joined the American Society of Engineering Education (ASEE) and began attending regional and national conferences. It was an exciting time with plenty of new curricular and pedagogical innovations to digest and try. The Education and Research Methods (ERM) division was particularly active and I realized that my scholarship could be repositioned from my technical specialty (synthetic fuels from coal) to engineering education. The research questions were interesting, the experiments in our classes fun and potentially useful, and we felt we were making a positive contribution to our students and to engineering education.

However, by the mid-1990's, it became apparent to many of us that something was missing. At about the same time, Donald Stokes (1) published a thought-provoking book in which he proposed the model shown in Figure 1. In this model, Stokes distinguishes between various forms of inquiry along two scales – “the quest for fundamental understanding” and “consideration of use.” We soon realized that many of us were taking an Edisonian approach to our research without realizing that we needed to strive for a more fundamental understanding of why our innovations worked (when they did) and why they didn't work sometimes. We needed to approach our work as Pasteur would by understanding the theoretical

underpinnings of what we were doing in addition to our focus on classroom application. This approach was codified by a publication from the National Research Council in which six principles for conducting archival education research are listed (2). These principles are shown in Table 1 and clearly articulate an approach that will be familiar to anyone involved in scientific and engineering research. In practice, this approach often required partnering with colleagues in education or psychology who had expertise in education research methods.

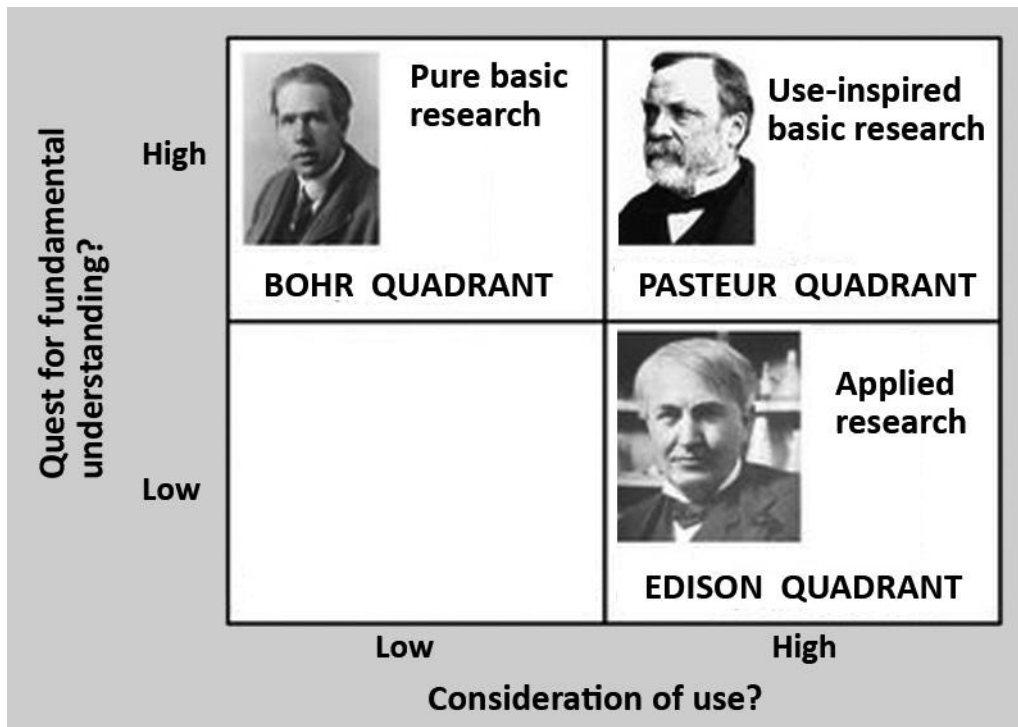


Figure 1. Model for Scientific and Technological Innovation (1)

**Table 1. Six Guiding Principles for Scientific Research in Education (2)**

- **Question:** pose significant question(s) which can be investigated empirically
- **Theory:** link research to relevant theory
- **Methods:** use methods that permit direct investigation of the question(s)
- **Reasoning:** provide coherent, explicit chain of reasoning
- **Replicate and generalize** across studies
- **Disclose** research to encourage professional scrutiny and critique

The result of this movement into Pasteur's Quadrant has been far-reaching and sometimes profound. The Journal of Engineering Education is now viewed as a top-tier journal with acceptance rates of less than ~20% and little chance of publication without research collaboration among engineering educators and cognitive scientists. Some now believe that the journal has moved beyond articles that can be read and used by engineering classroom teachers.

In the late 1990's, the Accreditation Board for Engineering and Technology (ABET) led by John Prados (3) embraced outcomes-based accreditation processes for which engineering programs were required to *develop* short-term outcomes for their students and long-term objectives for their graduates and *measure* how well benchmarks were met – benchmarks that are established in consultation with constituents inside and outside the university. This development gave rise to many discussions about how to measure student learning, especially professional skills (e.g. teamwork, ethical development, societal and global contexts for engineering) that are viewed as harder to define and quantify than technical skills such as problem solving, data analysis, and design (4). In addition, the National Science Foundation now requires education research questions with an accompanying research plan in many of their technical grants programs.

Unfortunately, developing engineering education research rigor has had the unwelcome and unexpected side effect of excluding faculty who conducted well-intentioned classroom experiments for which useful (but often not archival) results were obtained. Some of these faculty members felt marginalized and unappreciated

in the rush to create a new discipline of engineering education research. Fortunately, Ernest Boyer gave us a pathway forward. Boyer's short book (5) about scholarship in the professoriate argued that academic scholarship should extend beyond conducting original research and publication (termed the scholarship of discovery). As shown in Table 2, he identified three other forms of scholarly rigor in an interconnected and overlapping landscape of faculty activity (integration, application, teaching).

**Table 2. Boyer's Academic Scholarship Framework (5)**

- **Scholarship of Discovery** – creating new knowledge in a discipline
- **Scholarship of Integration** – connecting information and knowledge from different disciplines to obtain new understanding
- **Scholarship of Application** – building upon results from discovery and integration to use knowledge for practical purposes
- **Scholarship of Teaching** – assessing and evaluating the impact of new classroom innovations on student learning

Streveler, et al. (6) expanded Boyer's scholarship of teaching into the five categories shown in Table 3. Here they made the important distinction between, on the one hand, teachers and effective teachers who generally teach as they always have without much of any scholarly approach to their courses and students, and on the other hand, three categories of teaching scholarship with increasing research emphasis and rigor. The advantage of the Streveler model has been that faculty who are interesting in some level of teaching scholarship but are not interested in rigorous engineering education research can find a legitimate and valued place for their work as scholarly teachers or scholars of teaching and learning (7). We have also found Boyer's model useful as a framework in which to think about organizing faculty development and education research activities within the Colorado School of Mines Center for Engineering Education (8).

**Table 3. Levels of Inquiry in Engineering Education Research (6)**

Teacher	Teach as taught
Effective Teacher	Teaching using accepted pedagogical theories and practices
Scholarly Teacher	Assesses performance and makes improvements
Scholar of Teaching and Learning	Engages in education experimentation, shares results at conferences
Education Researcher	Conducts education research, publishes archival papers

### **Case Studies**

In this portion of the lecture, I will try to answer the question that forms the title of this lecture – namely, does education research offer anything useful to classroom teachers that will improve student learning, particularly in engineering? As is often the case in education, I believe the answer to this question is “sometimes.” To illustrate, I present brief case studies of: 1) research that has led to demonstrated successful classroom practices, 2) research that has failed to meet intended curricular, pedagogical, or assessment objectives, and 3) research for which the impact is still not clear.

I’ve drawn some of these case studies from the open education literature; others are based on my own research work with colleagues in engineering and cognitive sciences. Cases were selected to be illustrations of how education research has impacted the practice of engineering education but are not intended to be all-inclusive. I have, however, included a short list of “honorable mention” candidates for each research category to indicate other research initiatives that might be somewhat familiar to the reader.

### **Case Study #1 – A Success Story**

Of all the research-based classroom innovations I’m familiar with in the last 30 years of teaching, in my judgment the most widespread and effective one has involved adopting various forms of active learning or student engagement as

classroom pedagogy. Here I define active learning as any instructional method that engages students in the learning process *in* the classroom as opposed to traditional activities such as homework, labs, or out of class project work. Although not new [see reference (9) for a historical perspective of student engagement in classroom contexts], the serious use of active learning in engineering college classrooms probably began sometime during the 1980's and continues to gain popularity. Over half the colleagues in my department are familiar with some form of formal or informal active learning and are using it in their classrooms. The percentage is even higher among our younger instructors and it's likely the same trend is happening across many U.S. engineering schools.

The reasons for this trend are varied but I believe they can be distilled into three categories:

- The current generation of students (known as “millennials”) has short attention spans in the 10-15 minute range (10) with documented intolerance for non-engaging pedagogies (11) and a preference for collaborative work and “learning by doing” (12,13)
- An overwhelming amount of research supports theoretical frameworks of student activity in class and informs simple ways it can be implemented effectively
- The pedagogy works and simple engagement strategies can be employed by any faculty member without the need for special training.

Couple these reasons with a large body of research that shows students learn and retain very little in traditional passive lecture courses (14,15) and it seems obvious that providing some degree of student engagement in class is useful and valuable.

As noted by Felder, et al. (16), active learning in all its forms is probably the most thoroughly studied instructional method in use today. A significant meta-analysis by Springer, et al. (17) of small group work in 39 rigorous studies of science, math, engineering and technology classes showed positive mean effect sizes in the range of 0.5 (considered a medium-sized effect) for student achievement, persistence, and improved attitudes toward engineering. This work also showed that any introduction of active learning in class no matter how modest resulted in

statistically significant positive learning gains and that in-class group work was more effective than out-of class group meetings. Smith, et al. (9) and Prince (18) have also provided excellent summaries of research on the effects of active learning (particularly cooperative learning) and related pedagogies such as problem-based learning. These studies consistently show significant positive effects on student performance; Felder, et al. (16) attributes these results to several factors:

- weaker students are less likely to quit when they get stuck if they are working collaboratively with strong students
- stronger students strengthen their own understanding when required to explain and clarify concepts and problem-solving strategies to other students
- students working alone may tend to skip or delay assignments while working in a group requires each student to meet the expectations of their group mates

One of the important strengths of active learning is its flexibility and wide range of effective strategies that can be deployed (19,20). As shown in Table 4, classroom engagement can range from informal groups working on short tasks during a lecture period to formal cooperative learning groups and base groups. Karl Smith (an engineer) and his colleagues have shown that several characteristics of cooperative learning (e.g. positive interdependence, individual accountability to group mates, deliberate formation of heterogeneous groups, attention to development of team skills, and group processing) promote the largest learning gains (19,20), but as mentioned earlier, Springer's meta-analysis (17) demonstrates that even informal group work has measurable positive effects on student learning. This means that faculty new to active engagement in their classes can start with a modest, occasional activity in an informal group setting and still expect to see positive results.



**Table 4. Types of Active Learning Groups (19, 20)**

Type of Group	Characteristics
Informal group	Unstructured ad hoc groups used to focus students on small tasks (e.g. concept questions; predicting a phenomenon; short problems to solve; explaining an equation or concept in words) to break up lecture.
Informal cooperative learning group	Structured ad hoc groups used in lecture settings such as “book ends on a lecture” in which mini-lectures of 10-15 minutes are interspersed with short group activities.
Formal cooperative learning group	Groups which work together over many class periods approaching an entire semester; focus is on positive interdependence, individual accountability, teamwork skills and group processing in addition to completing technical tasks.
Cooperative base group	Long-term, heterogeneous cooperative learning groups with stable membership whose role is to provide support, encouragement, and assistance to students in the group during the semester.

Such modest activities might include use of the “think/pair/share” structure in which: 1) a question or problem is posed to individual students for a few minutes, 2) students are asked to pair up and compare answers and perhaps develop a better answer or determine who has the correct answer, and 3) some groups report to the full group. Sample tasks that work well for think/pair/share activities are shown in Table 5. Electronic “clickers” can also be used to solicit anonymous individual and group answers to questions or to vote on proposed solutions. Another popular task employs group problem solving in which members develop a solution by explaining their ideas to each other and comparing results as they work towards a common solution (21). Problem solving in class can be structured using a problem-based learning pedagogy in which self-directed groups of students solve multi-faceted problems; content learning occurs during problem-solution (22).

In spite of the overwhelming amount of research supporting use of active learning, some faculty members are still reluctant to adopt the pedagogy – why might this be? The most often cited reason is a perceived inability to cover all the necessary material in a course (21,23), an indication that knowledge is being viewed

as delivery of information packets to “be covered” rather than knowledge as construction of relevant mental models in students’ brains – an epistemology that focuses more on schema development than knowledge as “stuff.” Since we can’t possibly “cover” all topics in a typical textbook, focusing on developing students’ schema for solving problems or mental models of important concepts is necessarily the correct strategy. Active learning represents a critical pedagogy to helping students achieve this goal.

**Table 5. Sample Engineering Student Tasks That Work Well in Think/Pair/Share Classroom Activities**

• Describe a concept in non-technical language	• Draw a conclusion from presented data
• Answer a concept question	• Predict or explain a phenomenon
• Explain an equation in words	• Give reaction to a theory or concept
• Solve a problem	• Elaborate on presented material

**Honorable mention** – examples of other education research efforts that have lived up to their promises of consistent, positive effects in student learning include: 1) learning styles models such as the Kolb model (24) that remind us our class consists of students who learn in different ways that faculty members must address, 2) learning community structures (25,26) that provide a supportive learning environment and enhance retention of many types of student populations, and, 3) cognitive apprenticeship models in which students work closely with faculty coaches to become better critical thinkers and engineering problem-solvers (27).

### **Case Study #2 – A Failure**

Beginning in 1997, colleagues at the Colorado School of Mines and I were involved in a significant effort to develop a new “pencil and paper” method for measuring intellectual development in engineering students (28-32). This work was based on two complementary models of intellectual development observed in

college undergraduates – the Perry Model of Intellectual Development (33) and the King/Kitchener Reflective Judgment Model (34).

As shown in Table 6, these models describe the intellectual maturation of students along a hierarchical construct of stages ranging from: 1) a “black/white” view of the world in which all knowledge is obtained from authority figures (e.g. teachers, textbooks) followed by, 2) a relative view of the world in which “everyone is entitled to their own opinion,” to 3) a more sophisticated understanding of knowledge and problem-solving in which the use of evidence is acknowledged as necessary to selecting the best choice among available alternatives. Other intermediate stages are included in each model and Perry extends his model beyond stage 6 to describe commitment to action based on articulated values, but the salient developments for undergraduate students occur when moving from stage 2 to 4 and 4 to 6. Overall, each model describes student development from a novice engineer towards maturity to engineering expertise. This process is slow, requiring four years of undergraduate studies and well beyond, but Pavelich and Moore (35) have shown that well-designed engineering courses that give students instruction and practice in open-ended problem solving, team processes, and professional communications can help students develop more quickly than traditional curricula.

Unfortunately, the standard method for evaluating students' developmental stage is a structured, hour-long interview, conducted by a trained expert. The interview is transcribed and then studied and rated by a second trained expert. Thus gathering data using traditional methods is time consuming, requires expertise, and is costly (approximately \$150 and 7 person-hours of time per student). Our research was therefore focused on developing a cheaper, shorter method for reliably making these measurements. A review of the relevant literature (28) showed several previous attempts at “pencil & paper” instruments, all of which gave poor results (correlation coefficients between interview and paper/pencil instruments of no better than 0.4-0.5).

**Table 6. Important Stages in the Perry and Reflective Judgment Models of Intellectual Development (28)**

Stage 2	<ul style="list-style-type: none"> <li>• dualist; things seen as right or wrong</li> <li>• authority has all the answers</li> <li>• use of evidence is not understood</li> <li>• ambiguity is a shortcoming or game to get the answer</li> </ul>
Stage 4	<ul style="list-style-type: none"> <li>• ambiguity legitimate, but vexing</li> <li>• uses evidence, but without trust</li> <li>• sees no need to consider alternatives</li> <li>• "all opinions are equally valid"</li> </ul>
Stage 6	<ul style="list-style-type: none"> <li>• ambiguity common to most questions</li> <li>• evidence used to explore alternatives</li> <li>• finds better or best answer in context</li> <li>• commitment using own, considered value system</li> </ul>

We believed that we could improve on the performance of pencil/paper instruments that suffered from the inability to adapt follow-up questions based on student responses as a trained interviewer would. We intended to overcome this deficiency by writing an intelligent, interactive computer program that would emulate the role of interviewer and that would use sophisticated data analysis tools such as trained neural networks to analyze what inevitably would be noisy data. The software, named Cogito<sup>®</sup>, contained the following 4 controversial scenarios (similar in nature to the ones used by human interviewers):

- Dealing with overpopulation problems
- Goals of a college education
- Deciding whether rich or poor people should get tax cuts
- How nitrate contamination in groundwater should be controlled

One original design idea involved adaptive follow-up questioning guided by an artificial intelligence engine; however, collecting and coding the intelligent

decisions used by experienced interviewers ended up being too difficult so this feature was dropped. Instead, neural networks were added as a robust data analysis tool to look for evidence of intellectual development within each student's response patterns. Over 100 test subjects ranging from high school students to full professors sat for intellectual development interviews and also responded to the Cogito<sup>®</sup> software scenarios. These data were used to train and test over 50 different neural net models. Our best results gave correlation coefficients in the 0.5-0.6 range – better than pencil/paper tools but still not sufficient for reliably assessing the effect of curricular changes or other interventions on long-term student growth.

The reasons Cogito<sup>®</sup> didn't work better are illustrative of potential problems in any education research project. They included the following:

- Intellectual development is difficult to measure and requires more complex data collection and analysis that Cogito<sup>®</sup> and other pencil/paper instruments can ever provide.
- Although data over a wide range of intellectual development levels were obtained (from high school students to full professors), more data were needed at all intellectual development levels to better train robust neural networks on what ended up being noisy data. Project constraints of time and money simply didn't allow this to happen.
- The absence of a human interviewer to probe for clearer and deeper thinking and meaning about complex issues precluded obtaining data with a sufficient "signal to noise" ratio.

As a result of the software's mediocre performance and the difficulty of overcoming the problems listed above, the project was abandoned in 2001 and no further development work with Cogito<sup>®</sup> is anticipated.

**Honorable mention** – other education research efforts that haven't lived up to their promises of consistent, positive effects in student learning include: 1) distance learning (at least for undergraduates) in which the promise of asynchronous or just-in-time learning is often counterbalanced by the need for young students to learn in a supportive social setting and by students who don't possess sufficient discipline or maturity to stay on track and, 2) ill-designed applications of technology in the classroom in which the pressure to create "smart" classrooms overrides serious discussions about the true purpose of the intervention

and the needs of instructors and students. The notion that technology will *automatically* enhance learning is not supported by research results and often the design of an intervention is not based on relevant learning theory or past research findings but more often on expediency or the desire to build a glitzy classroom.

### **Case Study #3 – The Jury is Still Out**

Most methods for assessing engineering student learning focus on either procedural knowledge (e.g. solving specified classes of problems, designing a process or artifact, using appropriate engineering tools, oral and written communication) or development of affective and behavioral characteristics (e.g. teamwork, life-long learning, professional and ethical responsibility). Beginning in the 1970's, education researchers and educators began to identify conceptual shortcomings in students and the propensity for students to carry with them strongly-held misconceptions describing how the world around them worked (36).

One of the first systematic methods for assessing students' conceptual understanding was reported for undergraduate physics education by David Hestenes and his colleagues (37). The instrument they developed, known as the Force Concept Inventory (FCI), consists of 29 multiple-choice items designed to probe students' understanding of Newtonian force concepts (38). Each item consisted of a question, often accompanied by a picture, a correct answer, and carefully developed incorrect answers based on commonly held beliefs or misconceptions (39).

Hake and Mazur increased the visibility and impact of the FCI in the late 1990's. Hake published FCI results for approximately 6000 undergraduate students that clearly showed the positive effect of active learning and inquiry-based pedagogical techniques on understanding of the force concept as measured by FCI scores (40). Mazur at Harvard used the FCI with his students and found that, much to his surprise, student gains were no better than results reported in Hake's study (41). Along with other innovators, Mazur began the revolution in physics education

in which a renewed focus on conceptual understanding replaced some of the emphasis on routine problem solving.

As the positive effect of the FCI on physics education has become more widely known, concept inventories (CIs) have been developed for many science and engineering fields. In addition to the Thermal and Transport Concept Inventory (TTCI) which I have helped develop, CIs are now available or under development in electric circuits (42), electromagnetic waves (43), fluid mechanics (44), heat transfer (45), materials engineering (46), signals and systems (47), statics (48), statistics (49), strength of materials (50), and thermodynamics (51), among other fields. These CIs have been created using a variety of methodologies and have been subjected to varying degrees of validity, reliability, and bias testing (52,53). Some CIs are psychometrically strong and some are not. Some CIs purport to measure fundamental concepts and some focus on topics aligned with typical textbook frameworks. As a result, the impact of concept inventories on transforming engineering education (as the FCI has done for physics) is not yet known and in fact, I believe there is now evidence of overuse and improper use of concept inventories for assessments not intended by the CI developers such as ABET outcomes assessment.

To create a high quality concept inventory requires several key steps best described by the assessment triangle developed by Pellegrino, et al. (54), which identifies three key aspects of creating any valid and reliable assessment instrument:

- Cognition corner – describes how students learn about the target domain (e.g. heat transfer). When addressing the cognition corner one considers misconceptions students might have about the target domain, developmental trajectories as students gain expertise, common errors that are made, etc.
- Observation corner – represents a description or set of specifications for assessments tasks that will elicit illuminating responses from students about the target domain to be measured. Simply said, the observation corner represents the kinds of tasks that will make up the assessment itself. The assessment tasks that are chosen should make sense with respect to the cognition corner.

- Interpretation corner – encompasses all the methods and tools used to reason from fallible observations that have been made in response to the tasks defined by the observation corner of the triangle. Thus the interpretation corner guides us in choosing analysis methods appropriate for the tasks that have been created in the observation corner.

Full details on how we used this framework to create the TTCI have been published (55). In short, we used a modified Delphi study with experts drawn from chemical and mechanical engineering faculty and authors of thermodynamics, fluid mechanics, and heat transfer texts to identify important but often misunderstood concepts by undergraduate engineering students. The results of this exercise are summarized in Table 7 and represent the cognitive domains encompassed by three individual TTCI assessment instruments.

**Table 7. Concepts and Misconceptions Included in the Thermal and Transport Concept Inventory**

• Bernoulli equation	• Entropy/2 <sup>nd</sup> law of thermodynamics/reversible vs. irreversible processes
• Conservation of linear momentum	• Internal energy vs. enthalpy
• Viscous momentum flux	• Heat vs. energy
• Conservation of mass	• Temperature vs. energy
• Ideal gas law	• Steady-state vs. equilibrium processes

Once these concepts and misconceptions were identified, we followed the process steps listed below to develop and pilot test individual inventory items:

1. Draft open-ended questions about the concept
2. Collect student response data orally (think-aloud problem solving sessions) and in written form
3. Use the responses to convert the open-ended questions to multiple choice items with distractors describing plausible but incorrect answers
4. Beta test the drafted items on groups of engineering students



5. Collect expert reviews of each item (which also provides evidence of content validity)
6. Revise items based on statistical performance and expert feedback
7. Collect additional student response data to establish psychometric parameters including discrimination and difficulty indices for each item and reliability and face validity for each inventory

A sample item developed using this process and included in the TTCI heat transfer inventory is shown in Figure 2. In this item, students are asked to determine whether an equal amount of ice cubes or crushed ice will cool a glass of ice tea more. This item was written to probe students understanding of differences between the rate of cooling and the ultimate temperature reached by the ice tea. Note that wrong answers (termed “distractors” because they offer plausible but incorrect explanations) are carefully crafted to encompass expected student misconceptions related to the “rate vs. amount of transfer” concept.

This particular two-question item performs reasonably well in the TTCI heat transfer inventory with a discrimination index of  $\sim 0.7$  for each question and difficulty index of  $\sim 0.45$  for each question (i.e. about 45% of chemical and mechanical engineering students in our pilot dataset answered each of the two questions correctly). The most popular distractors were answers “a” and “e” indicating that a substantial portion of these students (approaching 30%) focused on the rate of ice tea cooling and equated the increased rate of cooling with crushed ice to a lower ice tea temperature. This same misconception also shows up in other engineering applications such as reaction kinetics where a small but not insignificant portion of chemical engineering students believe that a fast reaction will always achieve a higher conversion level than a slow reaction.

More information about the TTCI instruments can be found on-line at [www.thermalinventory.com](http://www.thermalinventory.com). Each inventory has an established Kuder-Richardson reliability index of about 0.7 or above which is considered acceptable for collecting meaningful student data (a higher reliability would be nice but is difficult to achieve for instruments containing many difficult items). The inventories themselves are

password protected and a password can be obtained by writing me at [rlmiller@mines.edu](mailto:rlmiller@mines.edu).

You have a glass of tea in a well-insulated cup that you would like to cool off before drinking. You also have 2 ice cubes to use in the cooling process and have access to an ice crusher.

Assuming no energy is lost from the tea into the room and no ice is lost in the crushing process, which form of ice (cubes or crushed ice) added to your tea will give a lower drink temperature?

- a. the crushed ice
- b. the ice cubes
- c. either will lower the drink temperature the same amount **[correct]**
- d. can't tell from the information given

because:

- e. crushed ice has more surface area so energy transfer rate will be higher
- f. energy transfer is proportional to the mass of ice used **[correct]**
- g. crushed ice will melt faster and will transfer energy from the tea faster
- h. ice cubes contain less energy per mass than crushed ice so the tea will cool more
- i. ice cubes have a higher heat capacity than crushed ice

### Figure 2. Sample Item from the TTCI Heat Transfer Concept Inventory

Because of the popularity of the Force Concept Inventory and its dramatic positive effect on how introductory physics is now taught across the United States, many engineering concept inventories have been developed and are now available. As I mentioned earlier, some if not most of these inventories have not been developed using accepted psychometric practices and have not established reliability and validity metrics. As a result, it is not clear what results from these

inventories might mean in terms of student conceptual learning and the ultimate impact on informing curricular and pedagogical innovations in engineering. Thus, the original vision of engineering education transformation towards more focus on conceptual understanding and less on rote problem solving remains unresolved and unattained. Whether we will ever see the same transformation that physics has experienced remains to be seen – time will tell.

**Honorable mention** – other education research efforts which may eventually provide consistent, positive effects in student learning but haven't yet reached their potential include: 1) outcomes-based assessment, especially as embraced by accreditation agencies such as ABET in which clearly defined, measurable outcomes of a students' education are expected to guide curriculum development and implementation (see reference 56 for a recent study of the impact of ABET EC 2000 on changes in preparation of engineering graduates) and 2) variations on problem-based learning such as the use of Model-Eliciting Activities, a class of open-ended analysis and design problems with structured emphasis on model development as a mechanism to improve learning of engineering concepts and skills (57).

## **The Future**

In recent years, we've seen a number of reports from influential groups describing problems with engineering education and recommendations for changes in the ways we educate engineers for the 21<sup>st</sup> century (see for example references 58-60). As part of this national discourse, I'm intrigued by the ideas from a workshop sponsored by the National Academy of Engineering in 2009 where ~40 distinguished engineering educators and representatives from industry, government agencies, and professional societies were tasked with developing ideas on enhancing the education experience of our students. Themes that emerged from their discussions included:

- “restructuring engineering curricula to focus on inductive teaching and learning”

- “applying integrated, just-in-time learning of relevant topics across STEM fields”
- “making more extensive use and implementation of learning technologies”

Clearly, engineering education research has addressed each of these with varying degrees of success but much more remains to be accomplished if any of these themes are to eventually help effectively transform and improve the engineering education enterprise. It should be an interesting journey.

### References Cited

- 1) Stokes, D.E. (1997). *Pasteur’s Quadrant: Basic Science and Technological Innovation*, Brookings Institution Press, Washington, DC.
- 2) National Research Council, Committee on Scientific Principles for Education Research (2002). *Scientific Research in Education*, Shavelson, R.J. and Towne, L., eds., National Academy Press, Washington, DC.
- 3) Prados, J.W. (1997). “Engineering Criteria 2000 – A Change Agent for Engineering Education, *Journal of Engineering Education*, pp. 69-70.
- 4) Shuman, L.J., Besterfield-Sacre, M.E., and McGourty, J. (2005). “The ABET Professional Skills: Can They Be Taught? Can They Be Assessed?,” *Journal of Engineering Education*, pp. 41-55.
- 5) Boyer, E.L. (1990). *Scholarship Revisited: Priorities of the Professoriate*, Jossey-Bass, San Francisco.
- 6) Streveler, R., Borrego, M. and Smith, K.A. (2007). “Moving from the ‘Scholarship of Teaching and Learning’ to Educational Research: An Example from Engineering,” *Improve the Academy*, Vol. 25, pp. 139-149.
- 7) Borrego, M., Streveler, R.A., Miller, R.L., and Smith, K.A. (2008). “A New Paradigm for a New Field: Communicating Representations of Engineering Education Research,” *Journal of Engineering Education*, pp. 147-162.
- 8) Streveler, R.A., Moskal, B.M., and Miller, R.L. (2003). “Using Boyer’s Four Forms of Scholarship to Advance Engineering Education,” *The Journal of Scholarship of Teaching and Learning*, 3, 2, pp. 41-50.

- 9) Smith, K.A., Shepard, S.D., Johnson, D.W., and Johnson, R.T. (2005). "Pedagogies of Engagement: Classroom-Based Practices," *Journal of Engineering Education*, pp. 1-15.
- 10) Wankat, P. (2002). *The Effective Efficient Professor: Teaching, Scholarship and Service*, Allyn and Bacon: Boston, MA.
- 11) McGuire, S.Y. and Williams, D.A. (2002). "The Millennial Learner: Challenges and Opportunities," in *To Improve the Academy: Resources for Faculty, Instructional, and Organizational Development*, vol. 20, pp. 185-196, Anker: Bolton, MA.
- 12) Howe, N., Strauss, W. and Matson, R.J. (2000). *Millennials Rising: The Next Generation*, Vintage: New York.
- 13) Harris, M. and Cullen, R. (2007). "Civic Engagement and Curricular Reform," *National Teaching and Learning Forum*, 16, 4, pp. 4-6.
- 14) *How People Learn* (2000). Bransford, J.D., Brown, A.L., and Cocking, R.R., eds., National Research Council, National Academy Press: Washington, DC.
- 15) Finkle, L.D. (2000). *Teaching With Your Mouth Shut*, Heinemann: Portsmouth NH.
- 16) Felder, R.M., Woods, D.R., Stice, J.E. and Rugarcia, A. (2000). "The Future of Engineering Education II. Teaching Methods that Work," *Chemical Engineering Education*, pp. 26-39.
- 17) Springer, L., Stanne, M.E. and Donovan, S.S. (1999). "Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis," *Review of Educational Research*, pp. 21-51.
- 18) Prince, M. (2004). "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education*, pp. 223-231.
- 19) Johnson, D.W., Johnson, R.T., and Smith, K.A. (1998). *Active Learning: Cooperation in the Classroom*, Interaction Book Company: Edina, MN,
- 20) Smith, K.A. and Waller, A.A. (1997). "Cooperative Learning for New College Teachers," in *New Paradigms for College Teaching*, Campbell, W.E. and Smith, K.A., eds., Interactive Book Company: Edina, MN.
- 21) Felder, R.M. and Brent, R. (2003). "Learning by Doing," *Chemical Engineering Education*, pp. 282-283.

- 22) Woods, D.R. (1994). *Problem-Based Learning: How to Gain the Most from PBL*, Woods Publishing: Waterdown, ON, Canada.
- 23) O'Brien, J.G., Millis, B.J., and Cohen, M.W. (2008). *The Course Syllabus: A Learning-Centered Approach*, Jossey-Bass: San Francisco, CA.
- 24) Kolb, D. (1984). *Experiential Learning: Experience as the Source of Learning and Development*, Prentice-Hall: Englewood Cliffs, NJ.
- 25) Olds, B.M. and Miller, R.L. (2004). "The Effect of a First-Year Integrated Engineering Curriculum on Graduation Rates and Student Satisfaction: A Longitudinal Study," *Journal of Engineering Education*, pp. 23-35.
- 26) Tinto, V. (2000). "What Have We Learned About the Impact of Learning Communities on Students?" *Assessment Update*, vol. 12, no. 2.
- 27) Collins, A., Brown, J.S. and Holum, A. (1991). "Cognitive Apprenticeship: Making Thinking Visible," *American Educator*, pp. 6-46.
- 28) Pavelich, M.J., Miller, R.L., and Olds, B.M. (2002). "Software for Measuring the Intellectual Development of Students: Advantages and Limitations," *Proceedings of the American Society for Engineering Education Annual Conference* (electronic), Montreal, Quebec, Canada.
- 29) Olds, B.M., Miller, R.L., and Pavelich, M.J. (2000). "Measuring the Intellectual Development of Students Using Intelligent Assessment Software," *Proceedings of the Frontiers in Education Conference* (electronic), Kansas City, Missouri.
- 30) Miller, R.L., Olds, B.M., and Pavelich, M.J. (1999). "Using Computer Software to Assess the Intellectual Development of Engineering Students," *Proceedings of the Frontiers in Education Conference* (electronic), San Juan, Puerto Rico.
- 31) Miller, R.L., Olds, B.M., and Pavelich, M.J. (1998). "Using Intelligent Computer Technology to Measure the Intellectual Development of Engineering Students," R.L. Miller, B.M. Olds, and M.J. Pavelich, *Proceedings of the Frontiers in Education Conference* (electronic), Tempe, Arizona.
- 32) Miller, R.L., Olds, B.M., and Pavelich, M.J. (1998). "Measuring Engineering Students' Intellectual Development Using Neural Network and Expert System Technology," *Proceedings of the American Society for Engineering Education Annual Conference* (electronic), Seattle, Washington.
- 33) Perry, W.G., Jr. (1970). *Forms of Intellectual and Ethical Development in the College Years*, Holt, Rinehart and Winston, Inc.: New York.

- 34) King, P.M. and Kitchener, K.S. (1994). *Developing Reflective Judgment*, Jossey-Bass Publishers: San Francisco.
- 35) Pavelich, M.J., and Moore, W.S. (1996). "Measuring the Effect of Experiential Education Using the Perry Model," *Journal of Engineering Education*, pp. 287-292.
- 36) Duit, R. *Students' and Teachers' Conceptions and Science Education*, Kiel, Germany: Institute for Science Education, <http://www.ipn.uni-kiel.de/aktuell/stcse/>, accessed September 2012.
- 37) Halloun, I.A. and Hestenes, D. (1985). "The Initial Knowledge State of College Physics Students," *American Journal of Physics*, pp. 1043-1055.
- 38) Hestenes, D., Wells, M., and Swackhamer, G. (1992). "Force Concept Inventory," *The Physics Teacher*, pp. 159-166.
- 39) Halloun, I.A. and Hestenes, D. (1985). "Common Sense Concepts About Motion," *American Journal of Physics*, pp. 1056-1065.
- 40) Hake, R.R. (1998). "Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses," *American Journal of Physics*, pp. 64-74.
- 41) Mazur, E. (1998). "Qualitative vs. Quantitative Thinking: Are We Teaching the Right Thing?" *Optics and Photonics News*, pp. 38.
- 42) Evans, D.L, Gray, G.L, Krause, S., Martin, J., Midkiff, C., and Notaros, B.M., (2003). "Progress on Concept Inventory Assessment Tools," *Proceedings of the 33rd Annual Frontiers in Education* (electronic), Boulder, CO.
- 43) Rhoads, T.R. and Roedel, R.J. (1999). "The Wave Concept Inventory – a Cognitive Instrument Based on Bloom's Taxonomy," *Proceedings of the 29th Annual Frontiers in Education* (electronic), San Juan, PR.
- 44) Martin, J.K., Mitchell, J., and Newell, T. (2004). "Work in Progress: Analysis of Reliability of the Fluid Mechanics Concept Inventory," *Proceedings of the 34th Annual Frontiers in Education* (electronic), Savannah, GA.
- 45) Jacobi, A., Martin, J., Mitchell, J. and Newell, T. (2003). "A Concept Inventory for Heat Transfer," *Proceedings of the 33rd Annual Frontiers in Education* (electronic), Boulder, CO.
- 46) Krause, S., Decker, J.C., and Griffin, R. (2003). "Using a Materials Concept Inventory to Assess Conceptual Gain in Introductory Materials Engineering

- Courses," *Proceedings of the 33rd Annual Frontiers in Education* (electronic), Boulder, CO.
- 47) Wage, K.E., Buck, J.R., Wright, C.H.G., and Welch, T.B. (2005). "The Signals and Systems Concept Inventory," *IEEE Transactions on Education*, pp. 448-461.
  - 48) Steif, P.S. and Dantzler, J.A. (2005). "A Statics Concept Inventory: Development and Psychometric Analysis," *Journal of Engineering Education*, pp. 363-371.
  - 49) Stone, A.D. (2006). *A Psychometric Analysis of the Statistics Concept Inventory*, PhD dissertation, University of Oklahoma, Norman, OK.
  - 50) Richardson, J., Steif, P., Morgan, J., and Dantzler, J. (2003). "Development of a Concept Inventory for Strength of Materials," *Proceedings of the 33rd Annual Frontiers in Education* (electronic), Boulder, CO.
  - 51) Midkiff, K.C, Litzinger, T.A., and Evans, D.L. (2001). "Development of Engineering Thermodynamics Concept Inventory Instruments," *Proceedings of the 31st Annual Frontiers in Education Conference* (electronic), Reno, NV.
  - 52) Santiago Román, A.I. (2009). *Fitting Cognitive Diagnostic Assessment to the Content Assessment Tool for Statics*, PhD dissertation, Purdue University, West Lafayette, IN.
  - 53) Streveler, R.A., Litzinger, T.A., Miller, R.L., and Steif, P.S., (2008). "Learning Conceptual Knowledge in Engineering: Overview and Future Research Directions," *Journal of Engineering Education*, pp. 279-294.
  - 54) Pellegrino, J., Chudowsky, H., and Glaser, R. (2001). *Knowing What Students Know: The Science and Design of Educational Assessment*, National Academy Press: Washington, DC.
  - 55) Streveler, R.A., Miller, R.L., Santiago Román, A.I., Nelson, M.A., Geist, M.R., and Olds, B.M. (2011). "A Rigorous Methodology for Concept Inventory Development: Using the 'Assessment Triangle' to Develop and Test the Thermal and Transport Concept Inventory (TTCI)," *International Journal of Engineering Education*, pp. 968-984.
  - 56) Lattuca, L., Terenzini, P.T., and Volkwein, J.F. (2006). *Engineering Change: A Study of the Impact of EC 2000*, Accreditation Board for Engineering and Technology: Baltimore, MD.
  - 57) Moore, T. J. and Hjalmarson, M. A. (2010). "Developing Measures of Roughness: Problem Solving as a Method to Document Student Thinking in Engineering," *International Journal of Engineering Education*, pp. 820-830.



- 58) National Academy of Engineering (2010). *Engineering Curricula: Understanding the Design Space and Exploiting the Opportunities: Summary of a Workshop*, National Academies Press: Washington, DC.
- 59) National Academy of Engineering (2004). *The Engineer of 2020: Visions of Engineering in the New Century*, National Academies Press: Washington, DC.
- 60) National Academy of Engineering (2005). *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, National Academies Press: Washington, DC.