

# IDEAS TO CONSIDER FOR NEW CHEMICAL ENGINEERING EDUCATORS

## Part 1. Courses Offered Earlier in the Curriculum

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Although teaching is a critical mission of any college or university, today's faculty members are increasingly becoming involved in other scholarly activities. Thus, when teaching a new course, developing a good set of instructional materials can be a challenging, time-consuming task. In this paper we provide a review of some of what we consider the best practices in engineering education, applied to the following courses: Freshman Chemical Engineering, Material and Energy Balances, Fluid Mechanics, Introductory Thermodynamics, and Separations. Note that a companion paper covering those chemical engineering classes that normally occur later in the curriculum is planned.

The format used for each course is:

- ▲ *Brief description of typical course content*
- ▲ *Discussion about novel and successful methods used, including best practices and new ideas*
- ▲ *Listing of "toughest concepts" for the students (and how to address them)*

We note that most of this material was originally presented

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## FRESHMAN CHE COURSE

Depending on the school, this course is either a “stand-alone” introduction to chemical engineering or is part of a college-wide introductory course (with a portion devoted to chemical engineering). Ironically, many chemical engineering educators may never have taken such a course.

A major goal of the course, since it is for freshmen, should be to cultivate student interest in engineering<sup>[3]</sup> and motivate students to pursue an engineering career. This course can have a wide variety of formats, depending upon the number of credits and objectives of the course for a particular institution. For example, Brigham Young University has a three-credit course that introduces (via an integrated design problem) all of the aspects of the chemical engineering curriculum,<sup>[4]</sup> while Tennessee Technological University has a one-credit course that focuses more on hands-on experiments and information exchange.<sup>[5]</sup> Whatever the course, it is important for a department to identify why they have introduced or are teaching such a freshman course and whether (via specific assessment) the goals and objectives of the class are being met, from both the faculty and student standpoint.

In the rest of this section, we briefly highlight (as a resource) some of the novel work available on freshman courses in chemical engineering.

### Best Practices / New Ideas

Some best practices that we have used (or discovered) for this course are:

- ▲ *The use of freshman design projects:*
  - *Design an economic analysis of a controlled-release nitrogen fertilizer plant<sup>[6]</sup>*
  - *Design, build, and test an evaporative cooler<sup>[7]</sup>*
  - *Design and build a pilot-scale water treatment plant<sup>[8]</sup>*
  - *Analyze and design sneakers with better material properties<sup>[9]</sup>*
- ▲ *Introduce in-class, hands-on experiments:*
  - *Melting chocolate and coating cookies<sup>[10]</sup>*
  - *Electrophoresis and brewing with microreactors<sup>[11]</sup>*
  - *Heat transfer scaling with hot dogs<sup>[5]</sup>*
  - *Human respiration process<sup>[12]</sup>*

One overlooked concept in designing this course is to consider the needs of the student from the *student* perspective. Recently, the University of Pittsburgh asked their freshmen engineering students to conduct a survey of other first-term freshmen engineering students on topics the students felt were important.<sup>[13]</sup> While the results of the surveys are interest-

ing in their own right, the most useful result is the types of surveys the students developed. The top 10 types of surveys were as follows:

1. *Getting enough sleep?*
2. *Has high school prepared you for college?*
3. *Do you feel safe on campus?*
4. *Any new romantic relationships?*
5. *Is partying getting in the way of schoolwork?*
6. *Exercise more or less than in high school?*
7. *Homesick?*
8. *Favorite campus food options?*
9. *Susceptible to doing drugs / alcohol now?*
10. *Confidence in time-management skills?*

It is noted that there is nothing about a student’s major listed in the top 10. Thus, a freshman engineering course requires a balance between what an instructor knows (or thinks) that a student needs, and what the students think they need. Therefore, while a freshman chemical engineering course must (obviously) contain information about the field of chemical engineering, it should also find ways to address non-chemical engineering related issues as well. Here, ample use of guest speakers in Counseling Services or similar offices on campus should be explored.

In addition to what has been discussed above, other ideas in freshman chemical engineering courses exist as well. Roberts discusses a course that focuses on, among other areas, communication skills.<sup>[14]</sup> Worcester Polytechnic Institute looks to mix writing with first-year engineering in a course shared by a ChE faculty member and a Writing faculty member.<sup>[15]</sup> Vanderbilt University describes a course where students are introduced to chemical engineering by “using examples from cutting-edge research to illustrate fundamental concepts.”<sup>[16]</sup> At Youngstown State University they are demonstrating combustion principles to chemical engineering (and non-chemical engineering) students using a potato cannon.<sup>[17]</sup>

### Trouble Spots

Trouble spots for this course include:

- ▲ *Most students do not know what chemical engineers do—one idea is to have teams of like-minded students investigate where chemical engineers work in a particular field. Each team will present this information to the rest of the class at the end of the semester. Also, The Sloan Career Cornerstone Center<sup>[18]</sup> has short “Day in the Life” interviews with various young chemical engineers in a wide variety of industries that are quite informative at emphasizing the diversity of career options accessible for B.S. chemical engineering graduates.*
- ▲ *Most students have only a vague idea as to why they are taking math—one idea is to have upperclassmen come into the class and tell them how they are using math in their courses. In fact, using upperclassmen as much as*

possible during the semester is a good idea as it indoctrinates the students more easily into the program.

- ▲ Many students struggle with the transition from high school—one idea is to use upper-class peer mentors or speakers from on-campus who can discuss student-relevant issues. Having students conduct their own surveys, as discussed in a previous section of this work, might identify the most important issues for your students.

## MATERIAL AND ENERGY BALANCES

This course may also be called the Stoichiometry or Process Principles course by faculty. Students may refer to it as a weed-out class as some students drop and switch majors during or after completing the course. Much of this perception may be because it requires students to think at a higher level than in previous courses. A typical course will cover: units and dimensions, properties, measurements, phase equilibria, material balances, energy balances (nonreactive and reactive systems), and combined mass and energy balances. The course should prepare students to apply conservation laws to process simulation as the first source of modeling equations. The course is the foundation for the rest of the curriculum—it is all about planting seeds for the future!

### Best Practices / New Ideas

Some best practices and useful tools that we have used (or discovered) for this course are:

- ▲ *Emphasize importance of communication in problem solving.*<sup>[19]</sup> Requiring students to submit a solution or two that meets corporate standards can be a useful exercise in developing students' communication skills. Overuse of such a requirement can distract from the problem-solving objectives, so use sparingly.
- ▲ *Teaching by analogy.*<sup>[20]</sup> Using simple analogies for explaining confusing topics such as mass/mole fractions, steady-state, specific volume, saturated air, and others can help students grasp topics that might elude them from lecture and reading alone. Analogies provide a link between what the student already knows and what you are trying to teach them.
- ▲ *Mass and energy balances on the human body.*<sup>[21]</sup> In this module students are asked to measure flows and compositions using a medical gas analyzer while exercising and at rest. They then apply several ChE fundamental principles (ideal gas law, partial pressure, stoichiometry, relative humidity, heat of reaction, work, efficiency, and process simulation) to analyze their results.
- ▲ *Starting the unit operations early in the curriculum.*<sup>[22]</sup> The equipment is already in the laboratory, so why not use it within the material and energy balance course? This allows for introduction of measurement, application of conservation laws, and an introduction of the fundamentals of design. Any time students can apply knowledge to a real task, they learn better.
- ▲ *Incorporating programming with templates.*<sup>[23]</sup> Pro-

gramming is an effective way of teaching students numerical methods. The problem with programming is that it often has significant overhead (input/output, user interface, etc.) that has nothing to do with the objectives of an assignment. Using templates, or "almost finished" programs lacking only the numerical method code, enables students to focus on implementing the numerical method and concentrate on the learning objectives for the assignment.

- ▲ *Student-centered teaching.*<sup>[24-26]</sup> These references provide a host of suggestions for the material and energy balance course, including: developing a well-structured team approach to homework, posting homework answers (but not solutions), giving open-book exams, and developing clear objectives and exam study guides to aid in student learning.
- ▲ *Psychrometric chart applet.*<sup>[27]</sup> This applet allows the user to calculate properties of humidified air, and helps students understand how to use the psychrometric chart. It also frees up valuable lecture time when assigned to students to study on their own and then assessed through in-class active-learning exercises.
- ▲ *Richard Felder's Resources in Science and Engineering Education.* This is a popular site containing a link to the stoichiometry course taught by the textbook<sup>[29]</sup> co-author. The site also contains links to Excel tutorials.<sup>[30]</sup> Furthermore, there are many links to information on using active learning in your courses.
- ▲ *Graph paper Web site.*<sup>[31]</sup> Assuming you still expect students to learn fundamentals of graphing such as use of logarithmic axes, these papers will come in handy.

### Trouble Spots

Trouble spots for this course include:

- ▲ *Reluctance to show work.* Students should be required from the start to show clean, detailed solutions even on the easiest problems assigned earlier in the class. Significant point deductions for deviations early in the course help train students to clearly communicate with their problem solving.
- ▲ *Reluctance to apply rigorous methods to simple problems.* The grader must pay attention to the method and not just the final answer. Requiring students to start from the general material balance even on problems that can be solved intuitively will aid students in solving more complex problems later in the course.
- ▲ *Misunderstandings about density / specific volume and  $g_c$ .* Repetition, drills, quizzes, and clear examples help to clear up some of these common misunderstandings. Warning students that these can be challenging issues may help a few pay more attention. Keeping a reference page at the beginning of their notebook or in the cover of the textbook with notes on these and other key subjects can also help.
- ▲ *Trouble with thermodynamic diagrams.* Students will not grasp these diagrams without working with them.

One approach is using online interactive tutorials. Another effective approach is to bring copies of charts (even if they are in the text) for students to use in working problems either with the instructor, or better still, in small groups. They will only learn how to use these charts if they practice using the diagrams.

- ▲ Reluctance to apply rigorous methods to simple problems. Yes, this problem is significant enough to mention twice.
- ▲ Lack of integration of “old” material into subsequent chapters. Students are going to tend to compartmentalize knowledge from each chapter (or each homework assignment, each exam, etc.) and not internalize the concepts into their problem-solving repertoire. Blending lectures in a manner that bridges the chapter divide, using problems that draw extensively on previous topics, and even giving quizzes on material covered earlier in the course can help develop anchors to key elements in a course as they move on to new topics.

## FLUID MECHANICS

Fluid Mechanics has an interesting history within chemical engineering programs.<sup>[32]</sup> It developed from steam and gas technology for industrial chemistry and chemical engineering needs. From this evolved Unit Operations, which helped make chemical engineering a unique field. Meanwhile, fundamental studies in fluid mechanics were quite popular (and remain so) in the literature. This research work became integrated into the chemical engineering curriculum mostly due to the *Transport Phenomena* text.<sup>[33]</sup>

### Best Practices / New Ideas

One major advantage of teaching a course in fluid mechanics is the visualization that could be easily brought into this course. Some best practices that we have used (or discovered) for achieving this in the fluids course are:

- ▲ Ford’s paper on “Water Day”<sup>[34]</sup> developed several observation stations so that students can visualize continuity, the Bernoulli equation, conservation of linear momentum, the vena contracta effect, and relative and absolute velocities.
- ▲ Incorporate high school outreach into the course
  - Using pressure concepts<sup>[35]</sup>
  - Using a tank-tube viscometer experiment<sup>[36]</sup>
- ▲ Use unit operations and/or research laboratories
  - Unique experiments have been developed by Fan<sup>[37]</sup> who discusses flow surrounding a bubble, two-phase theory, flow segregation, phenomena of bubble-wake dynamics, and computational fluid dynamics of particulate systems).
  - Particle technology is a field that offers a large number of simple experiments that can be brought into the classroom.<sup>[38]</sup> These include wet-powder systems (single-particle settling, hindered and lamella

settling, sedimentation and flocculation, interparticle force effects on colloidal suspension rheology, wetting behavior of dry powders, and granulation coalescence behavior) and dry particle systems (hopper flow, consolidation effects of powder flow, particle dilation, wall friction, segregation during hopper flow, vibrational segregation, fluidization, and flow improvement due to powder agglomeration). There are also a CD<sup>[39]</sup> and Web site<sup>[40]</sup> available with additional powder-technology education information.

- Golter, et al.,<sup>[41]</sup> have developed a methodology to teach students fluid mechanics and heat transfer inductively. Many of their modules are see-through to aid in visualization. These include Reynolds dye/flow-through clear pipe, pressure drop through fittings and valves, flowmeters (Venturi, orifice, and Pitot tube), extended surface heat exchangers, kettle boiler / steam condenser, 1-2 shell and tube heat exchanger, fluidized bed (compressed air through sand), and a double-pipe heat exchanger.
- Wright, et al.,<sup>[42]</sup> introduced bioseparations through a three-part laboratory experiment. This includes bed expansion characterization under fluidization conditions, tracer studies, and protein adsorption studies.
- Other experimental unit operations that could be demonstrated include agitation and aeration,<sup>[43]</sup> solid/liquid and liquid/liquid mixing,<sup>[44]</sup> and compressible flow analysis.<sup>[45]</sup>
- ▲ Use fluid mechanics videos from the Web
  - Most notable is the “Fluid Mechanics” video series starring Prof. Hunter Rouse of the University of Iowa. These videos are available online at the Iowa Web site.<sup>[46]</sup> General topics include the introduction to the study of fluid motion; experimental principles of flows; characteristics of the laminar and turbulent flows; fluid motion in a gravitational field; form drag, lift, and propulsion; and effects of fluid compressibility.
  - There is also the “National Committee for Fluid Mechanics Film Series”<sup>[47]</sup> with sample topics: aerodynamic generation of a sound, cavitation, channel flow of a compressible fluid, deformation of a continuous media, Eulerian Lagrangian description, and flow instabilities.
- ▲ Use commercially available software
  - Computational Fluid Dynamics (CFD) case studies in the fluids course<sup>[48]</sup> and for fluid-particle flow<sup>[49]</sup>
  - COMSOL modules for fluid dynamics and heat and mass transfer applied to fuel cells<sup>[50]</sup>
  - Use of Mathematica<sup>[51]</sup> to analyze non-Newtonian flow systems

### Trouble Spots

Trouble spots for this course include:

- ▲ Students may possess weak math skills. Instructors can develop handouts to step students through difficult

solution processes (such as solving differential equations). Have them practice with in-class problems and homework before testing them.

- ▲ Difficulty in connecting highly theoretical content to real industrial applications—if there is an Internet-connected computer and projector in the classroom, instructors can use online and/or laboratory demonstrations to make a strong connection. This connection can also help students with their subsequent classes.
- ▲ Students often do not know order-of-magnitude values for pressure drops, velocities, Reynolds numbers, etc. The teacher can provide them with general values on a handout they can paste in the front of their textbook.
- ▲ Students struggle with when to eliminate terms in the governing equations. If they are provided with handouts to step them through difficult solution processes (such as solving differential equations), they will be prepared for more advanced homework and exam questions.

## INTRODUCTORY THERMODYNAMICS

This course is normally the first of two thermodynamics courses where fundamental thermodynamics concepts are introduced (first and second law of thermodynamics) while solution properties are normally not discussed. Processes and equipment are emphasized, including various thermodynamic cycles and the analysis of their components (turbines, compressors, throttling valves, etc.) The course enrollment can also include non-chemical engineering students, so the instructor must also be aware of issues that mechanical or civil engineers may encounter in their careers.

German Physicist Arnold Sommerfeld said it best when discussing the topic of thermodynamics:

*“Thermodynamics is a funny subject. The first time you go through it, you don’t understand it at all. The second time you go through it, you think you understand it, except for one or two small points. The third time you go through it, you know you don’t understand it, but by that time you are so used to it, it doesn’t bother you anymore.”*

### Best Practices / New Ideas

The subject of thermodynamics can be confusing due to a number of issues, but most notable is the lack of an intuitive feel for certain integral concepts, such as entropy, internal energy, fugacity, chemical potential, etc. Recently one of us observed, in research involving student-prepared study guides, that entropy and the second law of thermodynamics are the most confusing topics. In fact, students did not put much information, if at all, on their study guides for these two topics—not because they were comfortable with them, but because they had a poor understanding of the topics. This manifested itself in exam scores on problems with these concepts.<sup>[52]</sup>

One way to connect this concept for students is through unique, nonlecture methods. Kyle discusses the mystique of entropy, applied to a wide range of fields including

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cosmology, time, life, and art.<sup>[53]</sup> Müller integrates second law concepts into common life experiences and economic theories.<sup>[54]</sup> Foley presents a view of entropy as a quality of energy degraded.<sup>[55]</sup> There are also newer thermodynamic terms that are gaining in popularity, including exergy (maximum work done by a system that brings it into equilibrium with a reservoir) and emergy (the cost of a process or product in solar energy equivalents).

Another problem that students face with thermodynamics is the strong importance placed on the use of differential calculus concepts. While students have normally been exposed to all of these concepts in their calculus sequence, the act of placing it in a thermodynamic context often proves a significant barrier. Working with  $F=F(x,y)$  is, seemingly, different from working with  $P=P(T,v)$ . Accordingly, the thermodynamics instructor has two options. The first involves re-teaching the fundamental concepts of differentials, partial derivatives, meaning of integrals, etc. within the thermodynamics course. The second is to work with the people who are teaching students these math concepts, which are Mathematics Department faculty members. If chemical engineering (or any engineering) faculty were to work with calculus instructors to provide context to some of the math they are learning, this could potentially mitigate the need for the remedial work when their students arrive in the classes that depend on this knowledge.

Other new ideas associated with this course include:

- ▲ Incorporation of biological concepts in addition to traditional chemical engineering examples. For example, Haynie<sup>[56]</sup> describes the irreversible increase in entropy involved in how a grasshopper jumps. Additional problems are available in this area as part of the Bioengineering Educational Materials Bank.<sup>[57]</sup>
- ▲ Development of a Personalized Class Binder<sup>[58]</sup> that requires students to put class notes, handouts, in-class problems, quizzes, exams, and homework into a binder. The binder is graded at various points during the semester. Students are also required to rewrite or type

the notes neatly for inclusion in the binder and to show reworked exams, quizzes, and homework. Finally, the binder will include brief biographies of the scientists mentioned in the course, which goes toward humanizing the subject matter.

- ▲ *Creative Expression Day*, where students make posters to be placed above the chalkboard that contains various concepts or formulas important for the course. Students can then easily “view” this information during the whole semester.
- ▲ *Extensive use of NIST WebBook for data to perform any of a number of comparisons of involving polar and nonpolar substances.*<sup>[59]</sup>
- ▲ *Earlier presentation of power cycles (such as Rankine) as motivation for studying and contextualizing turbines, efficiency, latent heats, etc.*

Do note that many articles in the journal *Chemical Engineering Education* have been written on thermodynamics problems, especially in the “Class and Home Problems” section. Some notable ones include a powerful example on energy consumption relating the second law, by Fan and colleagues<sup>[60]</sup>, an open-ended design estimation problem from Lombardo<sup>[61]</sup>, and the description of an experimental vapor-liquid equilibrium laboratory at the University of Delaware.<sup>[62]</sup>

### Trouble Spots

Trouble spots for this course include:

- ▲ *Difficulty comprehending the second law of thermodynamics. One idea is to use the statistical nature of entropy as an introduction as well as the works of Foley<sup>[55]</sup> and Fan.<sup>[60]</sup>*
- ▲ *Difficulty translating concepts of mathematics into this course. Rather than assume knowledge of differentials, partial derivatives, etc., spend some time to remind students of these concepts.*

### EQUILIBRIUM-STAGED SEPARATIONS

This course typically combines steady-state material and energy balances with phase equilibrium to form the student’s first experience with equipment design. Students apply equilibrium relationships to the design of staged separations equipment. Typical operations include flashes, cascades, absorption, stripping, binary distillation, and extraction. This course may also cover rate-based processes such as membranes, adsorption, and ion exchange.

Graphical methods are used to learn conceptual relationships and for order-of-magnitude design. Analytical methods are then used as rigorous design tools and provide a foundation for simulation.

### Best Practices / New Ideas

Some best practices that we have used (or discovered) for this course are:

- ▲ *Ask the experts. Sometimes we do not teach the courses for which we have the most relevant experience. Both Chemical Engineering Progress<sup>[63]</sup> and Chemical Engineering Magazine<sup>[64]</sup> routinely publish relevant articles on separations applications. They are often written at a level that students can understand better than their textbooks.*
- ▲ *Bring in the history of the field.<sup>[65]</sup> Separations have been performed for millennia. The earliest recorded use of distillation dates back to 50 B.C.; it was used in the 12th century for ethanol processing; and in the 16th century it was widely used for perfumes, vinegars, and oils. Occasionally interrupting terribly interesting technical lectures with historical anecdotes can renew students’ interest in a lecture while giving them perspective on their current course of study.*
- ▲ *Use literature from industrial suppliers.<sup>[66]</sup> Many manufacturers and distributors of industrial equipment have useful applications papers describing not only their equipment in particular but general concepts as well. A Web search will easily find vendor articles such as “Factors Affecting Distillation Column Operation,” “Evaporator Handbook,” and “Liquid-Liquid Coalescer Design Manual.” These are also written at a very accessible technical level.*
- ▲ *Wankat’s “Why, What, How?” approach. Establish why you’re teaching something (economics, core of chemical engineering), what exactly you’re teaching (equilibrium staged separations), and then teach it using best pedagogical practices (lecture with simulation labs, inductively structure the course, using both graphical and then analytical methods, and then reinforce with laboratory exercises and design projects).<sup>[67]</sup> This process should lead to a deeper understanding of the subject.*
- ▲ *Levels of understanding.<sup>[68]</sup> Dahm combines Wankat’s approach with Haile’s Special Hierarchy of understanding to give a specific possible formulation of the levels of understanding in teaching separations.*
- ▲ *Separations using spreadsheets.<sup>[69]</sup> Working with students to develop an analytical approach to graphical separations on a spreadsheet forces a connection between the graphical methodology and the theoretical underpinnings. Automating shortcut separations develops an understanding of what is required to be known in what order.*
- ▲ *Use of commercial simulation.<sup>[70]</sup> Use of commercial simulators in the classroom enables a range of inductive exercises to be incorporated into a course. Instead of performing time-consuming laboratory exercises (which do have an esteemed place in the course) to explore a piece of equipment, experiments can be performed virtually with the simulator, enabling students to observe results and draw conclusions. When the theory is later discussed, students have a framework of understanding whereby they can assimilate the salient points of the discussion.*

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### **Trouble Spots**

Trouble spots for this course can include:

- ▲ *Reluctance to show work; reluctance to apply rigorous methods to simple problems; trouble with thermodynamic diagrams. These are problems encountered in earlier courses and they have been discussed in the Material and Energy Balances portion of the paper.*
- ▲ *Looking for "answers" instead of trends. Students often fail to see that the point of solving model equations (outside of homework and exams) is not to find a particular number. Models are always approximations or subject to other forms of error. The real value of models is in simulation to determine answers to questions such as "What happens if my flowrates vary +/- 50%" or "What would be the effect of a malfunctioning thermocouple?"*
- ▲ *Expecting rigor in graphical approximate solutions. You will need to constantly remind and reinforce the fact that assumptions are being made throughout the course. Some of the assumptions may not be significant (equimolar counter diffusion for a binary distillation with similar substances) or may change the character of the entire separation (use of inappropriate thermodynamic models).*
- ▲ *Disconnect between theory and simulators. If students do not learn how to use a process simulator for separations as they learn theory, they will have difficulty reconciling the terminology used in their text and the input fields in the simulator. Fostering that connection throughout the course makes use of simulators more effective.*

### **USE OF ACTIVE LEARNING**

The authors are all advocates of using active learning within their courses. As such, a brief background and listing of simple ideas on how to integrate active learning into a core chemical engineering course is provided.

Studies have shown<sup>[71-75]</sup> that students typically learn best in an active mode; however, engineering is usually taught as lectures. The use of active learning is underscored in teaching textbooks<sup>[71-72]</sup> and those intended for the new professor<sup>[73]</sup> as well as in numerous conference proceedings and engineering education archival publications. A good listing of references is presented by Smith<sup>[74]</sup> and by Dyrud.<sup>[75]</sup>

A great deal of information on improving student-teacher interaction through active learning is presented at the National Effective Teaching Institute (NETI)<sup>[76]</sup> and the Excellence in Engineering Education (ExcEEd)<sup>[77]</sup> workshops. One former attendee and active learning advocate is Ken Reid, who highlighted the positive experiences in his classroom,<sup>[78]</sup> and summarized simple ways that faculty can increase active and collaborative learning in their lectures and within the laboratory.<sup>[79]</sup>

Improving student motivation may also improve learning, as was recently illustrated by Newell—who developed a game based on the reality television show *Survivor* within a material and energy balance course.<sup>[80]</sup> Newell referenced the student motivation classifications of Biggs and Moore<sup>[81]</sup>:

1. *Intrinsic—learning because of a desire to learn*
2. *Social—learning to please others*
3. *Achievement—learning to enhance one's position*
4. *Instrumental—learning to gain long-term rewards*

Game-based active learning exercises certainly address the social and achievement components of Biggs and Moore.<sup>[81]</sup> In his study, Newell<sup>[80]</sup> found that the *Survivor* game addressed all four motivation categories and improved student learning.

There are other quiz shows and contests that can be used within the classroom. The chemical engineering education literature has described ways to integrate formats from game shows and games such as *Jeopardy*, "Trivial Pursuit,"<sup>[82]</sup> and *Hollywood Squares*,<sup>[83]</sup> as well as offered professor-created games such as "Green Square Manufacturing,"<sup>[84]</sup> "True Blue Titanium Game,"<sup>[85]</sup> "Chemical Engineering Balderdash,"<sup>[85]</sup> and the "Transport Cup."<sup>[86]</sup> Most of these games usually only address the knowledge or comprehension component of Bloom's taxonomy.<sup>[87]</sup>

Other simple-to-use active-learning methods include:

- ▲ *Think-pair-share—think for 1-2 minutes, talk with neighbor for 1-2 minutes, then share answers with the rest of the class*
- ▲ *Poll the audience—with a show of hands, colored note-cards, or clickers*
- ▲ *Minute paper—the students write down 1-2 ways to do something, then the instructor solicits answers from the students. This is also a good way to get anonymous feedback on the course content, what the "muddiest" point of a lecture is, etc.*
- ▲ *Engineering Education articles from Rich Felder<sup>[28]</sup>—this site highlights recent teaching methods that have been proven to improve student learning*

### **CONCLUSIONS**

This paper has described some of the best practices for use in the chemical engineering courses that traditionally occur

earlier in the curriculum: Freshman Chemical Engineering, Material and Energy Balances, Fluid Mechanics, Introductory Thermodynamics, and Separations. A common thread is deviation from the traditional lecture format. When this happens, the students are given the opportunity to take ownership of their own learning. Popular methods include the use of in-class demos, hands-on activities, tours of the unit operations lab, and seeing a movie or simulation of a concept. Additionally, the softer skills of engineering are finding their way into the classroom, with the most popular ones being an increased emphasis on communication and on teamwork skills. It is noted that it is particularly important for instructors of beginning courses (freshman chemical engineering and/or material and energy balance courses) to understand the concerns facing the students as they begin their college careers. Incorporating novel methods into the classroom can increase learning as well as retention.

For copies of the presentation slides from the Summer School, contact one of the authors.

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