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The University of Wisconsin

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The University of Wisconsin

Bryce Richter, University of Wisconsin-Madison

The Memorial Union Terrace, on the shores of Lake Mendota, is a popular spot for eating, relaxing, studying, and sailing.

IF YOU WANT TO BE A BADGER...

Every schoolchild in Wisconsin learns that the state motto is "Forward," the state animal is the Badger, the state dance is the Polka, and the official state beverage is Milk. As the only chemical engineering department in the state, public or private, the Chemical and Biological Engineering (CBE) Department at the University of Wisconsin (UW) embraces all of these as part of our heritage and culture. The department especially embraces the "Forward" motto in its research and education efforts. We'll begin by highlighting three research foci.

GLBRC: GREEN INTO GOLD

UW is home to the Great Lakes Bioenergy Research Center (GLBRC), one of three centers in the nation funded by DOE to the tune of $125 million over five years. GLBRC is a consortium of researchers from UW and Michigan State University, working in collaboration with national labs and industrial partners, to develop a suite of new technologies to convert cellulosic plant biomass to energy sources. CBE faculty involved with GLBRC include **Jim Dumesic, Manos Mavrikakis, Brian Pfleger, Jennie Reed,** and **Christos Maravelias**. Their work spans all length scales, from molecular engineering to systems and economic analysis.

Jim Dumesic and his research group are pioneers in the conversion of lignocellulosic biomass to fuel and chemical grade compounds by means of heterogeneous catalysis. Jim uses his expertise in microcalorimetric and spectroscopic techniques to develop new catalytic processes for the conversion of biomass feeds to valuable end products. Jim works closely with Manos Mavrikakis, to tap his expertise in catalyst design from quantum mechanical first principles. The main strategy is to first deconstruct lignocellulose through controlled deoxygenation to obtain platform molecules (5-6 carbons) and monofunctional species that retain functionalities. These can then be reconstructed through upgrading reactions, and tailored to specific new purposes. Highlights from recent work include the production of H_2 and alkanes through aqueous-phase reforming of sugars, and conversion of sugars and sugar alcohols over a Pt-Re based bimetallic catalyst to a mixture of mono-functional intermediate molecules, such as alcohols, ketones and carboxylic acids. One of their most recently developed catalytic strategies is for the production of jet fuels starting from biomass through an integrated system for hydrogenation, decarboxylation, and oligomerization reactions.

Where Jim and Manos use synthetic chemistry, Brian Pfleger uses synthetic biology in the search for new biomass conversion pathways. Synthetic biology is the design and construction of new biological components and systems, and the re-design of natural biological systems, for useful purposes. Brian's research group is developing tools for engineering biological systems in order to design biological catalysts for producing high-value products from renewable resources. Fossil fuels are the raw materials for an enormous diversity of products such as plastics, solvents, and organic building blocks. Conventionally, conversion from fossil fuel to products is carried out through synthetic chemistry and processes familiar to any chemical engineer. As fossil fuel supplies decrease, Brian believes that it is time for synthetic biology to step in, as an alternative approach for manufacturing existing materials as well as a route to totally novel compounds. Currently, his group is engineering microorganisms to produce polymer precursors and diesel fuels.

Jennie Reed takes a systems biology approach, utilizing both experimental and computational approaches to study biological networks. Jennie and her team are building, analyzing, and utilizing metabolic and regulatory models of organisms involved in biofuels. These models are used to evaluate the capabilities of different organisms from a network-based perspective and to identify ways in which genetic manipulations could enhance their productivity. She also develops computational methods for designing strains or cell lines with enhanced production yields of desired products. These computational methods account for both metabolic and regulatory effects occurring inside the cell, and can identify metabolic or regulatory roadblocks that limit production in developed strains.

To be economically viable, any biomass-to-fuels strategy must be coupled to efficient conversion of biomass-derived oxygenated compounds to high-value chemicals. Although several pathways for these conversions are known, it is not established which high-value chemicals should be produced to make the overall process economically attractive, and how chemical and biological approaches should be integrated. Christos Maravelias and his research group have developed a network design approach, where existing fossil-fuel-based and emerging biomass-based technologies are considered. They formulate optimization models to evaluate in a systematic manner a large number of alternatives, and thereby address a series of challenging questions: Which chemicals can be produced most efficiently from biomass? Which emerging technologies could have the greatest impact? Can biomass-based technologies be used today to replace fossil-fuels technologies?

These combined efforts of several UW research groups, along with their collaborators on campus and beyond, are sure to move "Forward" the efforts to build a new biomass-based chemical and fuels economy, while protecting and preserving our natural resources.

WID: GOING VIRAL!

The Wisconsin Institutes for Discovery (WID) are two unique entities, one private and the other public, housed in one stunning 300,000-square-foot facility with a unique design to facilitate collaborative research, education, and public outreach. **John Yin** leads one of five thrusts, Systems Biology, in the public part of WID. This group of researchers is exploring how frontiers of experimental and computational biology can advance and be enriched by evolutionary biology. Every human being is an ecosystem, in continuous exposure to a diversity of microbial cells and viruses present on our skin, in our guts, and in our tissues. "No organism is an island," says John. "We have known for a long time how bacteria and viruses can cause human disease, but the new data suggest they also have important and intriguing roles in promoting our health." John and his research team are developing new approaches to understand how viruses grow, spread, and evolve. If a virus particle is able to invade a living host cell, it reprograms the cell to turn it into a virus factory. Upon release by the cell, the progeny virus particles move by convection and diffusion to other cells, where they initiate further infections. A quantitative understanding of the material and energy flows of the infection process can highlight opportunities for therapeutic intervention. But, because infections start with a single viral particle, the biochemical reactions are "noisy" or "stochastic." **Jim Rawlings** brings his expertise in stochastic modeling into this effort to understand how viruses replicate, survive, mutate, and flourish. The ultimate aim is to promote human health through effective management of microbe-host interactions.

Beyond connecting scientists and engineers in the systems biology thrust, WID is reaching further "Forward," connecting science to the arts and humanities, connecting ways of knowing to ways of understanding, and reflecting on the meaning of the new science on our humanity. Making connections from science to art is a particular interest of John, an accomplished cellist who studied at the Julliard School of Music and has performed with several symphony orchestras. Old friends of the department will be interested to know that our former chair, **Sangtae Kim**, returned to Wisconsin following stints in the pharmaceutical industry and government. Sang now serves as Executive Director of the Morgridge Institute for Research, the private half of WID.

MRSEC AND NSEC: BIG IDEAS COME IN SMALL PACKAGES

Just renewed with $18 million over six years, the NSF-supported Materials Research Science and Engineering Center (MRSEC) involves more than 40 faculty and 50 graduate students from disciplines ranging from chemical engineering to biology to medicine. The primary mission of the center is to understand and control the structure and dynamics of interfaces in a wide range of materials. Originally directed by **Tom Kuech** and now led by **Juan de Pablo**, MRSEC benefits from the participation of CBE faculty including **Nick Abbott, Paul Nealey, Sean Palecek,** Jim Dumesic, and **Dave Lynn**. The investigators work at the crossroads of advanced inorganic materials, polymers, and biological systems, connected by the common interest in heterogeneous interfacial phenomena. While the center is continuously evolving, at the current time MRSEC researchers are focused on three thrusts. The first seeks to create new semiconductors and is exploring new multi-element compounds through the manipulation of strain, dimensions, and deformability. The second thrust is organized around the study of molecular and electronic dynamics where carbon-based compounds meet inorganic compounds. "The work of our first two research groups will find direct applications in new technology for high-speed electronics, sensors, and solar cells," says Juan. A third team will build knowledge about coupling structural, mechanical, and interfacial interactions in liquid crystalline materials through an emphasis on defect manipulation, nucleation, mechanical strain, and growth. Liquid crystals have the properties of both conventional liquids and solid crystals, with many phases in between. Through techniques such as confinement, nanoscale patterning, and the addition of multifunctional polymers that induce structural order in the liquid crystals, the group will create new classes of materials that have applications in separations technologies, drug delivery, nanoscale materials processing, and biosensors.

Research at the NSF-funded Nanoscale Science and Engineering Center (NSEC) focuses on templated synthesis and assembly at the atomic level. The center is directed by Paul Nealey, and involves CBE faculty Juan de Pablo, Nick Abbott, and **Mike Graham**, as well as researchers across campus. NSEC researchers are directing the assembly of materials into functional systems and architectures through use of self-assembly, chemical patterning, and external fields. Researchers are developing new materials and processes for advanced lithography, in which self-assembled block copolymers are directed to adopt morphologies that advance the performance of nanomanufacturing processes. They are synthesizing biologically inspired organic nanostructures in which functional side chains display unique ordering, and exploring non-equilibrium processes for manipulating assembly of nanoscale objects.

Not content just to move nanoscience and technology "Forward," MRSEC and NSEC take seriously their responsibility to communicate with the public. Innovative K-12 outreach programs have led to the development of state-of-the-art lesson plans, instructional videos, and kits that are used throughout the world to educate the next generation of scientists and engineers. Over the last few years, the centers have distributed over 20,000 kits and reached 100,000 children!

AND THAT'S NOT ALL...

The above gives just a taste of the larger multidisciplinary projects at Wisconsin. There isn't room to describe all the exciting research going on in the CBE labs: We'll just mention (in alphabetical order): **Dan Klingenberg**'s work on electrorheological and magnetorheological fluids for automobile parts like brakes, shock absorbers, and engine mounts, **Regina Murphy**'s studies on protein aggregation and its relationship to neurodegenerative diseases like Alzheimer's, Sean Palecek's design of strategies to control cellular signaling pathways and regulate cell function in human pluripotent stem cells, Jim Rawlings' efforts at improving the ability of networked utilities to manage resources and demand using model predictive control, **Thatcher Root**'s initiatives in developing new catalysts and processing strategies for environmentally benign manufacturing, **Eric Shusta**'s advances in developing in vitro models of the blood-brain barrier and innovative strategies for noninvasive brain drug delivery, and **Ross Swaney**'s work to develop field theories for macroscopic modeling and robust computational methods.

BADGER ENGINEERS

Our undergraduate students survive one of the most grueling and rigorous curricula around: 133 credits of math, chemistry, biology, physics, liberal arts, and engineering. Despite, or maybe because of, the challenging curriculum, interest in chemical engineering among entering freshpeople is very high. At Wisconsin, students need to apply for admission into a specific engineering department. Currently we are admitting 104 students each year. In order to accommodate the demand, we offer core courses every semester, and have expanded and

Faculty in Wisconsin's Chemical and Biological Engineering Department. First row (left to right): John Yin, Regina Murphy, Juan de Pablo, Ross Swaney, Manos Mavrikakis, Christos Marevelias. Second and third row (left to right): Dave Lynn, Eric Shusta, Paul Nealey, Jim Rawlings, Nick Abbott, Sean Palecek, Dan Klingenberg, Charlie Hill (now retired), Jim Dumesic, Mike Graham, Thatcher Root, and Tom Kuech. Inset: our newest faculty members, Brian Pfleger and Jennie Reed.

upgraded laboratories. Of course, we are interested in not just quantity of undergraduates but also quality of the undergraduate experience, and have recently implemented many innovations, with others in the works. Dan Klingenberg has collaborated with faculty from other engineering departments to develop and offer a "Grand Challenges" class to freshmen. This is one of three introductory engineering classes that freshmen can choose; students scrutinize the application of engineering solutions to the "grand challenges" facing society in energy, health care, environment, security, and quality of life. Plans are under way to expand this very popular class to allow non-engineering students to participate alongside engineers. Alternatively, freshmen can choose a design-based Introduction to Engineering, where they work as teams on projects generated by Madison-area clients. Several CBE faculty, notably Thatcher Root, have participated in this fun, hands-on class.

Other curricular innovations take advantage of technology. Regina Murphy has developed online animated and narrated presentations, quizzes, and interactive modules to accompany the introductory material and energy balance class. The online materials allow students to learn and review basic concepts, and free up classroom time for greater instructor-student interaction, in-depth analysis of more challenging problems, and team projects. To better enhance the computational skills of our students, Jim Rawlings, Jennie Reed, and Ross Swaney have developed a Matlab-based course in Process Modeling, usually taken during the sophomore year. This course serves the dual purpose of teaching students the use of modern computational tools for modeling and data analysis, and of introducing students to concepts in process design, thermodynamics, kinetics, and transport that they will encounter in more depth later.

Upper-level electives provide opportunities for students to broaden and deepen their knowledge of particular areas of interest. Brian Pfleger has recently revived and updated a popular Biomolecular Engineering Laboratory, while Paul Nealey's course Plastics and High Polymers Laboratory provides students access to state-of-the-art equipment for polymer characterization. Tom Kuech, Nick Abbott, and Jim Dumesic share their respective expertise in Electronic Materials, Colloid and Interface Science, and Heterogeneous Catalysis. Thatcher Root has recently developed a new class in Energy and Sustainability, and also offers an undergraduate seminar-type class called Chemical Engineering Connections, where students explore chemical engineering topics that appear in the headlines.

SUMMER LAB (AKA 'CHEM-E BOOT CAMP')

One of the most distinctive ingredients in our undergraduate curriculum is CBE 424 Unit Operations Lab, better known as Summer Lab, an intensive 5-week, 5-credit course that students can complete in Madison, or in international locations (currently Oviedo, Spain, or Vienna, Austria). The formal experiments involve distillation, heat transfer, humidification, pumps, and reactors. The larger portion of the lab time is spent on informal experiments that challenge students through new-technology exploration, reverse engineering, product development, and optimization tasks. The experiments are not "scripted" but rather demand creativity and independent initiative as students construct their own apparatus and design experiments to achieve their goals. The pilot-scale projects closely resemble what students will encounter in industry. This course provides great value-added to employers of our students by strengthening skills such as teamwork, communication, time management, and creativity. Succinct oral and written communication also are emphasized, with memos favored over full reports, to reflect real-world practices. Students work with a variety of "bosses" for their different projects, and the diverse staff includes visiting faculty from abroad, retired practicing engineers, and UW-Madison faculty to provide a variety of perspectives, background, and expertise. Awards are given to pairs of students who exhibit the best teamwork and the most creative solutions. In a recent CBE alumni survey, one responder commented:

"As of your first day on the job, employers don't care what school you went to, how your grades were or how smart you think you are. They care that you are able to work on a team, solve problems, and finish projects quickly and well. They also care that you bring a professional attitude to work. CBE 424 demanded all of these things."

We've collected some other comments about Summer Lab from students in Table 1.

TABLE 1
Student Reflections on Summer Lab

This course gave practicality to the other coursework (book stuff).
This course simulated real work more than any other. It was very focused and allowed the student to consume themselves in something for a period of time.
I think learning how to solve the problem was pretty cool. The frustration I had with the course was the difficulty in building things. I do similar things all the time in my job, but I have a well-stocked storeroom with nuts and bolts and screws and fasteners of all types plus I can order anything I need on the Internet, while summer lab was an exercise in scavenging.
While very intensive, to say the least, that class alone provided enough practical application of the CHE concepts I learned to, and I quote, "stun" various interviewers. They were very impressed that independent projects, especially nine of them in five weeks with write-ups, were undertaken in undergraduate courses.
Teamwork was another aspect that was learned—it did prepare me for the array of people that you have to form teams with in the professional world.
I took mine in Oviedo and really enjoyed the chance to study and live temporarily in a foreign country and still study in English.
Very hands-on and met awesome people from Clemson in Vienna. I am still friends with them and one is my boyfriend.
Its only value was as a personal test of endurance.
Once you accomplish this course, you can get through almost anything.
There's some sense of pride that comes in finishing it, as well as some sense of "you should have to do it since I did!"
Pure torture.

BUSY BADGERS

Not content to spend all of their time in the lab or the library, undergraduate students at UW participate in an enormous variety of extracurricular activities. In any given year, about 100 students are conducting undergraduate research projects, 30 students are participating in 6-month industrial co-op experiences, and three students are studying abroad. Students participate in college activities from the Schoofs Prize for Creativity to the Burrill Technology Business Plan Competition to Engineering Expo—a three-day event run entirely by students that brings more than 10,000 visitors to campus.

Graduate students from Nick Abbott's group examine nanostructured materials.

Introduced in 2007, participation in iGEM, (international Genetically Engineered Machines) is increasingly popular, as student teams from universities around the world compete to design, conduct, and communicate experimental research projects in the field of synthetic biology. Teams receive a set of DNA molecules, called "biobricks," that they have to assemble into functional devices. The 2011 UW-iGEM team investigated the use of biosensors to quantify two biofuels, ethanol and alkanes, using red fluorescent protein as a signaling device. To improve the sensitivity and dynamic range of these *E. coli*-based biosensors, the team constructed an operon of genes for use in an iterative selection process. Once optimized, the biosensors will be used to screen libraries of bacteria in search of strains that yield high levels of biofuel. At press time we learned that the team won a gold medal in a regional competition and was invited to present their work at the iGEM World Finals.

PUTTING PEN TO PAPER

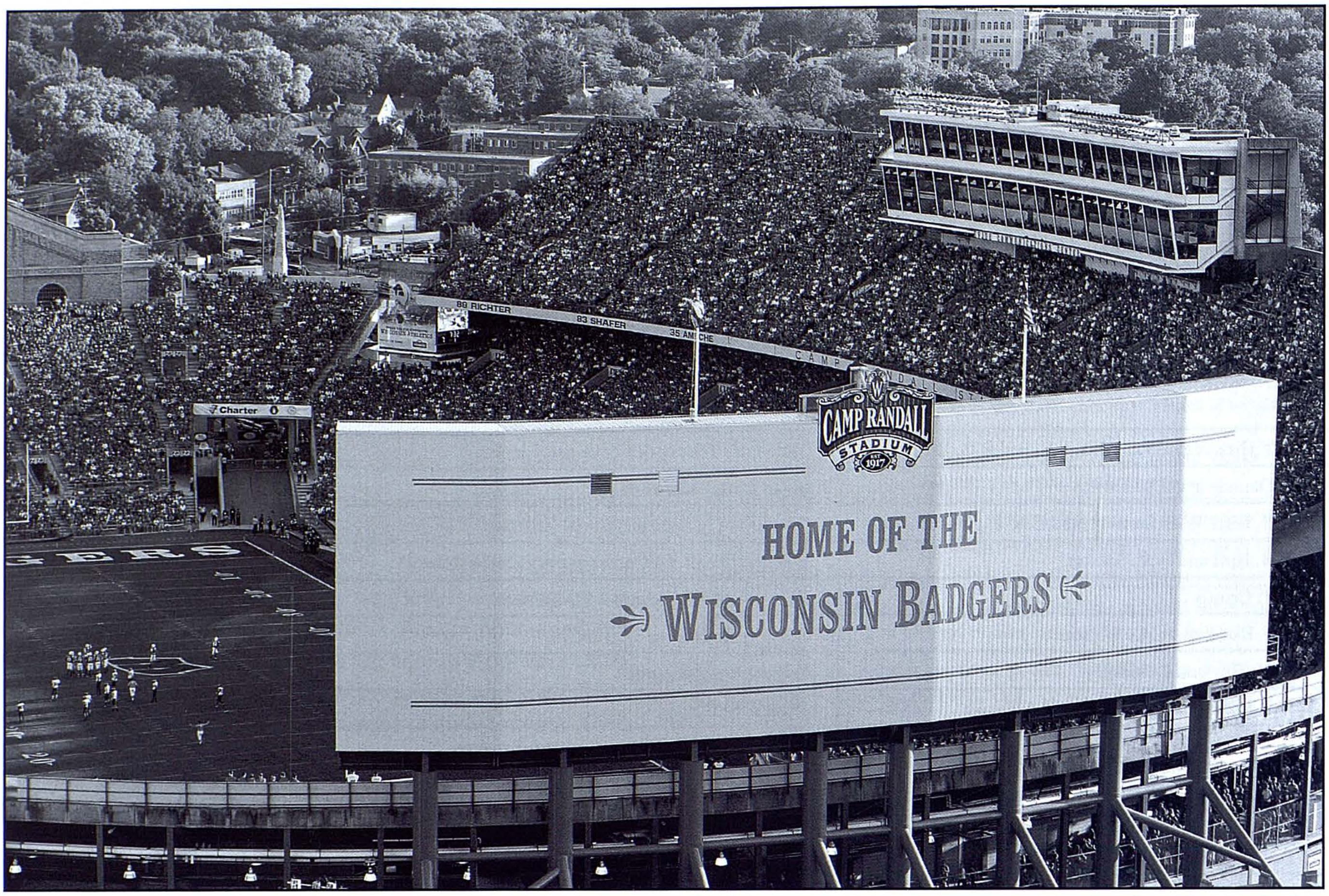
Wisconsin CBE faculty have a penchant for putting pen to paper (fingers to keyboard?). Table 2 shows a list of some of the books authored by past and present members of our

TABLE 2
Books Authored or Co-authored by Wisconsin Chemical Engineering Faculty

Author	Title	Year
O.P. Watts	Laboratory Course in Electrochemistry	1914
O.A. Hougen and K.M. Watson	Industrial Chemical Calculations	1931, 1936
O.A. Hougen and K.M. Watson	Chemical Process Principles (vol 1) Material and Energy Balances	1943, 1954
O.A. Hougen and K.M. Watson	Chemical Process Principles (vol 2) Thermodynamics	1947, 1959
O.A. Hougen and K.M. Watson	Chemical Process Principles (vol 3) Kinetics and Catalysis	1947
O.L. Kowalke	Chemical Process Calculations	1947
W.R. Marshall, Jr., and R.L Pigford	Applications of Differential Equations to Chemical Engineering Problems	1947
J.O. Hirschfelder, C.F. Curtiss, and R.B. Bird	Molecular Theory of Gases and Liquids	1954, 1964
F. Daniels and J.A. Duffie	Solar Energy Research	1955
R.B. Bird, W.E. Stewart, and E.N. Lightfoot	Transport Phenomena	1960, 2002
R.B. Bird and W.Z. Shetter	Een goed begin (A Contemporary Dutch Reader)	1963, 1971
E. J. Crosby	Experiments in Transport Phenomena	1961
D.F. Rudd and C.C. Watson	Strategy of Process Engineering	1968
W.H. Ray and J. Szekely	Process Optimization	1973
D.F. Rudd, G.J. Powers, and J.J. Siirola	Process Synthesis	1973
E.N. Lightfoot	Transport Phenomena and Living Systems	1977
J.A. Duffie and W.A. Beckman	Solar Energy Thermal Processes	1977
E.E. Daub, R.B. Bird, and N. Inoue	Comprehending Technical Japanese	1975
P.M. Berthouex and D.F. Rudd	Strategy of Pollution Control	1977
C.G. Hill	An Introduction to Chemical Engineering Kinetics and Reactor Design	1977
R.B. Bird, R.C. Armstrong, and O. Hassager	Dynamics of Polymeric Liquids (vol 1) Fluid Mechanics	1977, 1987
R.B. Bird, O. Hassager, R.C. Armstrong, and C.F. Curtiss	Dynamics of Polymeric Liquids (vol 2) Kinetic Theory	1977, 1987
J.A. Duffie and W.A. Beckman	Solar Engineering of Thermal Processes	1980, 1991
W.H. Ray	Advanced Process Control	1981
W.Z. Shetter and R.B. Bird	Reading Dutch	1985
E.E. Daub, R.B. Bird, and N. Inoue	Basic Technical Japanese	1990
S. Kim and S.J. Karrila	Microhydrodynamics: Principles and Selected Applications	1991
J.A. Dumesic, D.F. Rudd, L.M. Aparicio, J.E. Rekoske, and A.A. Trevino	The Microkinetics of Heterogeneous Catalysis	1993
B.A. Ogunnaike and W.H. Ray	Process Dynamics, Modeling, and Control	1994
N. Phan-Thien and S. Kim	Microstructures in Elastic Media: Principles and Computational Methods	1994
J.B. Rawlings and J.G. Ekerdt	Chemical Reactor Analysis and Design Fundamentals	2002
R.M. Murphy	Introduction to Chemical Processes: Principles, Analysis, Synthesis	2007
W.E. Stewart and M. Caracotsios	Computer-Aided Modeling of Reactive Systems	2008
J.B. Rawlings and D.Q. Mayne	Model Predictive Control: Theory and Design	2009

department. This impressive list includes some texts that have revolutionized the teaching and practice of chemical engineering, pushing the field "Forward." But did you know that **Bob Bird** has co-authored several books on Japanese and Dutch?

Recent textbook efforts include the 2nd edition of *BSL* (42 years after the first!), **Jim Rawlings'** book (with co-author **John Ekerdt**) that brings a new, mathematical/network approach to chemical kinetics, and Regina Murphy's text with



Bryce Richter, University of Wisconsin-Madison

Win or lose, the Wisconsin Badger football team draws a large, enthusiastic crowd to Camp Randall.

a modern, design-based approach to material and energy balances. Also in the works is the text *Chemical, Biological and Materials Engineering Thermodynamics*, co-authored by Juan de Pablo and UW alumni **Jay Schieber**, and a 2nd edition of **Charlie Hill**'s best-seller, *An Introduction to Chemical Engineering Kinetics & Reactor Design*.

Those of you who still have nightmares about those grueling homework sets on transport phenomena will be happy to learn about a new text now in the works. Dan Klingenberg is co-author, with Bob Bird of a new book, *Introduction to Transport Phenomena*, more in tune with the level of mathematical understanding of typical undergraduates. The new edition brings in Dan's years of experience in the classroom in our one-semester junior-level transport course, along with his research in rheology and his industrial consulting experiences. BSLK will re-arrange the presentation of shell balances, add missing steps in many examples and derivations, delete some of the most advanced concepts (those infamous Class C and D problems), and add chapters on dimensional analysis.

MADISON: 76 SQUARE MILES SURROUNDED BY REALITY

The University of Wisconsin campus is situated smack dab in the middle of the city of Madison, a lively college town plus state capitol. You can argue about the state's choice of milk as its official beverage while enjoying a pitcher of Wisconsin's unofficial state beverage at the Union Terrace and watching the sunset over Lake Mendota. State Street is the pedestrian thoroughfare, lined with cafes, restaurants, and shops, that links Bascom Hill at the center of campus with the Capitol Square. There are plenty of opportunities for music and theater, both on campus and in the beautiful Overture Center for the Arts. Outdoor activities abound; bicycling the rolling hills of the surrounding farmland is particularly popular. Winter brings out the ice fishermen, ice sailors, hockey players, and cross country skiers. Badger athletics keep sports fans happy. And at every football game there is the opportunity to try out the polka when the marching band plays "Roll out the barrel!" ❐

TIPS FOR BUSY NEW PROFESSORS

Phil Wankat
Purdue University • West Lafayette, IN 47907

New faculty are often surprised how busy they have become setting up a research program, writing papers and proposals, teaching and learning to teach, prioritizing competing tasks, and understanding a new work environment. The focus of the first part of the paper is balancing one's life while earning tenure and promotion. After discussing the promotion and tenure (P&T) procedures at research and undergraduate institutions, time management techniques are presented for teaching, research, and service. Since more experienced professors also often have difficulty balancing myriad urgent tasks, they may also benefit from some of the suggestions.

PROMOTION AND TENURE

Assistant professors should start their careers by clarifying their vision and deciding what goals are important to them. Some of the goals that other people in this position have thought are important include: P&T, focus and time with a significant other, family (and a key question is when to have a baby?), starting a company, becoming rich or famous, running a marathon, or spending significant time playing golf, fishing, or reading. The assistant professors' major professors and the other professors at their new institutions will assume that P&T is the absolute number one priority. But it is not their life. Everyone should periodically spend some time deciding what is truly important.

Most people have multiple goals. For example, they want to become a respected member of the academic community and earn P&T, but they also want to have a life. Having a life means that additional goals are also important. To achieve multiple goals most people need to prioritize and balance. Some engineering professors have decided, after prioritizing, that a tenure-track position at a major research university was too all consuming and did not leave time for other important goals. Thus, they made the decision to be instructors (non-tenure track), go into industry, pursue another career, or quit and raise a family.

Assistant professors who decide that P&T is one of their important goals should obtain and study the written rules. The written rules will help them understand the procedure and timing. Although the written rules are normally followed (not following them invites a lawsuit), they are never the entire story. To fill out the details of the entire story assistant professors need to discuss the unwritten requirements with knowledgeable professors both inside and outside their department. Because unwritten rules can be interpreted differently, knowledgeable professors will disagree; however, one can usually triangulate closely enough to what will happen during the process to provide useful guidelines.

Typical P&T requirements differ for research universities and undergraduate institutions.[1-3] At research universities the number one requirement is ***Money!*** The goal is to raise at least enough money to support the professor's research. Once money is obtained quality publications in good journals are expected. Some of these publications should be with graduate students, some should be collaborations with other professors, and some can be sole author publications. The ultimate goal of the publications is **Impact** which is measured by looking at quality, citations, invitations to present plenary lectures and seminars at other institutions, and a general buzz that one is doing great research. It helps to have Ph.D. graduates accept academic positions. Since impact takes time, for promotion to associate professor in-

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stitutions look for the **Potential** for impact through research. At many research institutions good, but not great, teaching is a minimal requirement although great teaching may help for early or slightly marginal promotions. Usually the only measure used by research institutions to assess teaching is student evaluations. Good citizenship and service—typically being friendly and doing one's share of the menial work—is expected. Professors are rarely promoted for citizenship and service although lack of citizenship and service may block promotion.

At undergraduate institutions the number one priority for P&T is good to great **Teaching**. The goal is still **Impact**, but it is impact through graduates. Because teaching is more important, additional measures such as peer reviews and teaching portfolios may be used in addition to student evaluations to assess teaching. Advising, service, and citizenship are usually more important than at research institutions, and advising may be considered as another form of teaching. Most undergraduate institutions expect a modest amount of research, but most of the research will be done with undergraduates. Grants still need to be obtained to support the research, but the amount of money required is significantly less than at a research university.

Usually in research universities (computer engineering is an exception) archival journal publications are the gold standard and publications in proceedings are almost ignored. Determine which archival journals are most prestigious. The same tends to be true for research grants—in general, NSF and National Institutes of Health grants are prestigious. Once assistant professors have some idea of what their departments and institutions are looking for, they can develop activities that will satisfy promotion and tenure committees. Then spend time *every week* on at least one of these activities. Of course, at the same time they need to balance their lives, and being efficient can help them do this.

EFFICIENCY TIPS

Goals and Activities

One immutable fact of academic life is *there is never enough time*. This does not change after promotion. Because of this, most professors will benefit from better time management.[2-4] A good place to start is by setting goals and prioritizing. Goals are what one would like to accomplish in a given time frame. Unfortunately, most professors have multiple goals that compete for time. Multiple goals can either be worked on simultaneously or one can delay working on some goals until other goals have been achieved. For example, common advice for engineering assistant professors is to not write a book until they have been promoted. This is normally good advice, but the danger with waiting is one may never achieve some important goals. On the other hand, working on a number of goals simultaneously tends to dilute the effort on every goal and it is easy to become unfocused.

New assistant professors often find that a semester goal list and a six-year goal list (the usual time frame for promotion to associate professor) are useful. For example, the six-year goal list may include being promoted and taking a vacation in the Bahamas. Once the goal list is prepared, prioritize it. Prioritizing may show that the vacation in the Bahamas should be delayed until after promotion is received—and then it will serve as a reward.

Achievement of many goals such as being promoted depends on the decision of others. After triangulating the requirements for promotion at their schools, assistant professors need to determine activities that will help them achieve this and other goals. The analysis of the P&T process should have identified these activities. At research universities writing proposals and papers are appropriate activities for the goal of being promoted.

Efficiency Tools

A To-Do list delineates items that one hopes to accomplish in a given time frame. It is useful to have several To-Do lists such as semester, weekly, and daily To-Do lists. For assistant professors the semester and weekly lists typically include goals for the P&T committee, their own work goals (which hopefully will partially overlap with the goals for the P&T committee), and high-priority non-work goals such as exercising. The daily list, which is often on a desk calendar, will include the mundane tasks such as attending committee meetings and writing lectures plus one activity that will help achieve a long-term goal. If an item is not finished one day, it is moved to the next.

Another important efficiency tool is to learn how to delegate work. Professors often do menial tasks that could be done by a secretary or work-study student. There are other tasks such as helping to prepare proposals and submitting papers that graduate students can do and that will help prepare them for research positions when they graduate. When delegating, give clear assignments and delegate responsibility for the details. Check on progress and provide feedback on the final product, not on the details of how the work was accomplished. Finally, give credit for good work. A sincere thank you, acknowledgment in a paper, or flowers will be greatly appreciated, and they help later tasks go smoothly.

Learn to say no pleasantly. One very useful response is "Let me think about it." Even if one eventually says no, the appearance of due diligence is helpful. Another useful response, particularly with supervisors, is "What would you like me to stop doing to take on this task?" Since department heads are not always aware of what extra work a professor does, reminding them can be useful.

The 55-Hour Rule and Family

It is very easy to work too much. Maximum productivity occurs with a steady rate of about 55 hours of work per week with one day off per week. Everyone needs to have time for other parts of their lives.

Professors need to reserve time for themselves and their families ("family" broadly represents people who are important to the professor). Five 10-hour days plus 1/2 a day on the weekend with at most six work days per week will be close to maximum productivity and allows for significant family time. Balancing work and family is often a stress point, and all studies indicate that balancing is harder for women because society has expectations that women will do more care giving.[5] Most people also need some alone time to refresh their batteries. This can be as simple as driving or walking to work, or losing oneself in a computer game for an hour. Developing a flow activity in which one's brain is focused entirely on the activity (examples include golf, cooking, jogging, fishing, or wood working) also refreshes and recharges one's brain.[6] A nice way to engage in a flow activity is to take short vacations by leaving a day early for a conference and spending one day engaging in the flow activity.

TEACHING

Numerous studies[7] have shown that the following elements lead to student learning.

1. *Students involved in learning*
2. *Students actively processing material*
3. *Both students and faculty have positive expectations*
4. *Practice – reflection – feedback, and repeat*
5. *Student time on task*
6. *Challenged, yet successful students*
7. *Enthusiastic, engaging teacher.*

Note that this list implies that lecturing to a passive audience will not lead to optimum learning. *What the students do is much more important than what the instructor does.*

Lecturing

Straight lecturing with passive students is not the optimum teaching method. Lecture can, however, be a good method for transferring information (only mastery learning is clearly superior); thus, it is reasonable that lecturing be part of everyone's teaching arsenal. Because lecture is not a good method for teaching higher-order skills such as critical thinking, creativity, design, communication skills, and team skills, do not overdo it.[3, 4, 8] Lecture has a number of advantages for new faculty. New professors are familiar with the lecture mode of teaching because they were probably taught that way. Departments and students usually expect that new faculty will lecture as their primary teaching method. In addition, lecturing does not require preparing far in advance. Lectures can be prepared a day or even a few hours before the class, and it is easy to adjust lectures if the class moves ahead or behind the course schedule.

One key to a good lecture is to be sure that the students are not passive for long periods. Remember that the average at-

New professors often believe they need a long chunk of uninterrupted time to prepare lectures. Then when they find that long chunks of uninterrupted time are very rare, they do not know how to proceed. A more efficient and effective approach is to build a lecture like a house.

tention span of undergraduates sitting passively in lecture (10 to 15 minutes) puts a constraint on lectures. If the instructor keeps talking past students' attention spans he/she will lose them for a few minutes. As the passive lecture continues, attention spans tend to decrease. To combat this, use **mini-lectures** with active learning **breaks**. The 10- to 15-minute mini-lecture is organized in a straightforward manner. Start with a short (30 seconds to one minute) *opener* that connects with previous work.

Then the *main body* of the mini-lecture explains the critical information. This is followed with a *brief summary* that also connects to the next step.

Breaks are used in between mini-lectures to provide time for the students to be active (or occasionally reflective). Breaks could be used for student introductions, small group discussions, stretch/restroom, one-minute quiz, demonstration, catch up on note-taking and share notes with a neighbor, quiz, reflection, and so-forth. The breaks should connect to the course objectives although an occasional break for fun is OK. Most breaks have to be prepared for in advance, although there are a few break methods such as brainstorming that can be used with little preparation. Active breaks will energize the class and provide enough student focus for another 10 to 15 minutes of mini-lecture. Initially students will be hesitant to start an activity. They have to be trained to talk to each other! But once they start they will not want to stop—it helps to have a signal such as a bell or flashing the room lights that the break is over. In order to have time for breaks the instructor must control *content tyranny*, which is letting the need to cover content control the teaching method. Relaxing in class and acting human is more important than covering everything.

New professors often believe they need a long chunk of uninterrupted time to prepare lectures. Then when they find that long chunks of uninterrupted time are very rare, they do not know how to proceed. A more efficient and effective approach is to build a lecture like a house. Houses are built by starting with the foundation, frame, outer walls, and roof first, then finishing touches are done room by room. It is also not unusual to move into a house before many of the finishing touches are finished. Houses and lectures are not built in one day. Start building a lecture with 10 to 15 minutes on the foundation and frame, and finish later. If "later" turns out to be after the lecture, instead of apologizing for the lack of preparation, lecture from the detailed outline. Most new professors are pleasantly surprised with how well this lecture is received. Most new professors spend *too much time* preparing lectures. They need to force themselves to learn how to prepare a new lecture—assuming they already *know* the material—in a maximum of two hours for a 50-minute lecture. Since controlling content tyranny starts at the preparation stage, also resist the urge to add those additional details that were just discovered last week.

Active Learning

Because it is what students do that leads to learning, teaching methods that force students to be active are often very effective.[9] In small classes students can be asked to solve problems at the board, and then selected students can explain their solution to the class. In classes of any size *cooperative groups* can be formed in which students work together to learn the material.[4, 9-10] Successful use of long-term cooperative groups requires that individual group members can only be successful if the entire group is successful, but at the same time each member is held individually responsible for learning the material. Thus, there must be some type of individual assessment such as quizzes. Project- and problem-based learning (PBL) are similar group methods except in project-based learning (commonly used in capstone design classes) students integrate what they have learned in previous courses to complete a project while in PBL new material must be used to solve the problem.[3, 9, 11] PBL can be difficult for less mature students particularly if there is not considerable tutorial support. The professor needs to have some skill as a facilitator if any groups become dysfunctional or student learning will be impaired.

Both hands-on and computer simulation laboratories require students to be actively involved in the process. Although a certain amount of cookbook instruction may be required initially, student learning is enhanced if they can ask and attempt "what-if" questions and learn by exploring. *Mastery learning*[4] takes the usual college formula for learning (time is fixed and the amount learned is variable) and reverses it by giving students opportunities to master the material with no or modest time constraints. For example, in a computer simulation lab we use a two-hour time limit for a mastery quiz that some students finish in 20 minutes. The students complete the quiz, have it scored, and are told what is wrong but not why it is wrong. They then return to their computer to fix their errors. This process is continued until they either have the quiz perfect with no penalty for repeated trials, or they run out of time. Over 95% successfully complete the quiz. Mastery learning is an excellent approach to bring students up to minimal standards on a critical skill.

Since these methods are unfamiliar to most professors and they, like lecture, can fail, professors trying the methods for the first time should obtain assistance. Either find a professor locally who has successfully used the method or attend a teaching workshop that provides hands-on experience with the method. It is often a good idea to start slowly and use the method for only parts of a course. For example, it is relatively easy to start using informal groups during break periods in a lecture class. Since groups are together for only a short period and student grades do not depend upon the group work, dysfunctional groups are rarely a problem.

A Baker's Dozen Useful Teaching Tips[2, 3, 8, 9]

1. *Write and share course objectives. Students are more likely to learn what the instructor wants them to if they know what that is.*
2. *Come to class early and stay late. Before or after class is the easiest time for students to talk to the professor and many students will never come to office hours. Before and after class is the most efficient time for the professor. In addition, coming to class early sends the subtle psychological message that the professor wants to be there.*
3. *Solve tests, quizzes, and homework before handing them out. If problems are not solved in advance sooner or later one of the problems will be unsolvable, and fair grading becomes very difficult if not impossible.*
4. *Make sure there is enough time available for tests. Students typically take 3 to 5 times longer than the professor to solve problems.*
5. *Allow students to request test regrades, but require that requests be in writing on a separate sheet of paper that is attached to their test. Occasionally a student who uses an unusual but correct solution method will make a simple algebraic or arithmetic error. In the rush of grading a large number of tests it is easy to overlook that the method was essentially correct and give too low a score. Allowing regrades provides redress. The requirement of written regrades reduces the amount of trivial requests.*
6. *If teaching assistants are used, train them. Go over a number of test problems and show how to grade them. Discuss the best way to tutor students. Explain how to operate a laboratory, computer, or recitation section. Discuss proper interactions with undergraduates.*
7. *After the first test, ask the students what will help them learn and make some of the changes suggested. I find that 3×5 cards turned in anonymously are useful for this.*
8. *List office hours and* be available *during office hours. Tell students that other times can be arranged by appointment.*
9. *Lecture less! Use active-learning methods.*
10. *Learn the students' names. This will increase rapport and reduce the amount of cheating.*

*11. Use an absolute grading scale (*e.g., *90 and above is an A) as a guarantee of grades, but give yourself the right to lower the cut-off points.*

12. Attend at least one teaching workshop. The ASEE National Effective Teaching Institute (NETI), which is held immediately before the ASEE annual meeting, is highly recommended. Use of a modest amount of an assistant professor's start-up package to attend a teaching workshop will pay handsome research *dividends because he/she will do a better job teaching in less time. This will provide more time and energy to start research.*

13. Remember: what students do is more important than what the instructor does.

RESEARCH

Research changes when one becomes a professor.[2, 3, 12] Less time will be available to actually do research; instead, professors become managers and funders of research groups. Obtaining money through grants and contracts becomes a major responsibility. In many engineering departments if a professor has no money there will be no graduate students. Budgeting is also a major responsibility. Careful budgeting and use of start-up money can greatly increase the amount of research that can be accomplished.

Money and Proposals[13]

How much money is needed to support an active engineering research program? Assume a professor at a research university plans to average one Ph.D./year at steady state and that the average time for a Ph.D. to graduate is between four and five years. In addition, assume that this professor will graduate one terminal M.S. every two years. At major research universities this group of five to six students is of moderate size. Depending on the type of research done and the stipend paid to graduate students, the current cost of one graduate student including tuition, equipment, supplies, and overhead will be in the range from \$40,000 to \$100,000 per year. For certain types of research these estimates are low. Plus at most schools professors need to raise money for two to three months of summer salary plus from 5 to 15 % of academic year salary, and they have to pay overhead on these amounts. The estimated total is between \$250,000 to \$600,000/year. In order to raise this much money every year professors need to become proficient at writing successful proposals. Attending a proposal writing workshop will probably pay dividends.

Unfortunately, obtaining funding is a challenge. Approximately 60% of science and engineering support is from federal agencies. The typical success rate is 10 to 15% in the engineering directorate, about 15% for NSF CAREER proposals and about 15% for NIH R01 for new faculty. In order to survive with these low percentages, many new faculty will submit close to 10 proposals/year. Of course, many of these proposals are revisions of previous unsuccessful proposals, with revisions following the advice of the reviewers.

For NSF and similar government proposals do not give the panel obvious reasons to decline your proposal. First, follow the proposal preparation rules. If the limit on number of pages of text is 15 with 11-point font do not try to turn in 20 pages and do not try to turn in 15 pages with 10-point font. Failure to follow the rules will usually disqualify the proposal. If the page limit is 15 pages, use very close to the full 15 pages. A 10-page proposal looks like the proposer does not have enough ideas. Complaining or whining about the lack of university support or how difficult it has been to obtain research funds will not endear oneself to the reviewers. Proofread the proposal carefully. Reviewers tend to think that writers of sloppy proposals will do sloppy research. Since there is always prior research, cite the work of other researchers in a positive fashion. The presentation of research needs to balance the broad picture with details. Most of the members of the review panel will not be expert in the research details. Thus, the proposal needs to explain the importance of the research. There will probably be at least one expert in the research area on the panel, however, and the opinion of this expert will be given a lot of weight by the other panelists. Thus, the proposal should provide sufficient research details to convince the expert that the proposer understands the research area, has chosen an important problem to work on, and has a clear approach to solve the problem.

Although the research part of NSF CAREER proposals is the most important part, the final decision of who receives a grant is often made based on the teaching part of the CAREER proposal. This apparent paradox occurs because there is usually too little money to fund all of the proposals with excellent research. Thus, the teaching part of the proposal often becomes the tie-breaker. Because of this, the teaching part must be prepared as carefully as the research part. There must be a literature review with appropriate references for both the content and the proposed pedagogy (*e.g.*, refer to the books in the References and to appropriate articles in *Chemical Engineering Education* and the *Journal of Engineering Education*). CAREER proposals typically include new course development and involving undergraduates in research; however, chances of receiving funding increase when a creative idea is included. The teaching part of the proposal is much more believable if the proposer documents long-standing interest in teaching and in training undergraduate researchers. In addition, reviewers like proposals that include plausible efforts to increase diversity and do K-12 outreach. NSF also requires evaluation and dissemination of results. Thus, the teaching part should include an educational research project.

There are strategies to learn quickly what the funding agencies want. Ask successful professors in your department to share the narrative portion of successful proposals with you. Collaborate with a more experienced professor and help develop a proposal as co-PI. Attend the NSF sessions at AIChE meetings and make a point to talk individually with the program directors. Contact the appropriate program director and volunteer to serve on a review panel for a proposal round that you do not intend to submit a proposal to. Watch the reactions of the panelists and the program director to different proposals and see which ones are funded. E-mail the program director a short description of the proposed research and a list of specific questions, or take a few minutes at a review panel to discuss proposal ideas with the program director. Surprisingly, advice to not submit (you will have to interpret the program director's lack of enthusiasm as a no) is just as valuable as advice to submit.

Effective Research

Running a research program and directing graduate students is quite different from doing research as a graduate student. The assistant professor must develop and fund research. Although it is common for assistant professors to stay in the same general area as their Ph.D./postdoctoral research and to finish some promising ideas from that research, P&T committees like new professors to go beyond this area. A balanced portfolio of initial research projects will have one or two projects that continue Ph.D./post-doc research, one or two new projects within the same research field and, if interested, one or two projects in a new research field. The portfolio can also balance high-risk with low-risk projects and balance slow publication/high-impact articles with fast publication/low-impact articles, although the impact of articles can be a surprise. Because of the time it takes to start a research program, assistant professors should not expect their graduate students to produce all the publications needed for promotion. Research papers need to be written with graduate students, in collaboration with another professor, and alone.

Students doing research are engaged in a type of experiential learning with their advisor as the teacher/guide. The pedagogical goal is to provide enough assistance to help students avoid costly errors, but to allow them enough freedom to discover how to conduct research. Unfortunately, there is a built-in conflict of interest since professors want to obtain research results as quickly as possible, but still need to allow students enough freedom to make mistakes, grow, and become independent researchers. Ph.D. students should not be treated as highly competent technicians who are expected to do what they are told. Keep the welfare of each graduate student paramount. Since different students have different needs, the amount of direction and help provided to hone their skills will be different and should decrease as students mature as researchers. The goal is to help the students achieve their career goals, not to produce clones unless that is the student's career goal.

Once the research reaches a certain state, research papers need to be written. Writing is the hardest part for most graduate students and many new professors.[3, 14] As noted in the discussion on preparing lectures, long periods of uninterrupted time are unlikely to appear. Fortunately, long uninterrupted periods of time are not needed to write. The key is to write several times every week and if possible every day.

A scheduled 30-minute writing/editing period every day will result in a completed paper much faster than waiting for that elusive block of free time. Although it is tempting to perfect each sentence before proceeding, most professors (there clearly are exceptions) will produce a high-quality paper faster if they write the first draft as quickly as they can and then edit.

Co-authoring papers is part of the education of graduate students. It is a truly rare graduate student who knows how to write a research paper. Even students with an excellent command of English will have difficulty properly structuring a research paper. Thus, the professor needs to provide sufficient scaffolding in the form of example papers, step-by-step critiques of several outlines and word-by-word critiques of several drafts of the paper. The first paper that a graduate student "writes" will take the professor more time than if the professor had written it alone. Fortunately, there will be improvement and time spent on the first paper will be saved in later papers and in the student's thesis.

COLLEGIALITY AND SERVICE

Assistant professors are rarely promoted and tenured on the basis of collegiality and service, although the lack of collegiality and service may prevent promotion and tenure.[1, 3] Since schools are making roughly a 30-year commitment when a new professor is tenured, some expectation that the professor will be collegial and pleasant is reasonable. Be collegial—smile! Say hello to colleagues in the hall. Network roughly two hours per week with colleagues. An occasional lunch or coffee with colleagues can help them get to know you and make any charges of lack of collegiality harder to sustain. It is neither realistic nor necessary to like all of your colleagues, but polite social behavior is expected. If possible, assistant professors are advised to avoid controversy.

Assistant professors should aim to be considered a good contributor to the departmental service load without spending too much time on this service. This is true for both undergraduate institutions and research universities, although expectations for service are typically higher at the former. In other words, assistant professors should do their share within the department and engage in a reasonable number of the common duties that every department has to perform. These common duties include attending committee meetings, meeting with visitors, hosting alumni, helping to write and grade qualifying examinations, and so forth. Volunteer to be in charge of one task or committee. For example, being in charge of the departmental seminar program is useful for assistant professors since it is great opportunity to network with professors from other schools.

Most engineering programs are trying very hard to attract more women and underrepresented minorities to engineering. When women and underrepresented minorities are hired as assistant professors, there is a natural tendency to ask them to serve on committees, advise undergraduate organizations, and help in recruiting. Unfortunately, the positive good of these roles is rarely reflected in the primary P&T requirements. A chat with the department chair may be very helpful in deciding how to respond to an invitation from the Dean or upper administrators. At a minimum the chat will make the chair aware of the extra service burden requested of women and underrepresented minorities. Since the decision of what extra duties to accept is ultimately up to the professor, it may be helpful to remember that upper administrators seldom vote on P&T decisions.

Finally, become involved in the profession. Join AIChE and ASEE and attend some regional and national meetings. Volunteering to serve on committees and co-chair symposia helps one to be known by other professors, which will make it easier to obtain letters of recommendation. Since presenting seminars at other universities is considered a sign of impact, leap at this opportunity.

CLOSURE

So far, we have focused on the challenges of being a new engineering professor without discussing the joys of being a professor. Being a professor is a job, but for people with the right skills and attitude it is the best job in the world. Working with students can be a joy. The growth of a student from fresh high school graduate to accomplished college graduate ready to start an engineering career is often amazing. And engineering professors make a significant contribution to that growth. Professors also have freedom to develop and conduct the research that they find interesting. They have the opportunity to help graduate students blossom into accomplished researchers who may eventually outstrip the accomplishments of their major professor. Despite the challenges and occasional disappointments, being an engineering professor remains one of the best occupations in the United States.

REFERENCES

1. Diamond, R.M., *Preparing for Promotion, Tenure, and Annual Review. A Faculty Guide*, 2nd edition, Anker Publishing Co., San Francisco, 2004 [ISBN 13 978-1-882982-72-1]
2. Reis, R.M., *Tomorrow's Professor*, IEEE, New York, 1997 [ISBN 0-7803-1136-1]
3. Wankat, P.C., *The Effective, Efficient Teacher*, Allyn & Bacon, Boston, 2002 [ISBN 0-205- 33711-2]
4. Wankat, P.C., and F.S, Oreovicz, *Teaching Engineering*, McGraw-Hill, New York, 1993, free as pdf files at https://engineering.purdue.edu/ChE/AboutUs/Publications/TeachingEng/index.html
5. Monosson, E., *Motherhood, The Elephant in the Laboratory: Women Scientists Speak Out*, Cornell University Press, 2008 [ISBN 978-0-8014-4664-1]
6. Csikszentmihalyi, M., *Flow: The Psychology of Optimal Experience*, Harper-Collins, New York, 1990
7. Chickering, A.W., and Z.F. Gamson, "Seven Principles for Good Practice in Undergraduate Education," *American Association for Higher Education Bulletin*, **39**, 3-7 (1987)
8. McKeachie, W.J., *Teaching Tips*, 9th edition, D.C. Heath & Co., Lexington, MA, 1994 [ISBN 0- 669-19434-4]
9. Prince, M.J., "Does Active Learning Work? A Review of the Research," *J Engr. Educ.*, **93**(3), 223 (2004)
10. Johnson, D.W., R.T. Johnson, and K.A. Smith, "Cooperative Learning Returns to College: What Evidence is There That It Works?" *Change*, **30**(4), 27-35 (1998)
11. Samford Univerrsity, <http://dlserver.samford.edu/edu/teacheredpbl.htm>, accessed Oct.30, 2011
12. Burroughs Wellcome Fund and Howard Hughes Medical Institute, *Making the Right Moves. A Practical Guide to Scientific Management for Postdocs and New Faculty*, 2nd edition, Howard Hughes Medical Institute, Chevy Chase, MD, 2006 Available online at <http://www.hhmi.org/labmanagement>
13. Anderson, T.J., and G.A. Prentice, "Workshop: Career Planning for Prospective New Faculty," AIChE Annual Meeting, Minneapolis, MN, Session 1, Oct. 16, 2011
14. Boice, R., *Advice for New Faculty Members*, Allyn & Bacon, Boston, 2000 [ISBN 0-205-28159- 1] ❐

TEXT MESSAGING AS A TOOL FOR ENGAGING CHEMICAL ENGINEERING STUDENTS

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Millennial/net generation students are more interconnected than any prior generation, often connecting through means not commonly used by the faculty. From a variety of social network sites to the pervasive use of mobile devices, these digital natives are fully comfortable interacting with people that, in some cases, they have never even met in person. Current modes of communication among instructors, however, still typically default to, in some order of preference, face-to-face meetings, e-mail, and phone calls. As such, there may be a disconnect in the ways students would prefer to interact with their instructors and the ways generally available to them. It would seem, then, that to maximize student engagement, retention, and support, instructors should, if possible and practical, interact with their students via means that students prefer.

A classic report established the "Seven Principles for Good Practice in Undergraduate Education."[1] Among these principles, student-instructor interactions are explicitly listed as critical to maximizing student learning. Recent data, however, reveal that student-faculty contact outside of class occurs on average only once per month, with 9% of students not meeting with their instructors outside of class even once during an entire semester.[2] This lack of engagement with their instructors, combined with a reduced personal investment in their studies—today's full-time students spend 13 fewer hours on coursework than students in past generations (27 vs. 40)[2,3]—has impaired student learning to the point that one-third of students make no gains in critical thinking during four years of undergraduate education.[2] Although the faculty cannot make students choose to work harder, faculty members can encourage contact by continuing to evolve in

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how they engage students both in and out of class. Applying new technologies is often a focus of new strategies/interventions in this regard.[4-7]

Among the technologies that should be considered is text messaging. Roughly 2.5 trillion text messages were sent worldwide in 2008.[8] A recent Pew Research Center project determined that 75% of 12- to 17-year-olds own a cell phone and use texting as their primary mode of communication with friends, texting at nearly twice the frequency of face-to-face interactions.[9] The frequency with which these students text also increases as they age, with older students (ages 14-17) sending roughly 60 messages per day and younger students (ages 12-13) sending 20. Interestingly, while text messaging was found to be the preferred means of peer communication, teens reported using voice calls preferentially to reach their parents. This suggests that these students recognize that different modes of communication can be useful for communicating with different social groups or for different purposes. Moreover, it may suggest that the manner by which students choose to communicate is indicative of the type of relationship they have or would like to have with the other party.

In this work, we sought to determine if students would want to use text messaging for professional communication about chemical engineering course content and if doing so would increase their engagement with the course. The genesis of the project was the observation that attendance at office hours seemed to have decreased dramatically in the last few years, an observation that was supported by anecdotal evidence from colleagues. Over the same time period, text messaging had become essentially universal among students.[9] It prompted the question of whether students' ubiquitous use of this form of communication, which is inherently distinct from face-to-face meetings in synchronicity, portability, and relative anonymity, was in some measure responsible for the decline in office-hours visits. Thus, could enabling texting for class communication re-establish the more traditional, and potentially more valuable, routes of communication?

METHODS AND APPROACH

We focused this study on text messaging as it is more accessible and less formal than e-mail and presumably less intimidating than phone calls and face-to-face contact. It was important, however, to consider the practicality of using texting for an instructor who may not text for personal or professional communication (as was the case here). To address this issue and avoid privacy concerns, the texting contact number provided to the students was a free phone number provided through Google Voice.[10] Use of Google Voice allowed the instructor and TA to receive and respond to texts from their computers as if the texts were e-mails. In this way, the instructor (unlike the TA, who does text regularly) did not have to learn how to text or use his personal phone and number.

It was important to consider the practicality of using texting for an instructor who may not text for personal or professional communication (as was the case here).

Our study primarily sought to test two hypotheses: i) that students would prefer to interact with their course instructor via text messaging, as compared to interactions by other means such as e-mail, phone calls, and office hours; and ii) that students who text message their instructor would also be more likely to interact using other means. The rationale of the second hypothesis was that if a student were willing to make initial contact with the instructor via a "comfortable" method (*i.e.*, text messaging), then perhaps the student would be more likely to engage further with the instructor through means with which the student may have initially been less comfortable (*i.e.*, a face-to-face meeting during office hours).

We tested these hypotheses during Material and Energy Balances in the Fall semester, 2010. The class was composed of 54% (38 of 71) first-semester sophomore chemical engineering majors with the remainder a distribution of years and programs (including biotechnology, environmental engineering, and chemistry). Recognizing the relative youth of the students in the class—students who are still learning to navigate college life to some measure—we felt that this class provided an ideal setting for testing whether using a relatively new mode of student-instructor communication would improve the frequency and utility of student-instructor interactions and, in turn, improve student performance, learning, retention, and attitude toward the discipline.

The study was set up with two parallel class sections, one in which student-instructor communication by text messaging was enabled in addition to the more traditional e-mail, phone, and face-to-face meetings. In the other section, only e-mail, phone, and face-to-face meetings were made available to the students. It should be noted that the instructor was the same for both sections and tried to be consistent in his interactions with the students. With this experimental design, we sought to determine if the availability of text messaging would change student perceptions and behaviors regarding the use of texting for communication with the instructor regarding course content.

Each day at the end of class, the students in both sections were asked to submit "muddiest point" papers detailing the

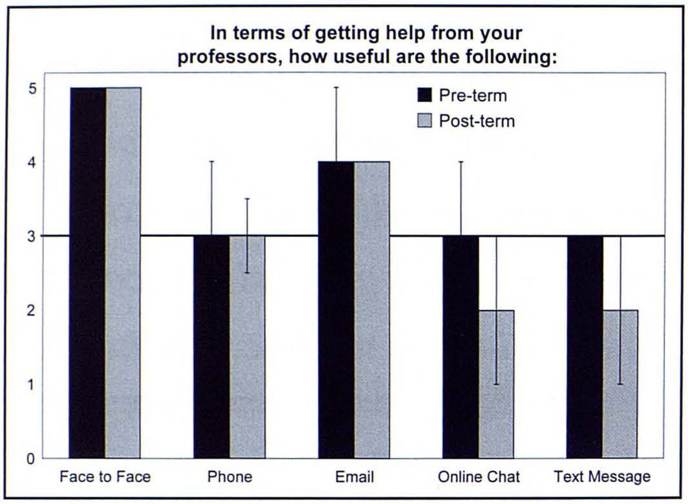

Figure 1. *Comparison of utility of different communication strategies. Students were asked which communication methods they felt were most useful for getting assistance from their professors. Rating scale: 5 = always useful, 4 = useful, 3 = neutral, 2 = rarely useful, 1 = not useful. Only face-to-face meetings and e-mail were favorably viewed. These attitudes did not change between pre-term and post-term surveys. Data are reported as the median ± the median absolute deviation; non-parametric statistical analysis by Mann-Whitney-Wilcoxon rank sum test; ranksum function in MATLAB with a significance threshold of p = 0.05.*

most confusing part of the day's lecture. In the texting section, responses could be submitted by paper or text message, while in the nontexting section all of the submissions were on paper. Students in the texting section also had the number at their disposal for use outside of class. The classroom assessment exercise served to initiate the process of texting in the texting section and to give students regular reminders of its availability. We felt that this was a fair way to ensure that the students did not forget about the availability of the texting channel while not biasing them into thinking we wanted them to use it.

To assess the project, we recorded the number of text messages sent to the instructor and TA, attendance at office hours (name and section of each student), and the number of e-mail messages sent to the instructor and TA. In addition, we performed pre-term and post-term surveys investigating students' attitudes and preferences regarding student-instructor communication. We presumed that students would not have been given the opportunity to use text messaging in their earlier courses (our pre-term survey data bore this out with only two students indicating they had previously used text messaging to contact a professor).

RESULTS AND DISCUSSION

We first wanted to measure students' perceptions of both the value in using a variety of modes for course communication as well as the students' preferences for one mode over another (Figures 1-3; note that throughout the results black shading and patterns are for pre-term data while gray shading and patterns are for post-term data; patterns are used to distinguish data from the texting and nontexting sections). Students indicated that face-to-face meetings and e-mail were the most effective means of getting course assistance (Figure 1), and these attitudes did not markedly change from pre- to post-term whether analyzed for all the students (Figure 1) or by comparing the students within each section (data not shown).

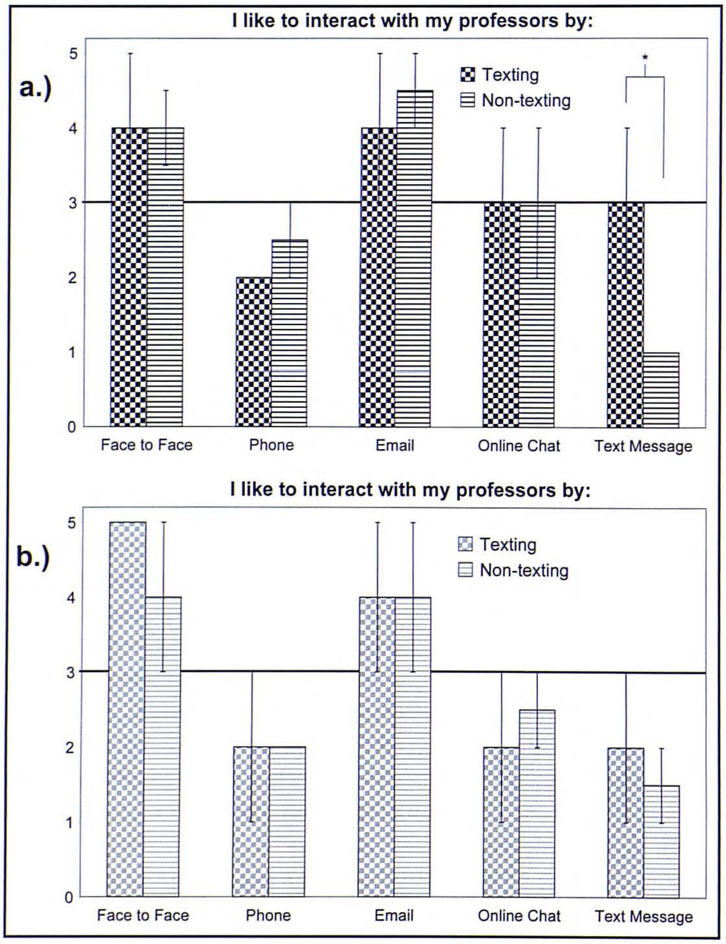

Figure 2 (left). *Comparison of preference for different communication strategies. Students were asked which methods they preferred for communicating with the course instructor in pre-term (**a.**) and post-term (**b.**) surveys. Rating scale: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree. As with the utility question (Figure 1), only face-to-face meetings and e-mail were preferred. Interestingly, pre-term preferences showed a significantly more positive attitude toward texting among the students in the texting section (a, checkerboard). Data are reported as the median ± the median absolute deviation; non-parametric statistical analysis by Mann-Whitney-Wilcoxon rank sum test; ranksum function in MATLAB with a significance threshold of p = 0.05. * indicates p = 0.004.*

There was, however, a difference in attitude towards texting between the two sections in the pre-term surveys (Figures 2a and 3a), although this difference was not evident in the post-term results (Figures 2b and 3b). The difference in initial attitude may be a reflection of the timing of the pre-term survey. Both sections were surveyed immediately following the first class of the semester during which the syllabus was discussed and the students in the texting section were made aware of the availability of texting communication. The students' audible response to this information (excited murmuring) suggested that they were glad to have this communication channel available. This alone may be evidence suggesting that making text messaging available to students may improve their engagement.

Why then did the difference not persist? Firstly, despite their near universal use of text messaging to communicate with each other,[9] the students hardly used texting to communicate with the instructor and TA during the term—only 22 total messages were sent to the instructor and TA during the entire semester. Similar reluctance has been seen by others in relation to using Facebook and Twitter to interact with instructors[11,12] and was specifically described by some students' comments in the open-ended sections of both the pre-term and post-term surveys:

> *"I would never text message a professor or TA. It just seems weird to me."*

> *"Personally, I would find text messaging my professor to be really strange."*

Based on these results, we speculate that students, in general, consider text messaging an immediate, informal, and private approach to communication with their peers and social networks that is not suitable for purely professional contacts such as instructors.

Secondly, at the end of the first lecture, a number of students attempted to text muddiest-point responses but could not due to lack of cellular signal in the classroom. This very likely limited the frequency of texting responses, whether in or out of class, for the entire term, if for no other reason than the number was not already stored in the students' phones. This should also serve as a caveat for those who may be interested in applying cell phone-based technologies in the classroom for any purpose.

Ultimately, the number of muddiest-point submissions by paper (over 1,000) far exceeded the number by text message (8). Perhaps with their pencils/pens already in hand for note-taking, paper submissions proved more convenient. Another explanation is that longer submissions or submissions containing mathematical symbols, though both of these were rare, were more easily completed by paper. Regardless, this underscores that students will decide which learning approach they feel is best/easiest for them, making it important to demonstrate the value of new technologies being used in instruction.

It should be noted that the text messages that were sent outside of class were not about course content but rather setting up meetings or letting the instructor know that the student would not be able to attend class. The instructor and TA did not make the students aware that

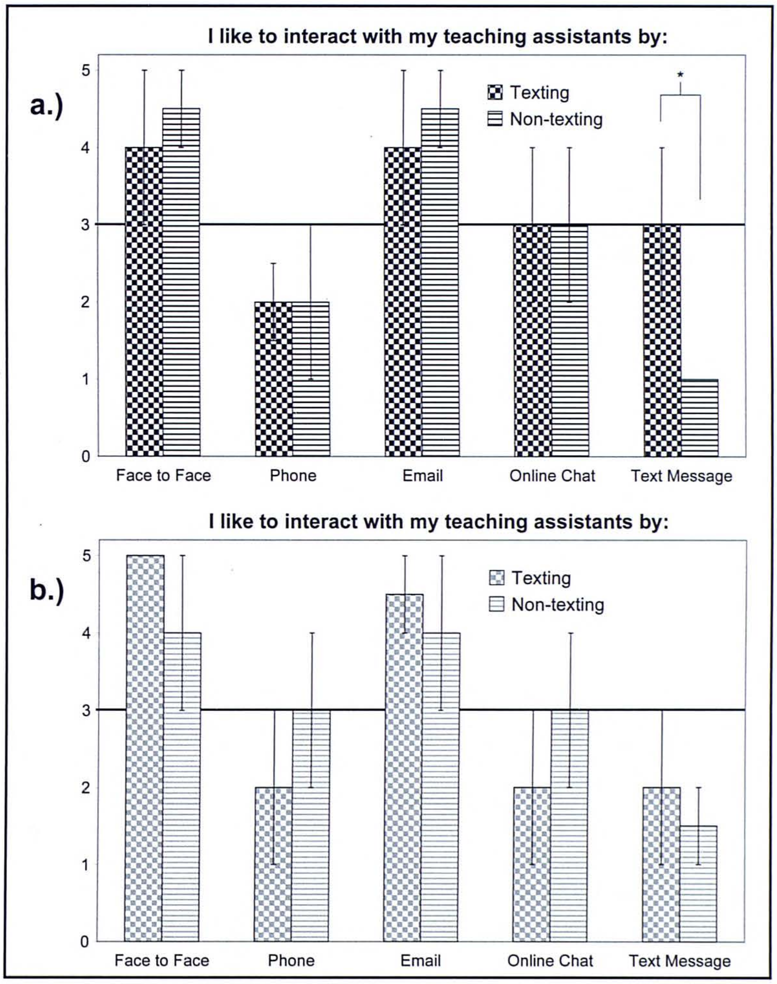

Figure 3. *Comparison of preference for different communication strategies. Students were asked which methods they preferred for communicating with the course TA in pre-term (**a.**) and post-term (**b.**) surveys. Rating scale: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree. As with the utility question (Figure 1), only face-to-face meetings and e-mail were preferred. Interestingly, pre-term preferences showed a significantly more positive attitude toward texting among the students in the texting section (a, checkerboard). Data are reported as the median ± the median absolute deviation; non-parametric statistical analysis by Mann-Whitney-Wilcoxon rank sum test; ranksum function in MATLAB with a significance threshold of p = 0.05. * indicates p = 0.006.*

text messages sent to them would not go directly to their phones. Perhaps if they knew that sending text messages outside of class would not interrupt the instructor and TA, they would have been more likely to text. Alternatively, if they knew that they would not necessarily receive an immediate response to a text, perhaps they would be even less likely to send messages in this manner. In future studies, we will continue to explore these questions.

Potential Impact: Text Messaging Availability

Despite no persistent change in expressed preferences towards communication and little overall use of texting, having the texting channel available may still have had an impact on student attitudes and behavior. In comparing the post-term results from the two sections, there was a significantly higher, if still only neutral, rating of text messaging in the texting section vs. the nontexting section, but only in regards to the specific instructor and TA (Figure 4).

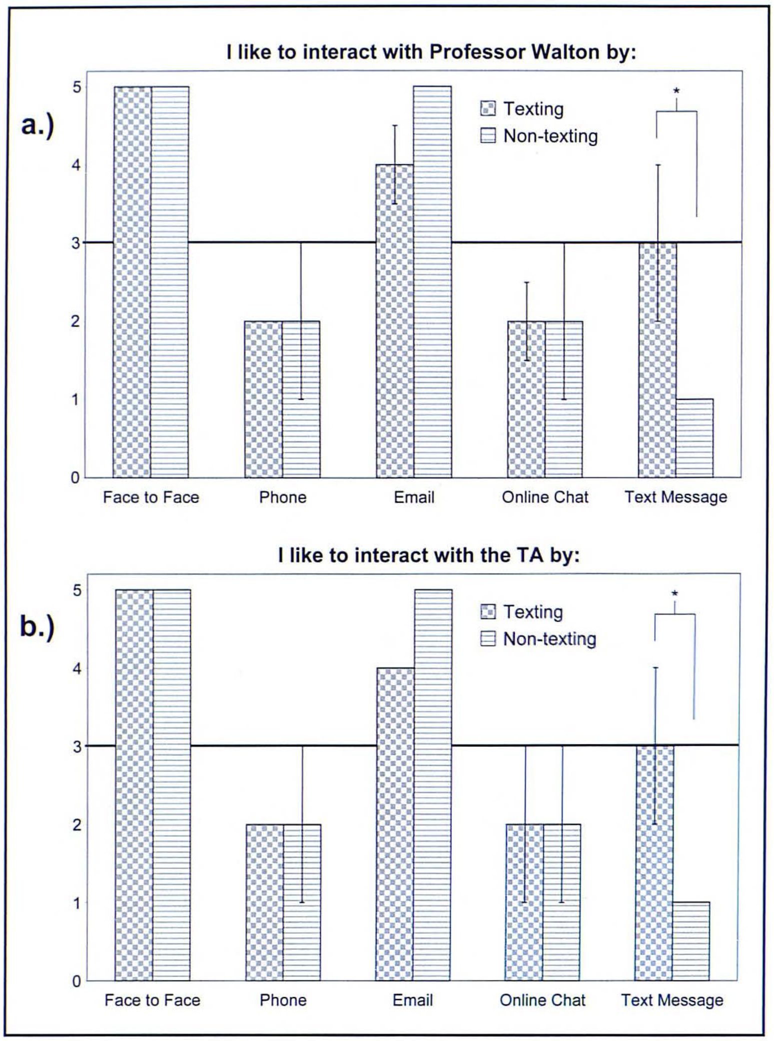

Figure 4 (left). *Impact of the availability of texting on post-term student preferences. A comparison of the post-term preferences from the texting (checkerboard) and non-texting (horizontal lines) sections shows that the texting section expressed a significantly higher preference for text messaging with regards to the specific instructor (**a.**) and TA (**b.**). Rating scale: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree. Data are reported as the median ± the median absolute deviation; non-parametric statistical analysis by Mann-Whitney-Wilcoxon rank sum test; ranksum function in MATLAB with a significance threshold of p = 0.05. * indicates p = 0.002 (a) or p = 0.024 (b).*

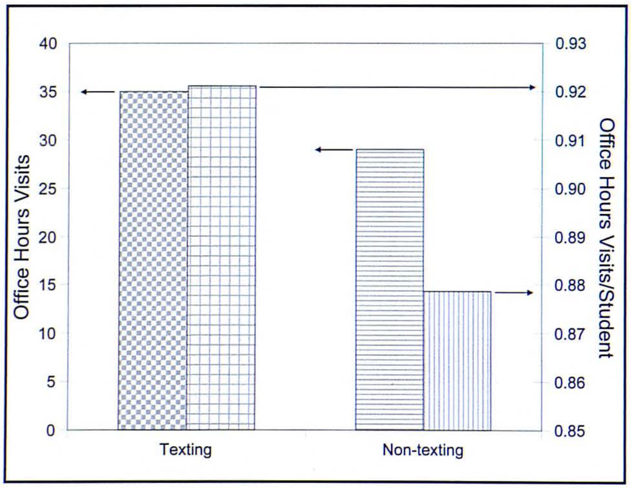

Figure 5. *Impact of the availability of texting on student attendance at office hours. Students in the section with texting attended office hours more times overall (checkerboard, left axis) and at a slightly higher per student frequency (boxes, right axis) than students in the section without texting (horizontal and vertical lines, respectively).*

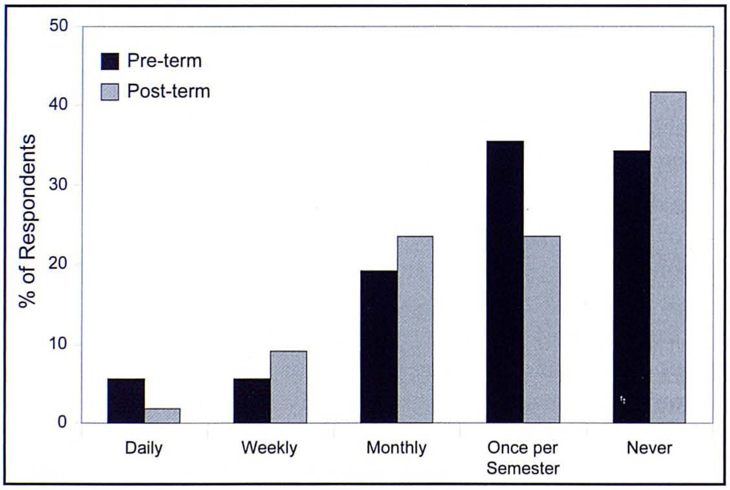

Figure 6. *Pre-/post-term comparison of students' interactions with any single instructor. Students were asked how frequently they met with their instructor outside of class for any reason. Roughly 90% of respondents said monthly or less frequently.*

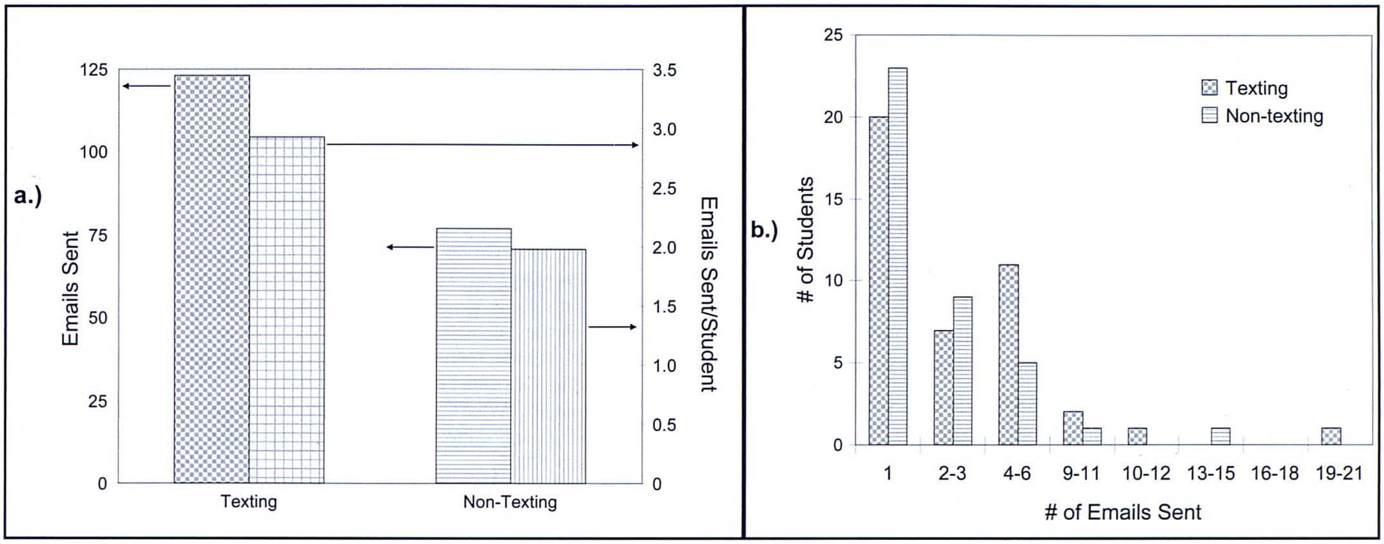

***Figure 7 a. (left) and b. (right)**, Impact of the availability of texting on student e-mail communication. a.) Students in the texting section e-mailed the instructor and TA more times during the semester (checkerboard, left axis) and with a greater per-student frequency (boxes, right axis) than students in the section without texting (horizontal and vertical lines, respectively). Standard deviations on the frequencies are not shown for image clarity. Mean ± standard deviations for the texting and non-texting section frequencies are 2.9 ± 3.8 and 2.0 ± 2.8 e-mails/student, respectively. b.) Shown are the histograms for the number of students who sent a certain quantity of e-mail messages to the instructor and TA. The results show that the bias seen in (a) is not simply a result of all of the most prolific e-mail senders being in the texting section.*

Thus, while general attitudes remain unchanged, the attitude with respect to specific individuals, with whom the students have established a rapport, improved. As such, it may be that repeated opportunities to use texting for classroom purposes may make it less unusual and uncomfortable for students. Students entering/attending universities today will increasingly have had opportunities to use texting to interact with their high school teachers and college professors, so attitudes may be evolving even now. Nonetheless, regarding our first hypothesis, our results indicate that students currently do not prefer to text message with their instructors, rather stating that e-mail and face-to-face contact are still the preferred modes of contact for professional endeavors.

Examining our second hypothesis, did the availability of texting, despite its limited use, influence students' behavior regarding other modes of contact? The students in the texting section did attend office hours more frequently than students in the nontexting section (Figure 5), although the increase was minimal (examine scale of right axis in Figure 5). In fact, when comparing pre-term and post-term self-reported likelihood to interact with their professors outside of class, no increase in self-reported interaction frequency was seen, either when examined for the class overall (Figure 6) or by section (data not shown). Unfortunately, disengagement has been found to be common among engineering students, worsening with increasing seniority.[13] The availability of texting does not seem to have improved engagement by the metrics of increased face-to-face contact at office hours or self-reported face-to-face meeting frequency.

Yet there may still have been an effect. In comparing the number and frequency of e-mail messages sent by students in each of the two sections (Figure 7a), students in the texting section e-mailed the instructor nearly 50% more frequently than the students in the nontexting section. It is often the case that a few students e-mail frequently while many students rarely do so. We wanted to ensure that it was not simply a situation where all of the prolific e-mail senders happened to be in the texting section (Figure 7b). The data show that while the most prolific sender (20 messages) was in the texting section, the second most prolific (14 messages) was in the nontexting section. With both sections of similar size (~40 students) and generally comparable in demographics, we could not identify another obvious reason for students from the texting section to contact the instructor more frequently. Although the result is not statistically significant ($p = 0.20$ by t-test comparing the per student means for each section), it does suggest that students in the texting section may have perceived a better rapport with the instructor, a factor known to support learning,[14] and so were more willing to initiate or sustain some form of communication with the course instructor.

We attempted to assess whether this sense of enhanced rapport existed by asking the students if they felt that the instructor and TA for the course were "cool," leaving it to the students to define what cool means to them. With regards to the course instructor and TA, all of the students in both sections rated them highly, so no difference was seen between the sections (data not shown). When comparing professors and TAs in general, however, the texting section rated professors and TAs that use texting as significantly more "cool" than students in the nontexting section (Figure 8). We believe this result to be a reflection of a greater sense of rapport between the students in the texting section with the instructor and TA, supporting our contention regarding the relatively higher e-mail contact from the texting-section students.

CONCLUSIONS AND FUTURE DIRECTIONS

First, our data strongly suggest that students choose e-mail and face-to-face contact as their primary modes of communication, even with other choices available. We do not fully understand the motivations for these choices, however, especially in light of the evidence about different communication modes they use with peers. Second, students do not take full advantage of opportunities to interact with their instructors, regardless of the means available to them, potentially leading to long-term disengagement from their coursework and impediments to their success.

Further study will be required to confirm if the availability of text messaging can serve as a means of driving greater rapport and engagement and establish any downstream relationship to improved student retention and/or performance. We will continue to make text messaging available to the students as a means of communication, as we believe both in the impact made and that students' attitudes will continue to evolve towards accepting the technology as a means of professional communication. As with any aspect of course construction, instructors need to manage it in a way that is practical for them (*e.g.*, use e-mail to respond to texts, establish guidelines for use).

Absent from our current study was the impact of student-student interactions on student engagement and performance. In particular, what utility do social network sites have for students with respect to their coursework? Also, does class size influence the likelihood that students will use texting? As we go forward, we will also begin to investigate these and other important questions regarding how best to engage and teach students in the current age.

ACKNOWLEDGMENTS

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REFERENCES

1. Chickering, A.W., and Z.F. Gamson, *Seven Principles for Good Practice in Undergraduate Education*, American Association for Higher Education (1987)
2. Arum, R., J. Roksa, and E. Cho, *Improving Undergraduate Learning: Findings and Policy Recommendations from the SSRC-CLA Longitudinal Project*, Social Science Research Council <http://highered.ssrc.org/files/SSRC_Report.pdf> (2011)
3. Babcock, P.S., and M. Marks, "The Falling Time Cost of College Evidence from Half a Century of Time Use Data.," *The Review of Economics and Statistics* (2011)
4. Liberatore, M.W., "YouTube Fridays: Engaging the Net Generation in 5 Minutes a Week," *Chem. Eng. Ed.*, **44**(3) 215 (2010)
5. Hadley, K.R., and K.A. Debelak, "Wiki Technology As a Design Tool for a Capstone Design Course," *Chem. Eng. Ed.*, **43**(3) 194 (2009)
6. Heys, J.J., "Group Projects in Chemical Engineering Using a Wiki," *Chem. Eng. Ed.*, **42**(2) 91 (2008)
7. Adams, R., D. Evangelou, L. English, A.D. Figuiredo, N. Mousoulides, A. Pawley, C. Schifellite, R. Stevens, M. Svinicki, J.M. Trenor, and D.M. Wilson, "Multiple Perspectives on Engaging Future Engineers," *J. Eng. Ed.*, **100**(1) 48 (2011)
8. Stross, R., "What Carriers Aren't Eager to Tell You About Texting," *New York Times*, <http://www.nytimes.com/2008/12/28/business/28digi.html> (2008)
9. Lenhart, A., R. Ling, S. Campbell, and K. Purcell, *Teens and Mobile Phones*, Pew Research Center Internet and American Life Project, <http://pewinternet.org/Reports/2010/Teens-and-Mobile-Phones.aspx> (2010)
10. *Google Voice—One Phone Number, Online Voicemail, and Enhanced Call Features*, available from <http://www.google.com/voice>
11. Hewitt, A. and A. Forte, "Crossing Boundaries: Identity Management and Student/Faculty Relationships on the Facebook," in *CSCW2006* (2006)
12. Johnson, K.A., "The effect of Twitter Posts on Students' Perceptions of Instructor Credibility," *Learning, Media & Technology*, **36**(1) 21 (2011)
13. Eris, O., D. Chachra, H.L. Chen, S. Sheppard, L. Ludlow, C. Rosca, T. Bailey, and G. Toye, "Outcomes of a Longitudinal Administration of the Persistence in Engineering Survey," *J. Eng. Ed.*, **99**(4) 371 (2010)
14. Murray, H.G., "Low-Inference Classroom Teaching Behaviors and Student-Ratings of College-Teaching Effectiveness," *J. Ed. Psychology*, **75**(1) 138 (1983) ❐

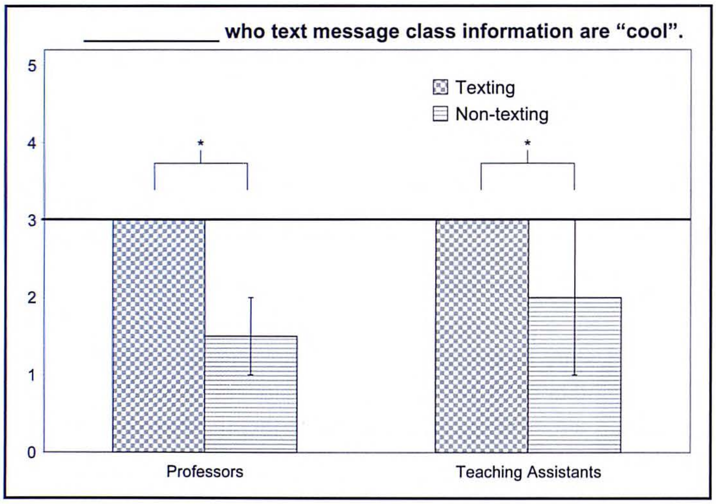

Figure 8. *Student attitudes towards professors and TAs who use texting for course communication. Students in the texting section declared professors and TAs who text to be significantly more "cool" than did students in the non-texting section. Rating scale: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree. Data are reported as the median ± the median absolute deviation; non-parametric statistical analysis by Mann-Whitney-Wilcoxon rank sum test; ranksum function in MATLAB with a significance threshold of p = 0.05. * indicates p = 0.022 (professors) or p = 0.031 (teaching assistants).*

Random Thoughts . . .

JUST-IN-TIME VS. JUST-IN-CASE

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The standard way to prepare people for a faculty career is not to. At most universities, new faculty members go to a campus-wide orientation workshop to be welcomed by the Provost and hear about their insurance and retirement options and the locations and functions of various campus administrative units, and graduate students learn how to work on a research project someone else has defined, but that's about it for academic career preparation. Little or nothing is generally said to either future or current professors about the three questions all new faculty members at research universities have uppermost on their minds: (1) How do I start and build an effective research program? (2) How do I teach? (3) How can I manage to do everything I need to do to get tenure and promotion and still have a life?

This is an absurd state of affairs. Being a tenure-track faculty member at a research university requires doing many things graduate school does not routinely teach, such as how to identify and approach funding sources and write successful proposals to them, compete with famous and well-funded faculty colleagues for good graduate students, design courses and deliver them effectively, write assignments and exams that are both rigorous and fair, deal with classroom management and advising problems and cheating, and learn a campus culture and integrate smoothly into it. Figuring out all those things on one's own is not trivial, and while there is something to be said for trial-and-error learning, it's not efficient. Robert Boice[1] studied the career trajectories of new faculty members and found that roughly 95% of them take between four and five years to get their research productivity and teaching effectiveness to levels that meet institutional standards. A 4–5 year learning curve is long and costly for universities, which invest as much as a million dollars in each new faculty hire, and the costs continue to mount for those faculty members who never manage to become effective at either research or teaching.

Boice also observed, however, that 5% of new faculty members meet or exceed their institutions' expectations for both research and teaching within their first 1–2 years. These *quick starters* do several things differently from their colleagues, including scheduling regular time for working on scholarly writing and sticking with the schedule, limiting lesson preparation time to less than two hours per hour of lecture (especially after the initial course offering), and networking with colleagues several hours a week, which helps the new faculty members transition into their institutional culture and cultivates advocates among colleagues who will eventually vote on their promotion and tenure.[1] The problem is that new faculty members are seldom made aware of those strategies and other things they should be doing to get their research and teaching careers off to a good start. In the absence of appropriate orientation and mentoring, most make the same mistakes

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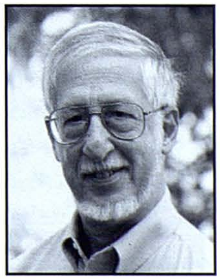

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95% of their colleagues make in their first few years, and the 4–5 year learning curve, tremendous stress and anxiety, and sometimes failure to earn tenure are the consequences.

As part of its comprehensive faculty development program,[2] shortly before the start of the Fall 2000 semester the N.C. State University College of Engineering (COE) gave a four-day orientation workshop to its new faculty members, covering essentially all of the topics mentioned in the second paragraph of this column. Since 2001 the workshop has been given jointly to new faculty in the COE and the NCSU College of Physical and Mathematical Sciences (PAMS), and it has now reached 257 faculty members (171 from COE, 86 from PAMS). Most participants were concerned about spending four days at a workshop shortly before the start of their first semester, but they were assured by their department heads and faculty colleagues that it would be worth their time. Those who participated clearly felt that it was: end-of-workshop rating forms have been completed by 238 attendees, who gave the program 209 "excellent," 29 "good," and no "average," "fair," or "poor" ratings.

Open responses in the post-workshop evaluations include many positive comments about the following workshop features:

- **Practicality.** The emphasis in the workshop is on "just-in-time" information as opposed to the "just-in-case" material that comprises most new faculty orientations. Besides tips on starting and building a research program and designing and delivering courses, sessions are devoted to dealing with common headaches in the life of a faculty member, including difficulty getting proposals and papers written and accepted; setbacks in research projects such as equipment breakdowns, unproductive research assistants, and loss of funding in mid-project; a wide variety of classroom management and academic advising problems; and cheating.
- **Interactivity.** While there is some lecturing in the workshop, a substantial portion of the four days is occupied with activities. The participants critique research descriptions, proposals, learning objectives, and examinations; work in bi-disciplinary pairs to outline a research project that involves the areas of expertise of both team members[3]; and find resolutions to hypothetical research, teaching, and advising crises. By the end of the first day the participants have clearly formed a learning community that continues to strengthen as the workshop progresses.
- **Relevance to the participants' disciplines.** Illustrative research and teaching scenarios and a mock NSF panel review are all STEM-related. In fact, a comprehensive workshop like this could not be given to a campus-wide audience, since many of the things faculty members need to know (especially where research is concerned) differ significantly between STEM and non-STEM disciplines.[4
- **Relevance to the local campus culture.** The participants learn about what they really need to do to succeed at N.C. State, with the message coming from engineering and science deans and department heads, research support staff, and some of the best STEM researchers and teachers on campus. Most participants leave the workshop with a strong sense that their administrators and senior colleagues are firmly committed to their success. They know where to go when they need help, and they feel comfortable asking for it.

To gauge the impact of the workshop, 32 attendees and nine non-attendees were surveyed three years after they joined the faculty. Attendees outperformed nonattendees in both research productivity and teaching evaluations. When asked to rate their orientation to their new profession, the attendees gave it an average rating of 4.6/5 and the non-attendees rated it 3.4/5. The workshop also plays an important role in faculty recruitment efforts in the two colleges. Candidates have said that its existence was a major factor in their decision to come to N.C. State, since none of the other universities they were considering offered anything comparable.

When we visit other campuses to give teaching seminars we generally mention the workshop to our hosts, observing that its benefits to both new faculty members and their institutions are significant and the total cost of food and facilitators' fees is in the noise level of most institutional budgets. The overhead from a single substantial grant that would not have otherwise been awarded would more than cover the cost, and based on the feedback we have received, there have been many such grants. We don't understand why every research university is not doing something similar for its new faculty members. Does yours? If not, why not?

REFERENCES

1. Boice, R., *Advice for New Faculty Members*, Needham Heights, MA: Allyn & Bacon (2000)
2. Brent, R., R.M. Felder, and S.A. Rajala, "Preparing New Faculty Members to be Successful: A No-Brainer and Yet a Radical Concept," *Proceedings, 2006 ASEE Annual Meeting*, June 2006. *<http://www.ncsu.edu/felder-public/Papers/ASEE06(NewFaculty).pdf>*
3. Ollis, D.F., R.M. Felder, and R. Brent, "Introducing New Engineering Faculty to Multidisciplinary Research Collaboration," *Proceedings, 2002 ASEE Annual Meeting*, Montreal, ASEE, June 2002. *<http://www.ncsu.edu/felder-public/Papers/Bidisciplinary.pdf>*
4. Felder, R.M., R. Brent, and M.J. Prince, "Engineering Instructional Development: Programs, Best Practices, and Recommendations," *J. Engr. Education*, **100**(1), 89 (2011). *<http://www.ncsu.edu/felder-public/Papers/Instruct_Dev(JEEv100).pdf>* ❒

CAREER COACHING FOR PH.D. STUDENTS

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In recent decades, there has been a shift in employment options for engineers in the United States.[1, 2] For engineers with Ph.D.s, the shift has been from academic to non-academic positions. During this time, the focus of doctoral research has also shifted from basic research to applied research.[2] In 2006, 70% of doctoral recipients in engineering did not hold positions in academia. According to National Science Foundation (NSF) Division of Science Resources statistics, approximately 55% of engineering Ph.D.s were employed in the for-profit sector, 30% were in educational institutions, 7% were in government, 4% were in private non-profit institutions, and 4% were self-employed.[3]

To prepare students for work in the for-profit sector, seminars have been designed at various engineering doctoral programs within the United States in order to develop breadth of technical knowledge and transferable skills (often referred to as soft skills). For example, some chemical engineering departments require Ph.D. students to present their research to fellow graduate students at a seminar. By presenting the doctoral work to their peers, students' oral communication skills may be further developed.[4, 5] Some seminars have been designed to keep students informed of new developments within their field of engineering, thus developing students' breadth of knowledge.[4, 6] Other topics discussed in seminars include a critical review of literature, intellectual property, managing non-human resources, ethics, mentoring, and teaching.[6-10]

Seminars are also used to encourage doctoral students in

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their program of study by equipping them with "doctoral survival skills."[6, 11] These survival skills are important because only 64% of students who begin engineering doctoral programs complete their degrees within 10 years, according to the Council of Graduate Schools.[12] Topics in these "doctoral survival skills" seminars include how to choose an advisor, creating a resume, and career options for Ph.D.s, but they do not discuss the industrial research environment.[7, 11] Although seminars are offered at several universities, little research is available that uses a seminar course to present the industrial research environment to graduate students and documents students' perspectives on such seminars. The purpose of this paper is to first present the development of a non-technical seminar course for engineering doctoral students and then to discuss how students perceive the value of this seminar course.

COURSE DESCRIPTION

A seminar course was created with the following objectives: 1) to give students a greater understanding of the industrial research environment, 2) to develop students' awareness of transferable skills needed in this environment, and 3) to help students find a position within industry. To simulate an industrial research environment and encourage class discussion, the seminars were held in a conference room in lieu of a traditional classroom setting. The course was first offered on an experimental basis during Summer 2010. The process to permanently approve the course was initiated in Summer 2011 so that it can be repeated. In Summer 2010, students voluntarily enrolled in the course and received a one-credit-hour pass/fail grade. Class participation and attendance were 60% of students' final grade, with the remaining portion consisting of reading assignments and a two-page reflection paper. The reading assignments included journal articles, book chapters, and web resources discussing seminar topics. The final assignment was a two-page reflection paper asking students to discuss how a seminar topic of their choice had impacted them. The students had two weeks to complete this paper.

The instructor for the course held three positions in industry prior to obtaining his Ph.D. in chemical engineering. During his industrial experience, he observed that most engineers in industry not only spend time on technical tasks. but also on tasks that required transferable skills. These skills he observed included: communicating with coworkers to provide or request information; organizing and scheduling projects, collaborating with vendors and customers; and managing compliance, safety, and regulatory issues. As a result, he realized that transferable skills are critical for success in industry. While teaching the course he was an associate professor in the chemical engineering department. He invited several different speakers to the class to discuss their past and present job responsibilities and skills in order to help students gain an understanding of the different types of positions available to engineering Ph.D.s. The topics discussed in the seminar included intellectual property, managing customer and product requirements, engineers in business, and career management. A list of the course topics can be seen in Table 1.

The guest speakers had various combinations of experiences working in small businesses, large corporations, national labs, and academia. Several of the speakers were Ph.D. engineers who were working in industry or had significant industry experience prior to their current position. The speakers who did not have their Ph.D. in engineering were selected because of their unique expertise that would enrich the seminar. Speakers were encouraged to prepare a 15-20 minute presentation on their topic and to allow the remaining 30 minutes for questions and discussions from the students, with an occasional ice-breaking question from the instructor. Some presenters prepared an hour lecture while others had a list of topics they were willing to discuss and allowed students interested in the listed topics to guide the class discussion.

TABLE 1
Topics Discussed in Seminar Course

Topic	Discussion Leader
Overview and History of Graduate Research	Instructor
Career Services	Career Advisor from university's Career Services
Professional Etiquette	Instructor and Participant Observer
Intellectual Property	Attorney with a B.S. in chemical engineering and M.B.A. currently working for the university's Intellectual Property Office
Professional Ethics	Ph.D. working in industry
Negotiation, International Issues, and Networking	Instructor
Who's Really Your Boss?	Ph.D. engineer
Managing Customers and Product Requirements	Ph.D. engineer from a large corporation
Engineers in Business	Engineering professor with extensive industry experience, who is currently pursuing his p.B.A.
Career Management	Ph.D. with experience in industry, national labs, and academia

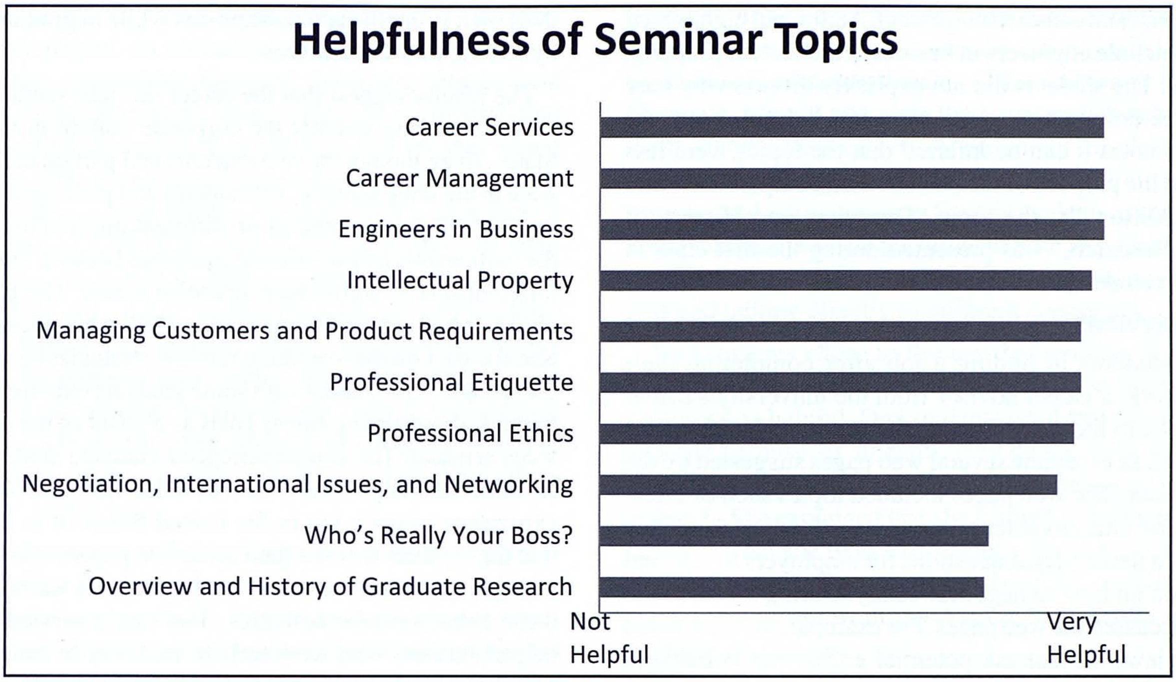

Figure 1. *Average response to the question: The topics discussed in ECHE 598Z are listed below. Please mark the one answer to indicate how helpful this topic is to your career.*

Fourteen students voluntarily enrolled in the course. The majority of students were in chemical or mechanical engineering doctoral programs. They had been enrolled in graduate school for various lengths of time. For example, one student was in her first semester of her graduate studies, while another student was graduating with her Ph.D. the semester the class was taught. Female students consisted of 42% of the class, and underrepresented minority groups made up 21% of the class. These proportions are higher than the university's graduate engineering program consisting of 23% female and 10% underrepresented minority groups.

METHODOLOGY OF DATA COLLECTION AND ANALYSIS

To address the question of how engineering doctoral students perceive the value of a non-technical seminar course, three different methods were used to collect data. The first data collection method was field notes taken by a participant observer during each seminar. Before pursuing her Ph.D., the participant observer had experience working in industry and in intellectual property. The notes she took included observations on the speakers' discussion and students' interaction with the speakers.

The students' two-page reflection paper was the second method of data collection. The reflection paper asked students to choose a seminar topic and discuss what they knew about the topic prior to the seminar, what they learned in the seminar, and how this knowledge might impact their future. As part of their final assignment, students were also solicited for suggestions to improve future "Graduate Student as Leader" seminar course.

The data analysis began by summarizing the field notes of the participant observer into paragraph form. The seminar summaries and reflection papers were analyzed to determine if students believed they had gained an understanding of the industrial research environment, transferable skills needed in industry, and information on how to find a position within industry.

The third method of data collection was a survey designed to assess the helpfulness of each seminar topic. Students were asked to respond according to the following question:

> *The topics discussed in ECHE 598Z are listed below. Please mark the one answer to indicate how helpful this topic is to your career.*

A list of the topics can be seen in Table 1. Students were given a four-point scale with choices ranging from "Not Helpful" to "Very Helpful." The survey results were then averaged.

HIGHLIGHTED SESSIONS

Rather than provide a detailed description of all the seminars, this paper focuses on the topics that students indicated were the most helpful topics discussed in the seminar as seen in Figure 1. These topics were also specifically discussed by one or more students in their final reflection papers. This enables one to gain some understanding of the actual student learning outcomes. The highlighted topics include career services, professional etiquette, managing project and customer requirements, and career management. Additional highlighted seminars include engineers in business, intellectual property, and ethics. The students did not explicitly discuss why they felt that the bottom two topics were less helpful. From the observer's notes it can be inferred that the topics were less relevant to the purpose of the course when compared to other topics. Additionally, the topic "Overview and History of Graduate Research," was presented during the first class in which the course syllabus was distributed.

Career Services

To aid students in finding a job after completing their doctoral work, a career advisor from the university's career center spoke to the class. Prior to the seminar, the instructor asked the class to review several web pages suggested by the career advisor. The web pages included topics such as creating a resume/vita, cover letter, examples of typical interview questions, a list of illegal questions for employers to ask, and information on how to negotiate salary. During the class the speaker discussed the web pages. For example, she mentioned that interviewers often ask potential employees behavioral questions. These questions allow potential employees to give specific instances of past behavior as a means to predict future behavior. To effectively answer behavioral questions, the speaker suggested first explaining the situation, and then the tasks and actions required to accomplish the end result. One of her concluding remarks was that while interviewing and after starting work, one should always be aware of actions and dress, because they reflect upon oneself.

At the end of the semester, two students wrote their reflective paper on the career services seminar. One student, who had been in the doctoral program two years, stated that he had never thought about work after graduate school. After the career services seminar he began thinking about his career. He realized that he needed clear objectives in order to create a plan to reach his career goals. In his reflection he did not specifically mention his career goals. He has, however, set himself several interim goals that he believes will give him tools to reach his career goal. His interim goals are: 1) to improve his spoken English (English was not his first language), 2) to work hard on his research, and 3) to consider joining student organizations to enrich his graduate student experience.

The second student was in her first graduate class in the United States. In her words, the seminar "blew her mind" because it made her realize the steps she needed to take as a graduate student to find employment in the United States after graduation. In her reflection paper, she stated that the career services seminar had given her strategies to answer tough interview questions, and motivation to develop professional networks and to have experiences outside the research lab. In her reflection paper, the student stated that networking is vital to a professional career because an opportunity may come through a friend, teacher, or neighbor. The student also mentioned that the speaker suggested that students discover their own strengths and weaknesses while in graduate school by having new experiences.

The results suggest that the career services seminar helped students prepare to enter the corporate culture in the United States. Even though the two students and participant observer were in the same seminar, the students and participant observer appeared to place emphasis on different information. Perhaps the participants heard different messages because they were at different places within their graduate career. The participant observer had approximately one year left in her doctoral work. She focused on the specific interview strategies discussed by the speaker. The student with some graduate experience began to think about setting career goals as a result of the career services seminar. The less-experienced graduate student gained an understanding of how to maximize her graduate school experience to get a job in the United States. It is interesting that the students focused their reflection papers' discussion on listing items on their resume/vita, not the skills learned through these extracurricular activities. The career services seminar helped students who were early to mid-way in their graduate career realize that activities outside of the research laboratory are important to develop their vita while those later in their graduate career learned about interview strategies.

Professional Etiquette

Both the instructor and the participants in the course provided content for the professional etiquette seminar. Topics covered in the seminar included appropriate conversations, greeting people, dining etiquette, and proper business and business-casual attire. For example, the instructor suggested avoiding topics such as politics and religion in the workplace. He suggested an appropriate topic such as the latest ballgame. Because different cultures have different styles of shaking hands, the discussion of how to greet others included instruction and a brief practice session on giving a firm handshake.

An international student wrote his reflection paper on this seminar. Prior to this seminar, he did not think etiquette mattered in the United States. He realized that professional etiquette is important and can be formal, especially in an interview. The student admitted that talking with Americans was difficult for him, but through this seminar he has begun to develop some talking points, such as discussing the latest football game.

Data suggests that this seminar gave international students a better understanding of American professional etiquette and culture. The student's reflection paper also indicated that the discussion may help him become more comfortable talking with Americans in a professional setting. This seminar appeared to be helpful to students who had little to no experience working in industry in the United States.

Managing Project and Customer Requirements

Engineering Ph.D.s need an expertise in teamwork to be successful in the industrial work environment.[13] In order for students to gain an awareness of these skills, a speaker from a large corporation discussed managing projects and customer requirements by using effective teamwork and communication strategies. For instance, the speaker stated that he was often the technical expert for the marketing team. As the marketing team wrote a contract with a customer, it was the speaker's job to be critical of engineering specifications because he would be held accountable to the contract specifications after it had been signed. He advised students to define explicit expectations when creating requirements in formal documents. Specifically, he suggested not to use words such as "similar, maximize, etc." but to make terms measurable. He also advised students to not allow others to define how a solution should be developed unless those others are experts in that area.

One student discussed the project and customer requirements seminar. He stated that he wanted to work in industry upon completing his Ph.D., but he had not known about project and customer requirements prior to attending this discussion. He mentioned that he had learned the importance of communicating effectively with the sales and marketing teams to ensure that project requirements were designed to address the specific issue. For example, he learned that a goal must be able to be measured in order for a design team to understand the goal. He reflected that words such as minimized and maximized are too vague for design teams. The student felt that the speaker had clarified the role that new Ph.D.s may have within large corporations. He also has gained clearer ideas of different career ladders for engineering Ph.D.s from this seminar.

In the managing customers and product requirement seminar, both the participant observer and the graduate student reflected on the importance of effective communication strategies while developing formal documentation for customers. This seminar also gave the student a greater understanding of potential careers that will allow him to make more informed decisions as he completes his graduate degree and enters the job market.

Career Management

The purpose of the career management seminar was to give students some basic advice on how to have successful careers after completing their Ph.D. The seminar was given by a guest speaker who had a Ph.D. in physics. She had worked in national labs, industry, and academia. Most of the seminar, however, was focused on working in industry. The seminar included many different techniques to help employees bring recognition and exposure to themselves. Some of these techniques include developing professional networks, finding mentors, and taking an inventory of accomplishments. Through developing networks and finding mentors, younger employees may gain exposure within a company as the mentor becomes the newer employee's advocate. Another technique she recommended was occasionally creating a list of greatest professional accomplishments. This technique forces employees to clearly articulate their accomplishments, helping them advance their careers. At the end of the class there was a question-and-answer session with discussion focusing on resumes and job experience. Several students asked questions about internships while pursuing their Ph.D.s. Ideas discussed on pursuing internships include working with students' advisors and talking directly to different companies.

Two students chose to discuss this seminar in detail, and a third student mentioned in his reflection paper that this seminar was helpful. One student stated that she enjoyed the seminar because, as students, they do not learn about career options in industry because they are focused on school and research. She explained that she learned to evaluate herself in terms of what she likes to do, things she is good at, and how she sees herself. The student enjoyed the speaker's discussion on how to grow professionally and on how employers evaluate employees.

The second student felt that this topic, along with other seminars from the Graduate Student as Leader seminar course, had broadened his career options. Before the seminar course, his goal was to work in academia. The seminar course gave him a better understanding of the work environment in industry. Now he believes that a career in industry is an "equally viable option" for him. The career management seminar gave him an understanding of opportunities to grow professionally in industry and the importance of technical knowledge, social skills, business skills, and communication. The student also learned about the importance of self-reflection to ensure that an employee is earning his or her company money.

The results indicate that this seminar gave students a greater understanding of the work Ph.D.s perform in industry. It also created an awareness of the importance of transferable skills and self-reflection. Before this seminar, both students indicated that they were unsure of how to grow professionally, but this seminar brought some understanding to this issue.

Engineers in Business

The purpose of the engineers in business seminar was to introduce entrepreneurship and business skills to the students. The guest speaker was an engineering professor. The professor had extensive industry experience and had recently returned from a two-year sabbatical as an industry consultant. At the time of the seminar, he was pursuing his master's of business administration. To begin the seminar, the professor distributed a list of topics that focused on entrepreneurship and business that he was prepared to discuss with the class. This list included topics such as:

- *Business Activities—financing, investing operations*
- *Corporate Structure—Board of Directors, CEO, CFO, COO*

- *Financial Statements—balance sheet, income statement, retained earnings, statement of cash flows*
- *Finance—finance instruments, derivatives, hedging, indexing and dollar cost averaging*
- *Intellectual Property—patents, copyrights, trademarks*
- *New Ventures—corporate structure, raising capital*

He asked students to choose the topics they wanted to discuss. The topic of new ventures was chosen, which included corporate structure and financing new ventures. The professor explained that most of the finance terms he encounters could be learned in a beginning finance class. The professor also had some suggestions on how to raise funding for a new venture company. One method for funding was identifying "angels" otherwise known as rich people who want to invest in companies. A second option was a private offering of stocks. Another option was a venture capitalist. The venture capitalist option comes with less freedom because the funders often have stakes in the company's future revenue. A fourth option was going to the bank with a well-written business plan. The students appeared to be very interested in this topic and asked many questions during the seminar.

One student chose to discuss this topic in his reflection paper. The student wrote that before this discussion, he did not know how start-up companies were funded. This student stated that he had learned several different methods of finding funding and a better understanding of the liabilities of running a business. From this seminar course, the student confirmed that he did not want to become a professor. The student also mentioned that he enjoyed the informal nature of this particular seminar because it was more engaging and allowed the class to determine the direction of the discussion.

Results indicate that several students were interested in learning more about how to start a small business. It appeared that some students may have an entrepreneurial spirit, but they have not had the time and/or guidance to explore this career option. This seminar began to answer students' questions on starting a small business and gave them some understanding of common business and finance terms.

Intellectual Property

A discussion of intellectual property (IP) was lead by an attorney from the university's intellectual property office. He has a background in chemical engineering and completed his master's of business administration before going to law school. During the seminar, the basics of patents were introduced, such as filing disclosures and preliminary patents. Additionally, the speaker discussed the rules and regulations surrounding patents, trademarks, and copyright laws on the national and international stage. The speaker mentioned different business aspects important to intellectual property, such as the value patents add to a company's portfolio and the relationship between branding and intellectual property. The issue of entrepreneurship and small-business startups was raised but was not discussed in detail.

One student discussed this seminar in his reflection paper. Prior to the seminar he stated that his knowledge of IP was limited. He had not known the complexity and pervasiveness of IP law. After the seminar, he realized that he had underestimated the influence of IP law in the academic and business/engineering setting. An example he gave was that academia is influenced by IP law during the publication process. While the information published remains the authors' intellectual property, the presentation of the information and any illustrations become property of the publishing company. The student also stated that the guest speaker had emphasized that industrial employers often insist on retaining all rights to employees' intellectual property while employed with the company and for some time afterwards. He also felt that in order to be successful, he needed some basic knowledge of IP law.

Students appeared to be interested in IP since the discussion lasted 15 minutes over the allotted time. From the reflective paper, results indicated that students were not aware of the complexity of IP law. After the seminar, the importance and influence IP has in a business setting and academic setting was clearer to the student. The student now has a better understanding of the basics of IP law that, regardless of his career path, is essential to his success.

Ethics

An ethics seminar was given by a local Ph.D. chemist. She discussed issues such as plagiarism, data fabrication, and the importance of understanding workplace policies. For example, she stated that very few people would write a journal article without citing others appropriately, yet it is common, but not correct practice, to present information to a group without citing appropriate sources. Another example she gave was who pays for a business dinner. Depending on the situation, it may be a business expense or a personal expense, one person may pay for everyone's meal or each person may pay individually. Other topics mentioned, but not discussed in detail included dating in the workplace and taking work home. In her concluding remarks, she cautioned students to keep e-mail and comments on social networking sites professional or private.

One student chose to discuss the ethics seminar in his final reflection paper. As an undergraduate student, he knew ethics was important, but he was never able to fit an ethics class into his schedule. Before the class discussion, he thought ethics was a set of rules that had to be followed. He stated that he had learned in the ethics seminar that it included avoiding conflicts of interest and ensuring the safety of others. Additionally, the student gained an awareness of "gray" areas in ethics, such as dilemmas that may save the company money, but threaten public safety or may not be entirely legal. He stated that he was interested in taking an ethics course that included case studies with multiple approaches and open-ended questions. He also felt an ethics course should include how other cultures deal with the same ethical questions.

From the ethics seminar, results indicated that students gained an understanding of the breadth of ethical concerns that engineering Ph.D.s may encounter. Ethical dilemmas are often gray areas. The seminar helped students understand that ethical decisions include more than just following a list of rules.

DISCUSSION OUTCOMES, LIMITATIONS, AND RECOMMENDATIONS

Overall, students gained a better understanding of the opportunities that come from possessing a Ph.D. in engineering. The students felt that they now know how to maximize the various opportunities that graduate school offers to find a position once they graduate. The degree of student interaction with the speaker was an indicator of the class's interest in a particular subject, as noted by the participant observer. It is also noteworthy that the most helpful topics for students in this seminar course were similar to topics students considered the most important in a similar seminar series at Oklahoma State University discussed by Madihally.[6]

Like any study, this one has limitations. The study was a qualitative study. The number of participants was kept small to enhance class discussions. One drawback of the limited number of participants was that demographic information was not collected in order to protect the anonymity of participants. The purpose of this study was not to generate generalizable results, but to provide information to aid the future development of non-technical seminar courses.

The purpose of this study was not to generate generalizable results, but to provide information to aid the future development of non-technical seminar courses.

The course instructor was satisfied with the overall format of the course. For future seminar courses, he would consider adding additional assignments, as students were often very passive. The challenge will be balancing the ability of additional assignments to better engage the students in class discussions with the consideration that workload not exceed the time available to the students. In recruiting students to the course, some faculty members voiced their concern about the course detracting from students' research during the summer semester. Unfortunately, some faculty members did not allow their students to enroll in the course.

There are several suggestions for others in planning a similar seminar course. One suggestion is to allow students to control more of the class discussion. This suggestion would help prevent significant overlap between guest speakers. Each class could begin with the guest lecturer distributing a list of topics he or she is prepared to discuss with the class. The class can then choose the specific topic(s) of the discussion that interest them or that they have not previously discussed.

Other suggestions for future seminars include information on how to pursue internships, preparing for an academic career, and a basic business course. Students were interested in internships as graduate students, but there was little or no guidance on how to pursue this endeavor. Another seminar course could be developed introducing the topics covered in a master's of business administration program in order to give students some foundation in business, but without the time commitment. Management skills were one of the most helpful topics in this study, and students rated that as one of the most interesting topics in a similar seminar course.[6] Additionally, similar seminar courses could include a discussion on the skills needed for an academic career, such as teaching. It is worth noting that in Madihally's study of a seminar that included teaching pedagogy and management skills, students did not find teaching topics interesting and did not consider them as important as management skills. These opinions may influence the sustainability of these seminar topics.[6]

CONCLUSIONS

A seminar course was developed to help engineering graduate students have an awareness of skills needed for careers in industry. Students' reflective papers and the participant observer's summaries suggested that the seminars accomplished this goal. The seminars on preparing for a career included discussions on resumes, cover letters, interviewing, and etiquette. The industrial work environment seminars entailed topics such as project and customer requirements, engineers in business, and career management. Topics such as intellectual property law and ethics were also discussed in the seminar course. By exposing students to this range of topics in a seminar setting, they gain more awareness of career options and the skills needed in an industrial research environment, thus students can make better decisions to help prepare them for careers in industry.

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REFERENCES

1. Cussler, E.L., "A Different Chemical Industry," *Chem. Eng. Ed.*, **40**(2), 114 (2006)
2. *Reshaping the Graduate Education of Scientist and Engineers*, Washington, D.C.: National Academy Press (1995)
3. National Science Foundation, Division of Science Resources Statistics. 2009. Characteristics of Doctoral Scientists and Engineers in the United States: 2006. Detailed Statistical Tables NSF 09-317. Arlington, VA,

<http://www.nsf.gov/statistics/nsf09317/>, accessed 24 January 2011
4. Georgia Institute of Technology School of Chemical & Biomolecular Engineering Graduate Handbook <http://www.chbe.gatech.edu/grads/handbook/GradHandbook09.pdf>, accessed 27 March 2010
5. University of Delaware Chemical Engineering Future Students Ph.D. Program, <http://www.che.udel.edu/futuregradphd.html>, accessed 26 March 2010
6. Madihally, S., "Reviving Graduate Seminar Series Through Non-technical Presentations," *Chem. Eng. Ed.*, **45**(4), 231 (2011)
7. University of Southern California-Viterbi Ming Hsieh Department of Electrical Engineering: EE Student's 'Practical Guide' Seminar Series, <http://ee.usc.edu/news/practical-guide/elements.htm>, accessed 9 May 2010
8. Princeton University: Keller Center Educating Leaders for Technology Driven Society, <http://commons.princeton.edu/kellercenter/events-news/coming-events-recent-news.html>, accessed 11 May 2010
9. Carnegie Mellon Graduate Support Programs: Past Professional Development Seminars, <http://education.andrew.cmu.edu/graduateprograms/past- seminars.php?&PHPSESSID=1a64259555e5098ff0eb87 5a0ac5e335>, accessed 9 May 2010
10. Minerick, A.R., "Journal Club: A Forum to Encourage Graduate and Undergraduate Research Students to Critically Review the Literature," *Chem. Eng. Ed.*, **45**(1), 73 (2011)
11. Holles, J.H., "A Graduate Course in Theory and Methods of Research," *Chem. Eng. Ed.*, **41**(4), 226 (2007)
12. Boulder, J., "A Study of Doctoral Students' Perceptions of the Doctoral Support and Services Offered by Their Academic Instiutions," Doctor of Philosophy, Department of Instructional Systems and Workforce Development, Mississippi State University, 2010
13. Watson, J., and J. Lyons, "A Survey of Essential Skills for Ph.D. Engineers in Industry," presented at the American Society for Engineering Education Annual Conference and Exposition, Vancouver, British Columbia, 2011 ❐

A CONTROLLED DRUG-DELIVERY EXPERIMENT USING ALGINATE BEADS

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Drug delivery is a burgeoning field that represents one of the major research and development efforts of the pharmaceutical industry today, with new drug delivery system sales exceeding $10 billion per year.[1] Chemical engineers play an important and expanding role in this exciting and inherently multidisciplinary field, which combines knowledge from medicine, pharmaceutical sciences, chemistry, and engineering.

Controlled drug delivery systems are engineered to deliver a drug to the body at a predetermined rate for an extended time. Controlled-release systems have expanded from traditional drugs to therapeutic peptides, vaccines, hormones, and viral vectors for gene therapy. These systems employ a variety of rate-controlling mechanisms, including matrix diffusion, membrane diffusion, biodegradation, and osmosis.[2].To design a drug delivery system, an engineer must fully understand the drug and material properties, the mass transfer mechanisms, and the processing variables that affect the release of the drug from the system.

While the role of the chemical engineer is vital to the development of new drug-delivery systems, undergraduate chemical engineering students are rarely exposed to drug delivery through their coursework. This paper describes an experiment that introduces students to drug delivery system design, formulation, and analysis from an engineering point of view. Students produce drug-loaded calcium alginate beads, obtain release data, and analyze the rate of release from the beads. They investigate effects of drug molecular weight, extent of polymer cross-linking, geometry and surface area, and external mass transfer resistance on the release rate of the drug. Using Excel and Polymath, students compare their results to a mathematical model in order to determine the rate-controlling mechanism of the release. Through this experiment students explore many concepts and tools that they will use throughout their engineering careers:

- *Application of chemical engineering principles (transport, materials, thermodynamics, mass balances)*
- *Instrument calibration*
- *Concentration measurement*
- *Design of experiments*
- *Use of spreadsheets for calculating and graphing*
- *Data analysis and parameter evaluation*
- *Design of drug delivery systems*

This experiment has been implemented in the Freshman

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Engineering Clinic at Rowan University, and its impact on student learning has been evaluated. While this paper describes the details of a freshman-level experiment, it may easily be adapted to more advanced courses such as mass transfer or a bioengineering/drug delivery elective course.

BACKGROUND INFORMATION

Drug Delivery

A conventional drug such as a tablet would be taken periodically, resulting in cyclical periods of ineffectiveness, effectiveness, and possibly toxicity.[3] Sustained-release delivery forms are designed to release a drug at a predetermined rate by maintaining a therapeutic drug level for a specific period of time. With targeted drug delivery, the drug is delivered to a desired type of cell or location in the body, while avoiding systemic administration that could harm other types of cells that are not the desired target. Some advantages of controlled-release delivery systems include the reproducibility of the release rate, less frequent required administration, decreased side effects, smaller quantity of drug needed, and improved patient compliance.

The most common methods of drug administration are by ingestion and injection. In recent years, several other routes of administration have been explored, including pulmonary (through the lung), transdermal (though the skin), and transmucosal (through a mucous membrane).[4]

Topics related to drug delivery are scarce in the chemical engineering educational literature. Farrell and Hesketh[5] presented a drug-delivery experiment using a dissolving matrix. Prausnitz and Bommarius[6] describe an undergraduate and graduate course on pharmaceutics that includes topics in drug delivery. Simon, et al.,[7] developed continuous stirred tank experiments to introduce topics of pharmacokinetics and drug transport to chemical engineering students. A review of chemical engineering course websites reveals that drug delivery is a topic included with increasing frequency in bioengineering elective courses at universities across the country.

Microsphere Drug Delivery Systems

Microsphere drug delivery systems are microscopic beads that comprise a polymer matrix that contains a drug. The polymer may be in the form of a solid bead throughout which the drug is dissolved or dispersed, or the drug may be encapsulated within a polymeric shell. Polymer microspheres have been used in controlled release and drug targeting to organs such as the liver, spleen, lung, and kidney.[8] Microspheres made from biocompatible natural and synthetic polymers can be used as drug-delivery systems for administration by injection, intramuscular, and through the nasal route. Microspheres can easily be modified and are compatible with many drugs, allowing them to be easily developed to contain a desirable drug. Moreover, the size of microspheres is easily controllable by modification of the preparation method.

Mass Transfer

The rate of release of a drug from a polymeric device can be controlled by Fickian diffusion through the polymer,[10] by external mass transfer resistance, or by polymer relaxation in the case of a swellable polymer.[11] In some cases, polymer degradation or erosion can also contribute to the rate control. The rate of diffusion depends on the molecular weight of the drug molecule and the cross-linking density of the microspheres.[4] A large molecule or a high degree of polymer cross-linking will result in slower diffusion. A high stirring rate is usually used in *in vitro* experiments to eliminate boundary-layer resistance and to simplify mass transfer analysis.

Ritger and Peppas present a simple model for drug release from a polymer that can be used to identify the mechanism of rate control.[10]

$$\frac{M_t}{M_\infty} = F = kt^n \tag{1}$$

Where M_t is the mass of drug released at time t, M_∞ is the mass of drug released after infinite time, F is the fraction released, k is a constant that depends on the diffusion coefficient and diffusion length, and n is an exponent which is indicative of the rate control mechanism. For Fickian diffusion in a slab, n = 0.5; for Fickian diffusion in a sphere, n = 0.43. This short-time approximation is valid for $M_t/M_\infty \leq 0.6$. A non-uniform particle size distribution results in a value of n<0.43; smaller beads cause an acceleration of drug release at early times, whereas larger beads cause a retardation of transport at later times.[10]

When the polymer is swellable, diffusion and/or polymer relaxation may govern the release rate.[11,12] For relaxation control, n = 1.0 for a slab and 0.85 for a sphere. When n lies between the values for Fickian diffusion and relaxation control, both diffusion and relaxation contribute to rate control.

The normalized release rate, $\frac{dF}{dt}$, can be found by differentiating Eq. (1):

$$\frac{dF}{dt} = knt^{n-1} \tag{2}$$

Alginate

Alginate (or alginic acid) is a biopolymer derived from the cell walls of brown algae. Its sodium salt forms a viscous gum when dissolved in water. Calcium alginate, an insoluble hydrogel formed by ionic cross-linking with calcium ions in solution, is nontoxic and biocompatible, and has wide applications in cell immobilization and drug encapsulation, for drug delivery via different routes of administration. In clinical trials, an oral alginate-antacid formulation has been used in humans for the effective treatment of GERD,[13] and an alginate-based drink formulation has produced a robust reduction in hunger to battle obesity.[14] Chitosan-treated alginate beads have been used for oral delivery of the drug Metronidazole for the treatment of H. pylori and resulted in 100% clearance of the infection in mice stomachs.[15] Oral delivery of the anti-diabetic drug gliclazide from alginate beads resulted in a significantly greater and more prolonged hypoglycemic effect over the conventional gliclazide tablet (Gliclazide®) *in vivo* in diabetic rabbits.[16] Alginate beads have been used for sustained delivery of vascular endothelial growth factor from alginate beads *in vitro* for vascular tissue engineering and wound healing applications.[17] Alginate implants have been used for delivery of the growth factor TGF-β for the improved repair of articular cartilage in rabbits.[18] Cells encapsulated in alginate have been used to deliver recombinant proteins to malignant brain tumors in rats.[19]

An important property of alginate is its ability to form gels by ionic cross-linking with divalent calcium ions. When sodium alginate solution is combined with calcium chloride in aqueous solution, ionic cross-linking of alginate chains occurs instantaneously. This cross-linking results in a matrix at the interface between the two solutions.[4] When drops of alginate solution are added to the calcium chloride, ionic cross-linking occurs at a spherical interface resulting in a polymer shell that encapsulates a solution of drug in alginate.

MICROSPHERE EXPERIMENT

Objectives

In this experiment, students produce drug-containing alginate spheres and investigate the factors that affect the rate of release of the drug from the polymeric beads. The model drug used in this experiment is tartrazine, a yellow food dye. Drug-release studies are performed by placing the drug-loaded beads in a beaker containing water and monitoring concentration as a function of time. Concentration measurements are made periodically by measuring absorbance of the surrounding solution (into which dye has been released) using a spectrophotometer. The release rate of the drug from the microspheres is analyzed using Excel. Through comparison to the mathematical model, the mechanism of rate control can be identified. Students investigate the effect of stir rate, surface area, cross-linking, and molecular weight on the release rate of the drug and the mechanism of rate control. Expected skills and measurable outcomes are summarized in Table 2 in the Evaluation section.

Microsphere Preparation

<u>*Materials*</u>

- *10 mL tartrazine (model drug, Acros Organics) solution (0.5 mg/mL), in small vial*
- *0.1 g alginic acid, sodium salt (Acros Organics)*
- *6 wt% calcium chloride solution (80 mL in 1 large weigh boat)*
- *Disposable syringe (without needle)*
- *Magnetic stir rod, small*
- *Magnetic stir plate*
- *Vacuum filtration set-up*
- *Tweezers*

<u>*Procedure*</u>

1. The alginate powder was added to the tartrazine solution in the small vial.
2. This was stirred vigorously until a smooth, uniform yellow solution was formed.
3. 3 mL of the alginate solution was loaded into the disposable syringe by immersing the tip of the syringe in the alginate solution and pulling up on the plunger.
4. The alginate was slowly dispensed into the weigh boat containing calcium chloride solution. By pushing very gently on the plunger, alginate solution was dispensed dropwise generating beads of alginate solution that solidify instantaneously on contact with calcium chloride solution. Drops falling on top of other drops should be avoided. This method produces approximately 70-100 beads in about 60s, depending on the rate at which the plunger is depressed.
5. The beads were immediately separated from the calcium chloride solution by filtration.

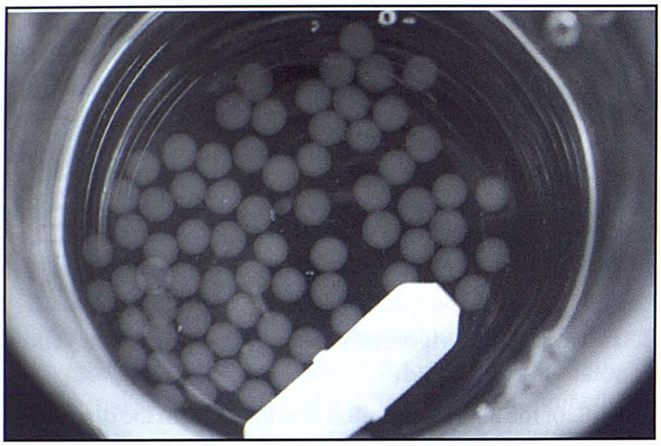
Measurement of Dye Release

<u>*Materials*</u>

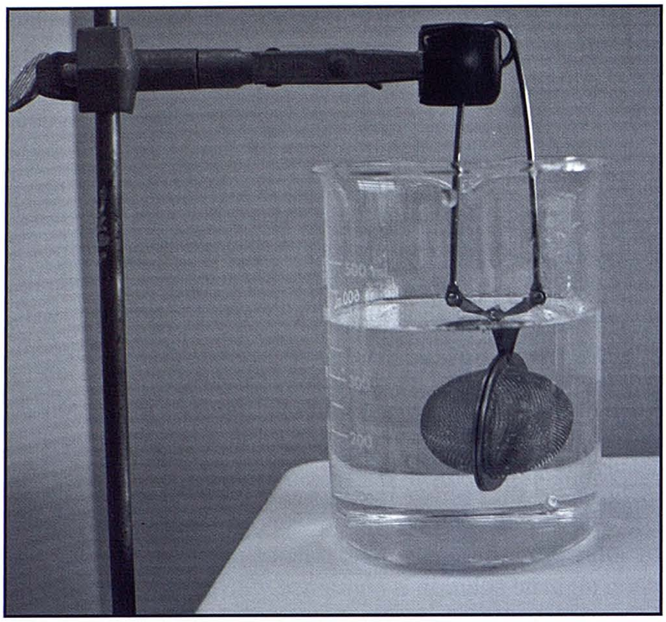
- *150 mL beaker*
- *Tweezers*
- *100 mL DI water*
- *Disposable pipette (2 mL) or disposable dropper*
- *Stir plate and magnetic stir rod*
- *Spectronic 21 spectrophotometer (Thermo Spectronic, Rochester, NY)*
- *Disposable cuvettes (Fisher Scientific)*
- *Dye-loaded alginate beads*

<u>*Procedure*</u>

1. A 150 mL beaker was filled with 100 mL of deionized water.
2. Alginate beads were transferred into the beaker filled with deionized water.
3. The beaker was stirred at 300 rpm using a magnetic stir bar.
4. Samples were removed with a pipette, and the absorbance was measured on a spectrophotometer at 427 nm every 10 minutes for 60 minutes total. Care was taken to ensure that beads were not withdrawn with the sample.
5. The measured sample was returned to the beaker to maintain constant volume.



__Figures 1.__ The experimental setup for beads and blob geometries. The beads (__a.__, above) are simply placed in a beaker with a stir bar and become suspended when stirring commences. The blob (__b.__, right) requires protection from the stir bar and is therefore encased in a tea infuser.



Variations on this experiment were the following:

- Extent of cross-linking: Rather than removing the beads immediately on contact with calcium chloride, the beads were removed after 10 minutes contact. Alternately, they may be contacted with $CaCl_2$ for the duration of the release experiment.
- Large molecule release: Bovine Serum Albumin (Fisher Bioreagents, Fraction V, approximate MW 66776 Da) was used instead of tartrazine (MW 534.4 Da). BSA release was quantified with a Micro BCA Protein Assay Kit (Pierce) per the manufacturer's instructions.
- Geometry/surface area: Instead of making beads, alginate solution was quickly dispensed from the syringe to form a solid mass of undefined geometry (referred to as a "blob")
- External mass transfer resistance: studies were performed using stir rates ranging from 100 – 400 rpm.

The experimental setups for bead and blob experiments are shown Figures 1. The beads become suspended when stir rate increases, and are therefore not disturbed by a stir bar. The blob requires protection from the stir bar and was therefore suspended using a tea infuser.

Analysis of Results

After the experiment was completed, the students used an Excel spreadsheet for data analysis. The students converted the recorded absorbance measurements into concentration values using the provided equation from the calibration curve given in Figure 2. Calibration data are provided with the lab instructions. Students are guided toward using only the linear portion of the calibration data; when this range is exceeded, an increase in concentration will not result in a proportional increase in absorbance. From the absorbance measurement for the calcium chloride filtrate, the concentration of tartrazine is calculated and the mass of tartrazine in solution is determined. The amount of dye remaining in the beads at the beginning of the experiment is determined by mass balance.

Students set up an Excel spreadsheet to calculate the following quantities at each sample time: Concentration of tartrazine in solution (C), mass of tartrazine released (M_t), and fraction of tartrazine released (F). The concentration is determined from the calibration equation:

$$C = 0.0231A \tag{3}$$

The mass of dye released is determined from the concentration and volume (V) measurements.

$$M_t = CV \tag{4}$$

Infinite time is considered to be when the absorbance does not change for three consecutive measurements over at least 30 minutes. After "infinite time" the drug concentration in the water is less than 0.01% of the saturation concentration, and some drug will always remain in the beads at equilibrium.

After converting the measured absorbance values to fraction of dye released, the students create a plot showing the fraction of dye released over the time of the experiment. Students are asked to predict how different factors would affect the release rate: polymer properties such as cross-link density, the drug molecule size, stirring rate, bead size, temperature, etc. Many of these factors were investigated experimentally by teams using shared data.

According to Eq. (1), a plot of the log of fraction released vs. log of time will result in a straight line with a slope of n. The value of n is used to identify the rate controlling mechanism as explained above. The release rate is calculated from Eq. (2) and plotted as a function of time.

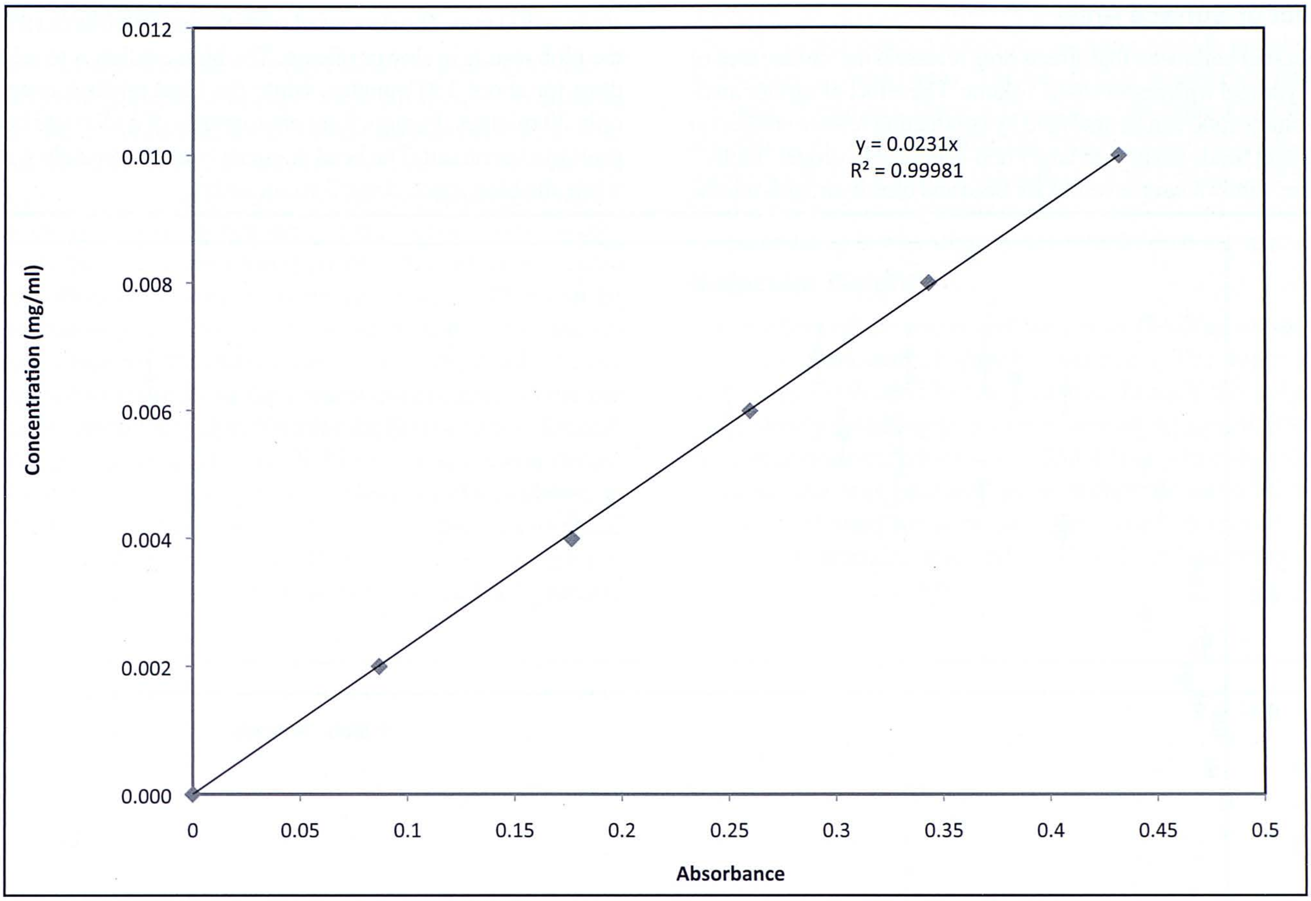


Figure 2. *Calibration curve for tartrazine at 427 nm.*

EXPERIMENTAL RESULTS

Effect of Stir Rate

If a mass transfer boundary layer exists, an increase in stir rate will result in faster drug release. Figure 3 shows the release profile for experiments conducted at 100, 300, and 400 rpm. Since an increase in stir rate from 100 to 300 rpm results in faster release, we may conclude that external mass transfer was significant at the lower stir speed. Increasing the stir speed to 400 rpm did not affect the release rate, so it was concluded that external mass transfer resistance was insignificant at 300 rpm. For subsequent experiments a stir speed of 300 rpm was used in order to study rate control within the beads.

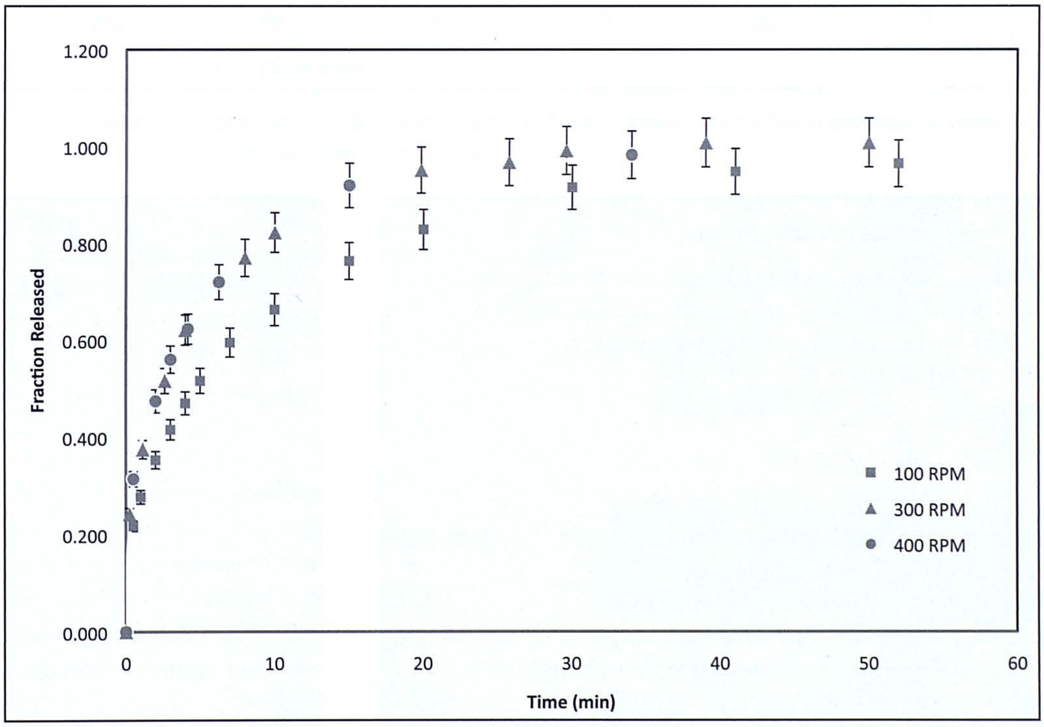


Figure 3. *Release profiles using different stir speeds. The external mass transfer resistance is significant at 100 rpm. At 300 and 400 rpm, the external mass transfer resistance is eliminated.*

Effect of Surface Area

Another parameter that affects drug release is the surface area of the hydrogel with respect to its volume. The effect of surface area-to-volume ratio can be analyzed by conducting release studies on hydrogel beads along with larger non-spherical hydrogel "blobs." Figure 4 shows sample results for bead and blob hydrogels release study at 300 rpm. The decreased surface-area-to-volume ratio of the blob results in slower release. The blob continues to release drug for about 130 minutes, while the bead releases drug for only 30 minutes. Figures 5 are photographs of a blob and beads prior to experiment. The bead diameter is approximately 4 mm, while the blob spans about 3 cm in width.

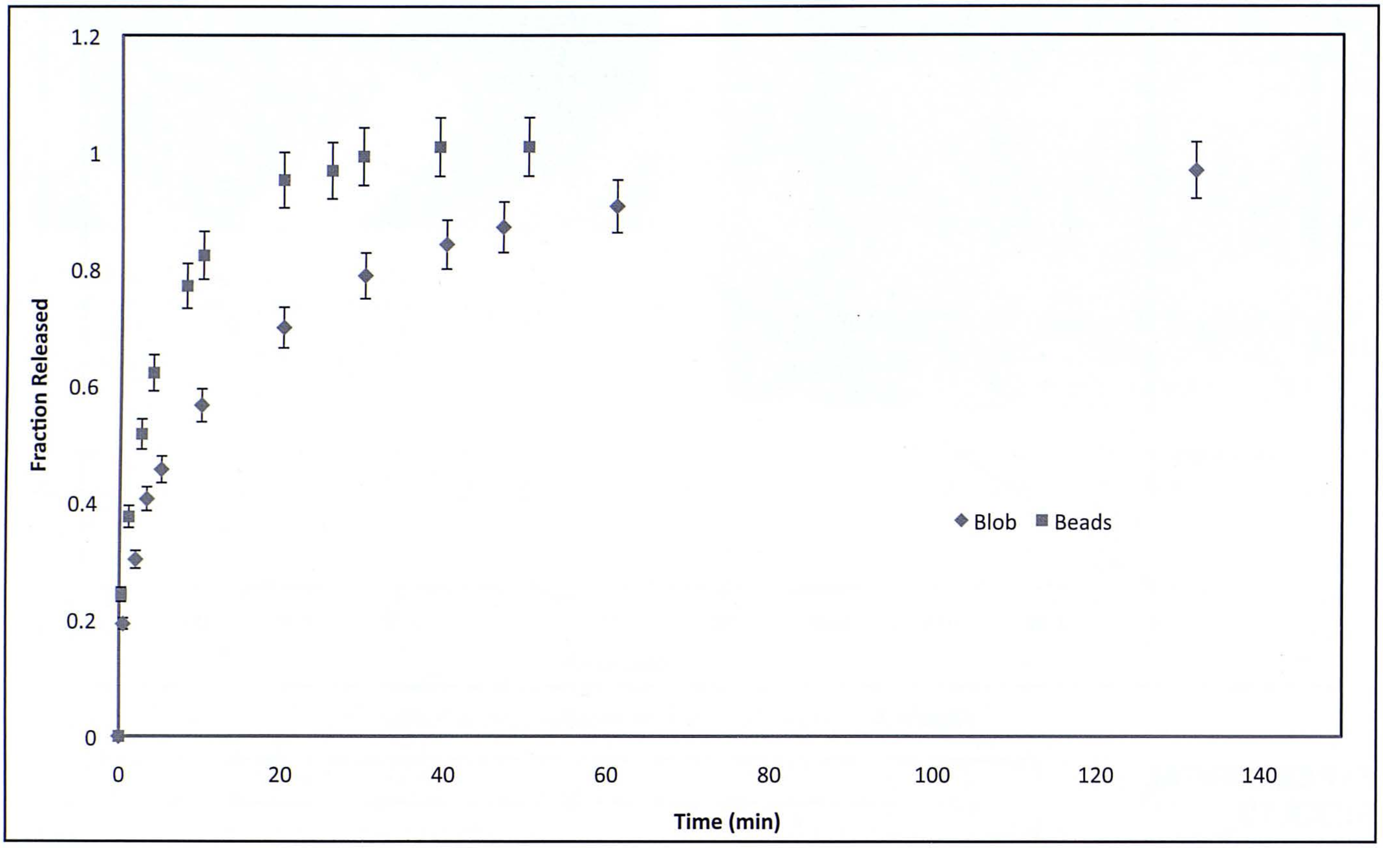
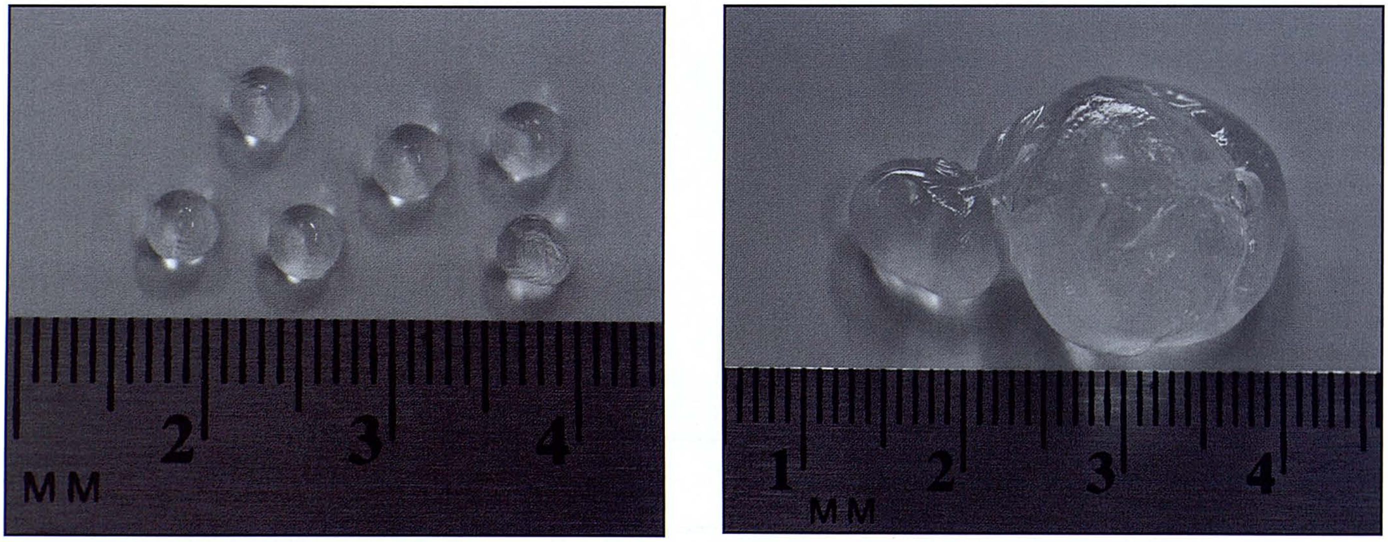


Figure 4. *Release profiles for beads and blob geometries. The decreased surface-area-to-volume ratio of the blob results in a slower release rate.*



Figures 5. *Alginate beads (**a.**, left) and an alginate blob (**b.**, right), prior to experiment. The bead diameter is approximately 4 mm, while the blob spans about 3 cm in width.*

Effect of Cross-Linking

The formation of the hydrogel beads is a direct result of the cross-linking that occurs when alginate is contacted with calcium chloride. By changing the time for which the alginate beads are contacted with the calcium chloride, the effect of cross-linking can be explored. A longer contact time results in more penetration of the calcium ions into the alginate bead and the formation of a thicker cross-linked shell surrounding drug in alginate solution. This can be investigated in an experiment in which $CaCl_2$ was the release medium for the duration of release. The results can be compared to those from the control experiment, where the beads are removed within 80s after the first bead was formed. The higher degree of cross-linking (thicker cross-linked shell) results in a slightly slower release of dye as shown in Figure 6. In another experiment, a 10 minute cross-linking time was used. There was no statistical difference between the 10 minute cross-linking time run and the $CaCl_2$ release medium run. Cross sections of beads produced by 2 minute and 10 minute contact times in calcium chloride are shown in Figures 7 (next page). The beads that were cross-linked for only 2 minutes show a distinct cross-linked shell and alginate core region, while the beads cross-linked for 10 minutes are cross-linked through the entire bead. The bead produced using a 2 minute contact time has an elongated shape because it was slightly deformed when it was cut.

Molecular Weight

The effect of the molecular weight of the drug on the release rate is shown in Figure 8 (next page). The larger BSA molecules (MW=66776 Da) diffuse through the polymer more slowly resulting in a slower rate of release of BSA in comparison to tartrazine (MW = 534.4 Da). While the release of tartrazine was near complete within 30 minutes, BSA release continued for over 24 hours. After 30 minutes, the fraction of tartrazine released was 0.992, and the fraction of BSA released was 0.389.

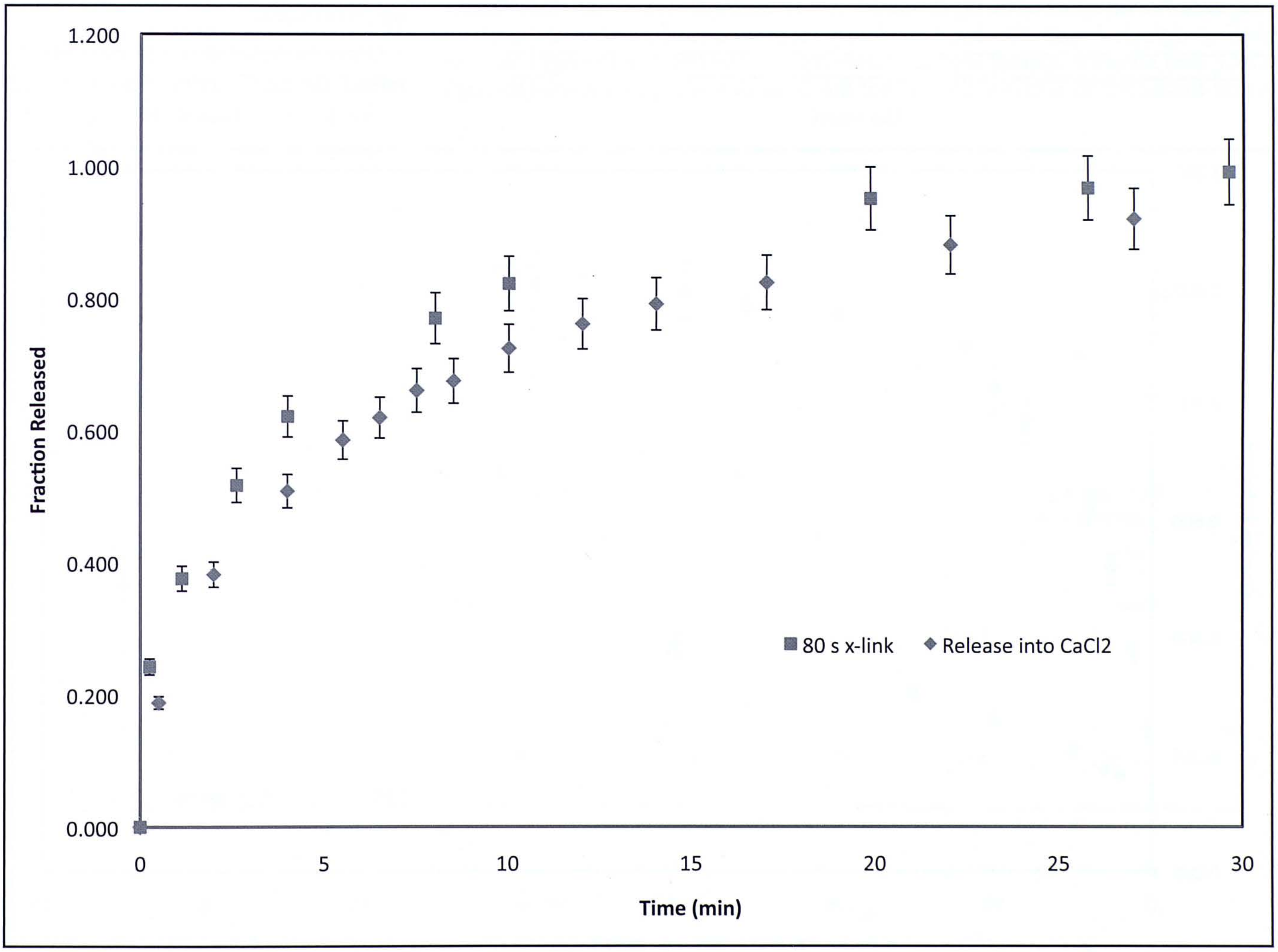
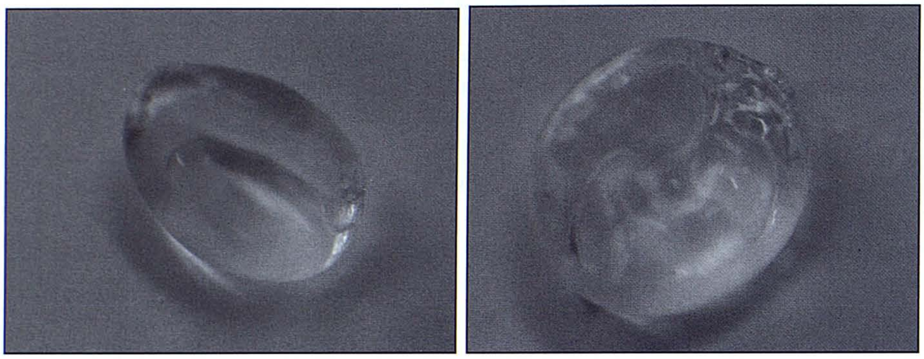


Figure 6. Longer contact between alginate and calcium chloride results in a thicker cross-linked shell that slows the release rate of the drug. Profiles are shown for beads using 80s and 10 min contact time with $CaCl_2$.

Mechanism of Rate Control

Figure 9 shows a plot of ln(F) (for $F < 0.6$) vs. ln(t) for two experiments using beads: an 80s contact time and a $CaCl_2$ contact time for the duration of the release (both with a stir speed of 300 rpm). The slope is equal to the value of n. For the case of short contact time, the value of n is equal to 0.33. Since this is less than n=0.43, the value expected for Fickian diffusion control, the data suggest that the rate control could be Fickian with an effect of non-uniform particle size distribution. For the longer contact time, the larger value of n (n=0.4749 > 0.43) indicates that the effect of swelling is present. Again, the effect of non-uniform particle size is probably significant. To confirm these conclusions, the effect of particle size distribution should be eliminated. This was done outside of class by conducting experiments using single beads. For a single bead and short contact time (80s), the value of n is equal to 0.4379, which confirms that Fickian diffusion is the rate controlling mechanism. For a single bead and a long contact time, the value of n was equal to 0.6813. Since this value is greater than n=0.43, it is concluded that swelling has an effect on the release rate. This is due to the thicker cross-linked shell in which swelling is significant. These beads were seen to double in diameter over the course of the experiment.



Figures 7. The effect of $CaCl_2$ contact time on the thickness of the cross-linked shell of alginate beads. The bead on the left (a.) was cross-linked for 2 minutes in $CaCl_2$ and shows a distinct shell and core region. The bead on the right (b.) was cross-linked for 10 min and shows that the cross-linked region extends through the bead.

Once the value of n has been determined, the rate of release can be found using Eq. (2). Figure 10 (page 106)

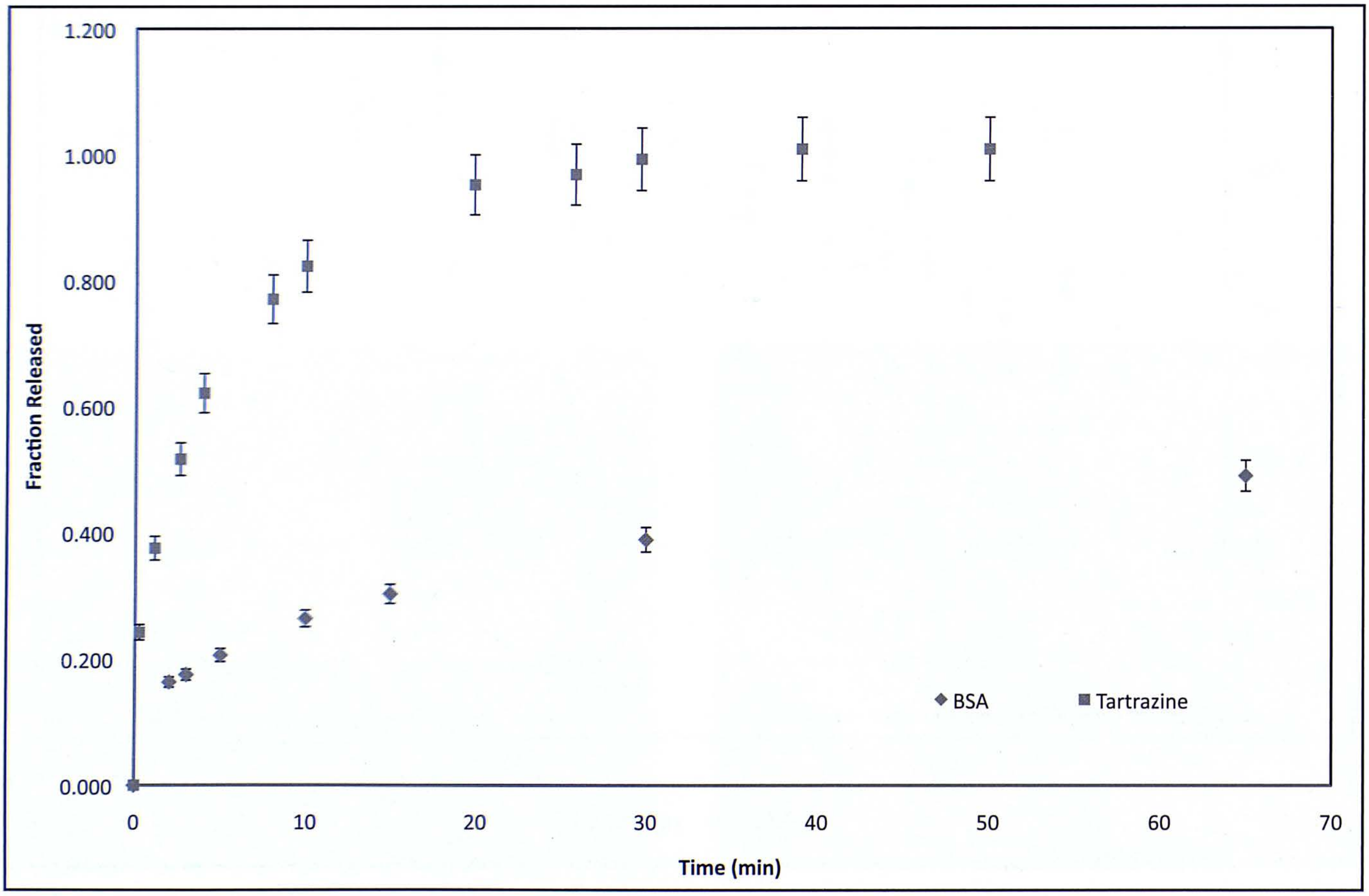


***Figure 8.** The effect of molecular weight on release profile. The release of BSA is slower than the release of tartrazine. After 30 min, F = 0.389 for BSA and F=0.992 for tartrazine.*

shows a comparison of release rates for the short contact time (Fickian diffusion control) and long contact time (swelling control).

EVALUATION

To evaluate the impact of this experiment on student learning, a quiz was administered to students before and after the lab. The quiz comprised 15 questions (12 multiple-choice, two choice-between-two-options, and one explanation) that were mapped to course and lab objectives and ABET objectives. An example of a multiple-choice question is:

The diffusion rate is directly proportional to

a) Equilibrium

b) pH

c) Molecular weight

d) The magnitude of the concentration gradient

The quiz questions covered topics of diffusion, hydrogels and cross-linking, surface area, material properties, release kinetics, release mechanism, and drug-delivery design. The questions were designed to evaluate whether the experiment was effective in introducing basic principles of drug delivery; reinforcing concepts of science, math, and engineering; and teaching skills of data analysis and representation. A summary of the quiz questions is provided in Table 1 (page 107) in which multiple-choice questions are presented as correct statements for brevity.

Questions were mapped to Rowan Engineering Clinic II course objectives and ABET outcomes as shown in Table 2 (page 108). The Table also shows the measurable skills that are associated with each outcome. Figure 11 (page 108) shows the average score on the pre-test was 56%±22% for n=14 students, and the average score on the post-test was 82%±9.9% for n=15 students.

For each outcome, the percentage of correct responses increased between 13-24% between the pretest and the post-test. The highest percentage of correct responses for both the pre- and post-tests was for outcome ABET C; students showed the lowest percentage increase for this outcome most likely because the pretest scores were so high. The lowest performance was

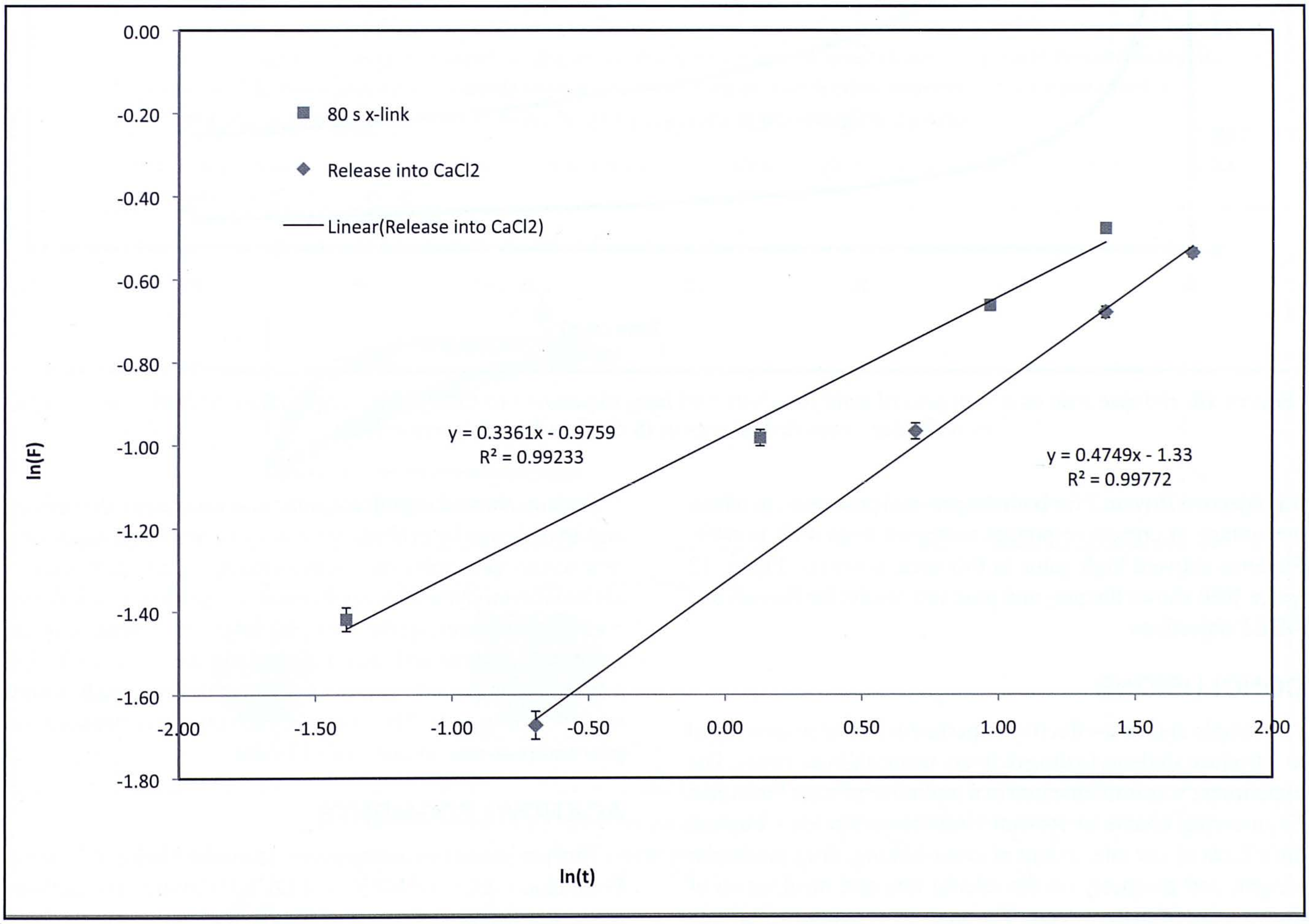


Figure 9. *Evaluation of rate controlling mechanism. The value of the slope is equal to the exponent n in Eq. (1). Longer cross-linking time results in the formation of a thicker shell in which swelling is significant over the course of the experiment. The shorter cross-linking time results in a thin shell and Fickian diffusion as the rate-controlling mechanism.*

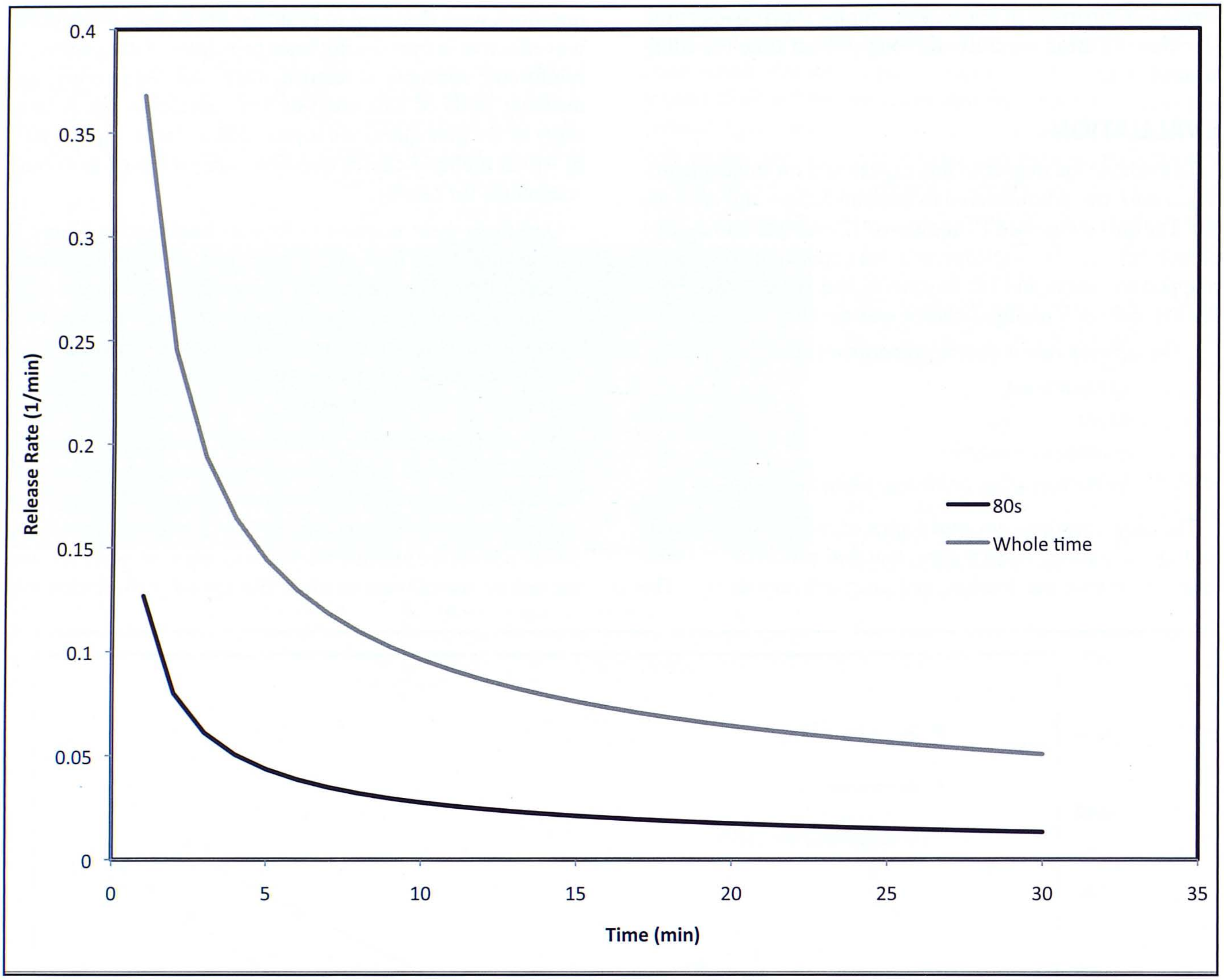


Figure 10. *Release rate as a function of time for short and long exposures to $CaCl_2$. The longer cross-linking time results in a thicker cross-linked region in the bead and slower release.*

for objective Rowan 2 for both the pre- and post-tests, in which percentage of correct responses increased from 40% to 64%. Students showed high gains in this area, however. Figure 12 (page 109) shows the pre- and post-test results for Rowan and ABET objectives.

CONCLUSIONS

A simple and cost-effective experiment has been developed to introduce students to drug delivery using alginate beads. The experiment was implemented in a multidisciplinary Freshman Engineering course at Rowan University. Students explore the effects of stir rate, extent of cross-linking, drug molecular weight, and geometry on the release rate and mechanism of drug release from the system. The analysis of experimental data introduces students to mass balances, spreadsheet calculations, data representation, and mathematical modeling.

Students showed significant gains in several areas: the science and art of design by evaluating the work of practicing engineers; new science principles such as mass balances, transport, materials and thermodynamics; application of knowledge of science, math, and engineering; the ability to design and conduct experiments and analyze and interpret data; and the ability to design a system, component, or process to meet desired needs within realistic constraints. The gains for each objective between the pre- and post-test ranged from 13-24%.

ACKNOWLEDGMENTS

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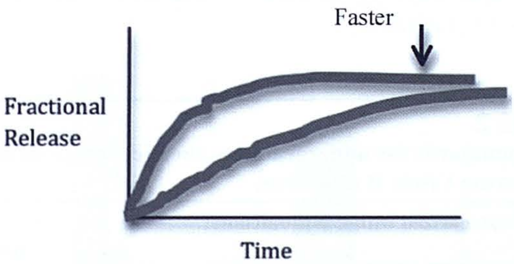
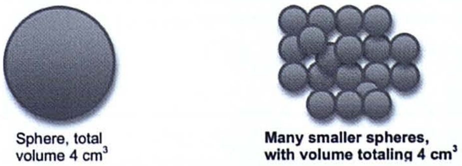
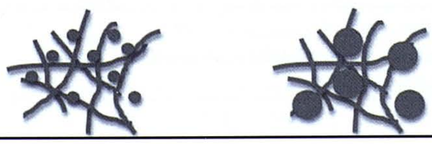
TABLE 1

Pre- and Post-module questions presented as correct statements.
The bold font indicates the choice that correctly completes each statement.

Question #	Correct Statement
1	The movement of molecules from a region of high concentration to one of low concentration is called **Diffusion**
2	The diffusion rate is directly proportional to **the magnitude of the concentration gradient**
3	Diffusion results in an increase in system **entropy**
4	Hydrogels are **three-dimensional networks of water-loving polymers**
5	In polymers, a cross-link is a **covalent, ionic, and physical connection that bonds one polymer chain to another, forming a "net" of polymer chains.**
6	Cross-links make a polymer material **insoluble in a solvent**
7	Drugs can be loaded into hydrogels, and they will be subsequently released from the polymer by a process called **diffusion.**
8	What is meant by the phrase, "The hydrogel is permeable to the flow of solute?" **A solid is dissolved inside the water that is absorbed by the hydrogel. The solute can diffuse through the hydrogel with little resistance.**
9	What is meant by surface area to volume ratio? **The area of the outer surface of an object per unit volume of the object.**
10	Someone hands you an object and asks you to describe its material properties. What is meant by material properties? **All of the above (color, electrical conductivity, hardness, surface roughness).**
11	The total US healthcare expenditures on biomaterials in 2000 totaled $1,400,000,000,000. As you can see, the need for engineers who design these materials is quite large. What is an example of a constraint that biomedical engineers have to take into account while designing materials that are to be implanted into patients? (**Correct answers include nontoxic, biocompatible, biodegradable or nonbiodegradable depending on application, functional constraints such as compatibility with drug in delivery system, desired properties in physiological conditions**)
12	Which of the following statements is true? **Diffusion rate of a drug through a hydrogel is inversely proportion to the molecular weight of the drug.**
13	Which curve represents a drug delivery system with a faster release rate? 
14	Which of the below systems have higher surface area to volume ratios? 
15	In which of the following scenarios does the hydrogel network have a higher permeability to the dissolved drug? **(The scenario on the left. Smaller molecules result in higher permeability)** 

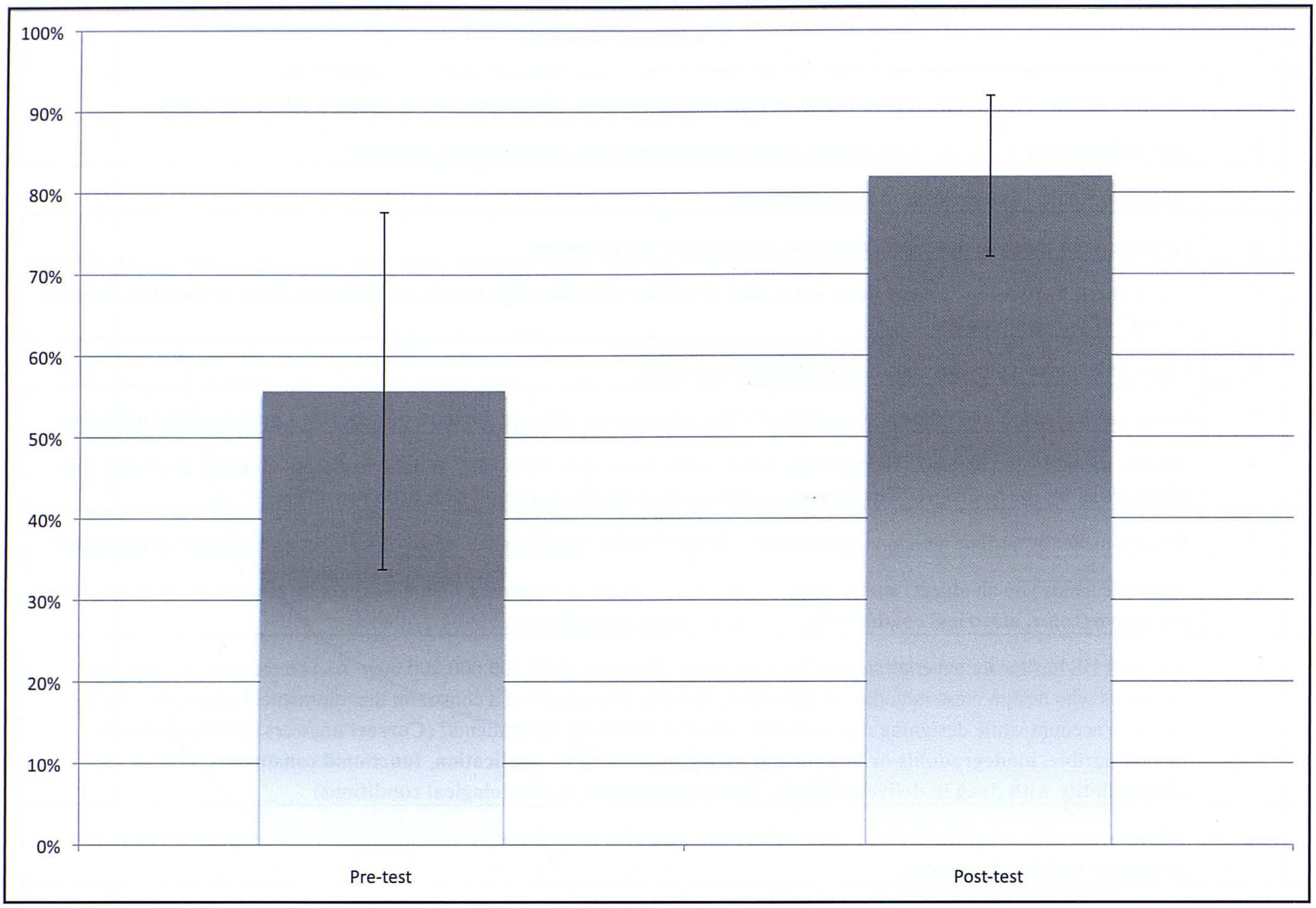


Figure 11. *Average pre- and post-test scores for the alginate drug delivery module. For the pretest, n=14 students. For the post test, n=15 students.*

TABLE 2
Pre- and post-module assessment questions alignment to: ABET standards for undergraduate chemical engineering students and Rowan University Engineering Clinic II objectives

Outcome	Measurable skills categorized within this outcome:	Pre- and post-test questions
Introduce students to the science and art of design by evaluating the work of practicing designers (Rowan 1)	To identify how hydrogel-based drug delivery systems work; how to measure drug release; connect engineering principles to the design of these systems	1,2,7,8,9,12, 13,14,15
Introduce multidisciplinary teams of engineers to science principles such as mass balances, transport, materials, thermodynamics (Rowan 2)	Identify variables that drive mass transfer; use structure-property in hydrogels to predict mass transfer behavior	2, 5, 6, 7, 8, 12, 14, 15
An ability to apply knowledge of mathematics, science, and engineering (ABET-A)	Successfully apply fundamental concepts of chemistry, material science, and transport phenomena to biomaterial science and drug delivery systems	1-8, 12-15
An ability to design and conduct experiments, as well as to analyze and interpret data (ABET-B)	Experience with the preparation and characterization of a drug delivery system will give the ability to identify key variables, analyze data, and evaluate its significance	3, 9, 12, 13, 14, 15
An ability to design a system, component, or process to meet desired needs within realistic constraints (ABET-C)	Students will identify scientific, safety, and economic constraints relevant to biomaterials, successfully apply them to the design and characterization of polymeric drug delivery system	11

REFERENCES

1. Langer, R., *Foreward to Encyclopedia of Controlled Drug Delivery, Volume 1*, Etith Mathiowitz (ed.), John Wiley and Sons, NY (1999)
2. Langer, R., "New Methods of Drug Delivery," *Science*, **249**, September 1990, pp. 1527-1533
3. Kydonieus, A.F., *Controlled Release Technologies: Methods, Theory and Applications. Vol. 1*, New York, CRC Press, Inc. pp. 48 (1980)
4. Mathiowitz, E., *Encyclopedia of Controlled Delivery. Vol. 2*, New York, John Wiley & Sons, Inc. pp. 493, 729 (1999)
5. Farrell, S., and R.P. Hesketh, "An Introduction to Drug Delivery for Chemical Engineers," *Chem. Eng. Ed.*, **36**(3), 198 (2002)
6. Prausnitz, M.R., and A.S. Bommarius, "Drug Design, Development and Delivery: An Interdisciplinary Course on Pharmaceuticals," *Chem. Eng. Ed.*, **45**(1), 47 (2011)
7. Simon, L., K. Kanneganti, and K.S. Kim, "Pharmacokinetics and Drug Transport for Chemical Engineers," *Chem. Eng. Ed.*, **44**(4), 262 (2010)
8. Robinson, J.R., and V.H.L. Lee, *Controlled Drug Delivery: Fundamentals and Application*, 2nd ed. Vol. 29. New York Marcel Dekker, Inc. pp. 56, 58, 557 (1987)
9. Lee, P.I. and W.R. Good, *Controlled-Release Technology: Pharmaceutical Applications*.,Washington, DC. 1987 Am. Chem. Society p. 201
10. Ritger, P.L., and N.A. Peppas, "A Simple Equation for Description of Solute Release I. Fickian and Non- Fickian Release from Non-Swellable Devices in the Form of Slabs, Spheres, Cylinders or Discs," *J. Controlled Release*, **5**(1), 23 (1987)
11. Ritger, P.L., and N.A. Peppas, "A Simple Equation for Description of Solute Release II. Fickian and Anomalous Release from Swellable Devices," *J. Controlled Release*, **5**(1), 37 (1987)
12. Peppas, N.A., and J.J. Sahlin, "A Simple Equation for the Description of Solute Release. III. Coupling of Diffusion and Relaxation," *Int. J. Pharmaceutics*, **57**, 169-172 (1989)
13. Kwiatek, M.A., S. Roman, A. Fareeduddin, J.E. Pandolfino, and P.J. Kahrilas, "An Alginate-Antacid Formulation (Faviscon Double Action Liquid) Can Eliminate or Displace the Postprandial 'Acid Pocket' in Symptomatic GERD Patients," *AP&T Alimentary Pharmacology and Therapeutics*, **34**, 59-66 (2011)
14. Peters, H.P.F., R.J. Koppert, H.M. Boers, A. Strom, S.M. Melnikov, E. Haddeman, E.A.H. Schuring, D.J. Mela, and S.A. Wiseman, "Dose-Dependent Suppression of Hunger by a Specific Alginate in a Low Viscosity Drink Formulation," *Obesity*, **19**(6), 1171 (2011)
15. Ishak, R.A.H., G.A.S. Awad, N.D. Mortada, and A.K. Samia Nour, "Preparation, In Vitro and in Vivo Evaluation of Stomach-Specific Metronidazole-Loaded Alginate Beads as Local Anti-Helicobacter Pylori Therapy," *J. Controlled Release*, **119**(2), 207 (2007)
16. Al-Kassas, R.S., O.M.N. Al-Gohary, and M.M. Al-Faadhel, "Controlling of Systemic Absorption of Gliclazide through Incorporation into Alginate Beads," *Int. J. Pharmaceutics*, **341**(1-2), 230 (2007)
17. Gu, F., B. Amsden, and R. Neufeld, "Sustained Delivery of Vascular Endothelial Growth Factor with Alginate Beads," *J. Controlled Release*, **96**(3), 463 (2004)
18. Mierisch, C.M., S.B. Cohen, L.C. Jordan, P.G. Robertson, G. Balian, and D.R. Diduch, "Transforming Growth Factor-β in Calcium Alginate Beads for the Treatment of Articular Cartilage Defects in the Rabbit," *Arthroscopy: The J. Arthroscopic and Related Surgery*, **18**(8), 892 (2002)
19. Read, T-A, V. Stensvaag, H. Vindenes, E. Ulvestad, R. Bjerkvig, and F. Thorsen, "Cells Encapsulated In Alginate: A Potential System For Delivery Of Recombinant Proteins To Malignant Brain Tumors," *Int. J. Developmental Neuroscience*, **17**(5-6), 653 (1999) ❐

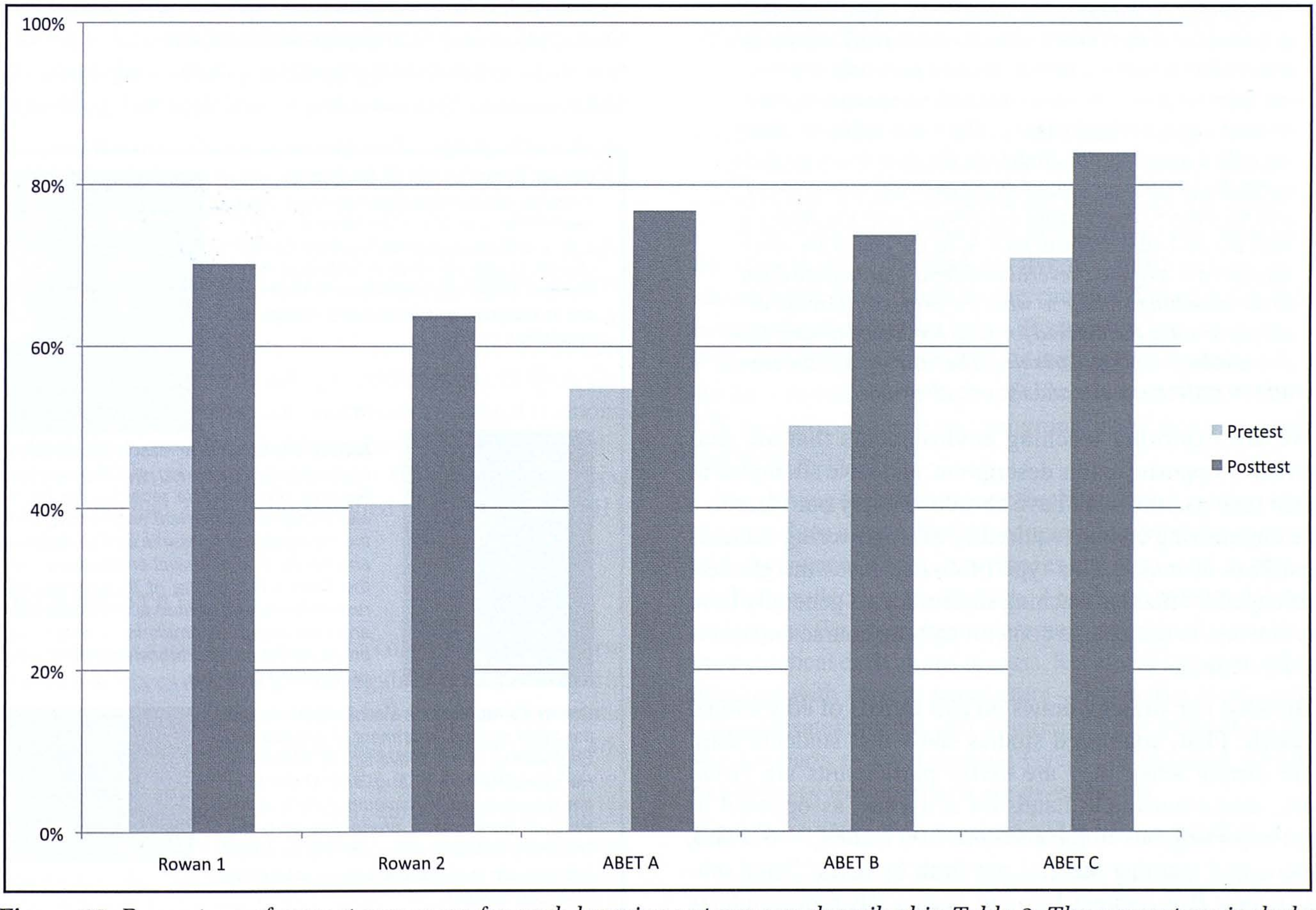


Figure 12. *Percentage of correct responses for each learning outcome as described in Table 2. The percentage includes responses for all questions mapped to a particular outcome.*

EXPERIENTIAL LEARNING AND GLOBAL PERSPECTIVE IN AN ENGINEERING CORE COURSE

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The typical engineering course is aptly described by Rugarcia, et al.,[1]

> *"The professor stands at the front of the room, copying a derivation from his notes onto the board and repeating aloud what he writes. The students sit passively, copying from the board, reading, working on homework from another class, or daydreaming. Once in a while the professor asks a question: the student in the front row who feels compelled to answer almost every question may respond and the others simply avoid eye contact with the professor until the awkward moment passes. At the end of the class students are assigned several problems that require them to do something similar to what the professor just did or simply to solve the derived formula for some variable from given values of other variables. The next class is the same, and so is the next one, and the one after that."*

We are exploring teaching environments that are diametrically opposite to this description, and have attempted to create such a course. We have chosen to apply our ideas to a core engineering course required by all engineering students regardless of major. This type of course faces the greatest challenge for effective teaching since students generally have low interest in the course content, and the course content is rigidly defined.

Broadly, our strategy draws on two thrusts of educational research. First, controlled studies show that students learn more deeply when they are *active* participants via group work, discussions, and hands-on activities, as opposed to passive participants in the audience of a lecture.[2,3] Second, experiential learning theories put forth by Kolb[4-6] and others suggest that optimal learning occurs when the students traverse a cycle in which they first experience something concrete, then have an opportunity to reflect on what they have observed, then develop an abstract model or ideas to explain the experience, and then carry out some sort of test of their ideas, which in turn generates new concrete experiences and starts another cycle operating at a more advanced stage of knowledge. This "Learning Cycle" approach is illustrated

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in Figure 1. In the context of technical fields of study, this cycle has a clear resemblance to what is commonly referred to as the "scientific method."

The basis of our approach is that we teach the course in a foreign country, and intertwine technical content with societal issues of the foreign culture; this connection is used to launch an experiential learning approach to the course. There are two key consequences of teaching the course in a foreign country. First, students are able to experience a direct connection between technical content and societal issues. Second, students take only one course over a few weeks (rather than multiple courses spread out over several months); this format creates opportunities for experiential learning, as the longer class meeting times allow for a range of activities throughout the complete Learning Cycle, and the absence of other commitments enables extended field trips for experiential activities.[7-9]

While much of engineering education is thought to be experiential because it deals with laboratory work and real-world applications, experiential learning in its full-blown form, as can be seen from its description, requires somewhat more structure. In this paper, we explicitly connect the learning activities to the elements of the cycle, to provide a template that can be adapted to other teaching contexts.

In addition to the pedagogical benefits, our approach also broadens the global perspective of the students. Study abroad is difficult for engineering students, due to the large number of required courses (which usually must be taken in a particular order) and the importance of summer internships. We confine our course to a three-week period in May, where it does not disrupt either the academic year or summer internships.

We implemented our idea for the first time in 2011, teaching a core engineering course that is required at Case Western Reserve University (CWRU). The technical content was connected to societal issues in sub-Saharan Africa, and the course was taught at the University of Botswana (UB) in Gaborone, Botswana. Botswana was chosen because it is among the wealthiest countries in Africa, has a stable democratic government and low crime rate, and English is the official language. We had 21 students enrolled in the course in 2011 (all from CWRU).

IMPLEMENTATION

Our course is a special offering of a core engineering course in thermal sciences at CWRU. The regular offering is taught in the traditional lecture format over a full semester. The course covers heat transfer (20% of the course), fluid flow (30%), and thermodynamics (50%), and uses the text *Fundamentals of Thermal-Fluid Sciences*, by Cengel, Turner, and Cimbala.[10] The technical content in our offering is the same as that in the regular offering. The workload is also the same, as quantified by the total number of contact hours, the number of homework problems, and the number of exams.

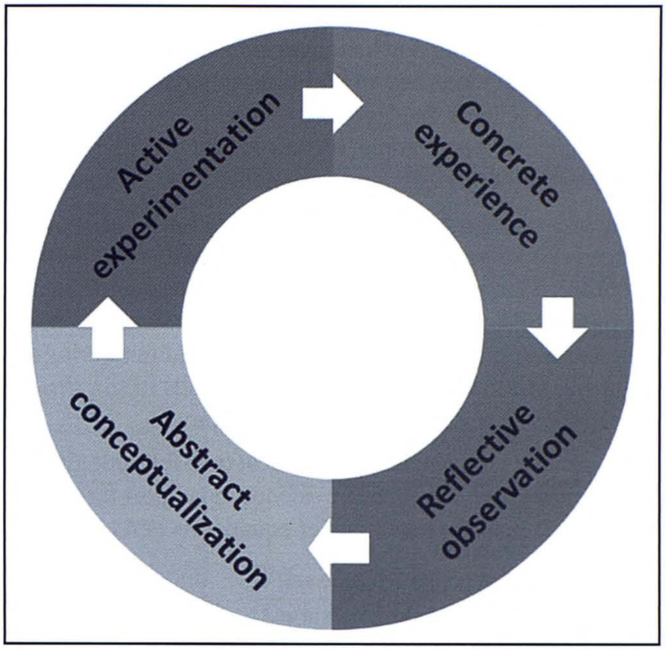

Figure 1. *Schematic of Kolb's learning cycle.*

The course runs during a three-week period in May. Classes are held an average of five days/week, but are dispersed throughout all seven days of the week in order to accommodate field trips. A typical class meets for 3.5 hours in the morning in a classroom at UB, but additional problem-solving sessions are held on an ad hoc basis during field trips in venues such as airplanes, buses, and hotel lobbies. Homework assignments are given each day the class meets and are due the next day; usually a significant fraction of the homework could be completed during the problem-solving segments of the class period. The students live in dormitories on the UB campus and have meals in the campus dining halls. While our course does not include UB students, we run a concurrent research program that does include UB students[11]—the students in our course have significant interaction with these UB students, as these two programs share housing, dining, and most activities.

The driving force behind our teaching is the Learning Cycle. We introduce a topic through concrete experiences associated with Botswana. These experiences are discussed in class, to facilitate reflective observation. Abstract conceptual models underlying the phenomenon are next developed, usually via mathematical derivations in class. Results of these models are obtained with various parameters—this active experimentation generates insight and intuition on the behavior. Often, various parts of the Learning Cycle are repeated. Detailed examples of this approach are given below.

Heat Transfer: The traditional African mud hut

Botswana's semi-arid climate leads to large temperature fluctuations between day and night. From their first day in Botswana, our students experience this first-hand—it is uncomfortably hot during the day while wearing shorts and a tee-shirt, but it cools down at night such that long pants and a sweatshirt are needed. In addition, we visit a traditional African hut (Figure 2a), and the students are told that while the hut appears very simple, it is actually a good design that responds well to temperature variations.

These concrete experiences serve as a lead-in to a discussion (reflective observation) on the engineering design of dwellings to optimize thermal comfort. At first thought, it appears that the optimal dwelling would have heavily insulated walls, to keep the heat out during the day and the cold out during the night. We tell the class that actually the walls of the African hut work even better than heavy insulation.

An abstract conceptual model of heat transfer through a hut wall is necessary to generate evidence to support this claim. The time dependent heat transfer equation is derived,

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p} \frac{\partial^2 T}{\partial x^2} \tag{1}$$

where t is time, x is the position in the wall, T is temperature at position x at time t, k is the thermal conductivity, ρ is the density, and C_p is the heat capacity. To determine the temperature inside the hut, we use as boundary conditions an oscillating temperature on the exterior side of the wall and zero heat flux on the interior side of the wall. The equation is solved numerically, using a finite difference method that is easily implemented in a spreadsheet.[12]

With this model, we carry out "what if" experiments to explore what factors influence heat transfer. Figure 2b shows the solution for the temperature inside the hut as a function of time, using thermal parameters for a mud brick[13] and a wall thickness of 20 cm. The temperature inside the hut oscillates with time, but these oscillations are out of phase with the oscillations of the outside temperature—the hut walls act as passive "air conditioners" in the day and passive heaters at night. Experimentation with the thermal parameters shows that a "modern" Western-style insulated wall is not nearly as effective in controlling the temperature, and that a wall thickness of approximately 20 cm is optimal.

Further reflection shows that the effect is an inherently unsteady state phenomenon, and the key parameter is the large thermal capacity of the walls (the product ρC_p). What happens is that the walls begin heating up during the day, but by the time the heat reaches the inner surface of the wall it is already nighttime; at night the walls begin cooling, but by the time the cooling reaches the inner surface it is already daytime. The mud brick wall is only effective when large daily temperature swings straddle the most comfortable temperature; if the temperature is always "too cold" or "too hot", then the wall material with the lowest k (modern insulation) is optimal as it minimizes heating or cooling costs.

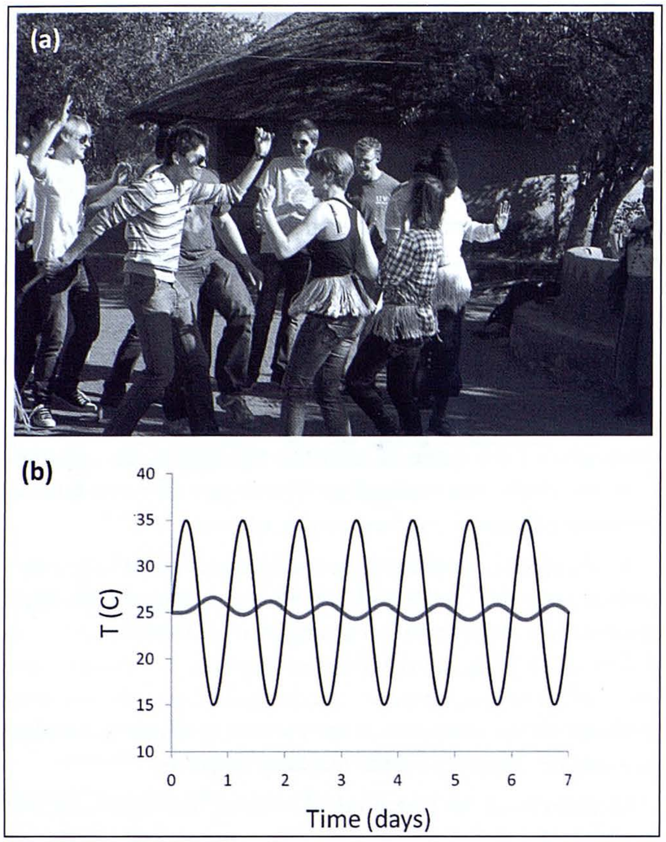

Figure 2. (a.) Our students enjoying themselves in front of a traditional African mud hut. (b.) Model results for the temperature inside the hut (thick grey line) when there are daily oscillations in outside temperature (thin black line). Results obtained using thermal parameters found in the literature for a mud brick wall (k=0.37 W/mK, ρ=1780 kg/m³, C_p=1190 J/kgK) and a wall thickness of 20 cm.

Fluid Flow

i. Providing water for villages in the Kalahari desert

Botswana is largely covered by the Kalahari Desert, and deep wells are needed to reach water. To give the students concrete experience in this regard, a data sheet for a water well in the village of Thamaga is obtained from the Botswana Water Authority and given to the students (Figure 3a). This enables students to see actual parameters for such wells, including the well depth (163 m), aquifer depth (106 m), well pipe diameter (165-230 mm, depending on depth), and water flow rate (25 m^3/h).

What factors affect the cost of providing water to the villages? A discussion facilitates reflective observation of this question. Of course, power is required to lift the water from the bottom well against gravity. Other factors, however, such as frictional energy losses at pipe walls, could also affect the necessary power.

An abstract conceptual model is developed to quantify the power needed to pump the water. We derive the energy bal-

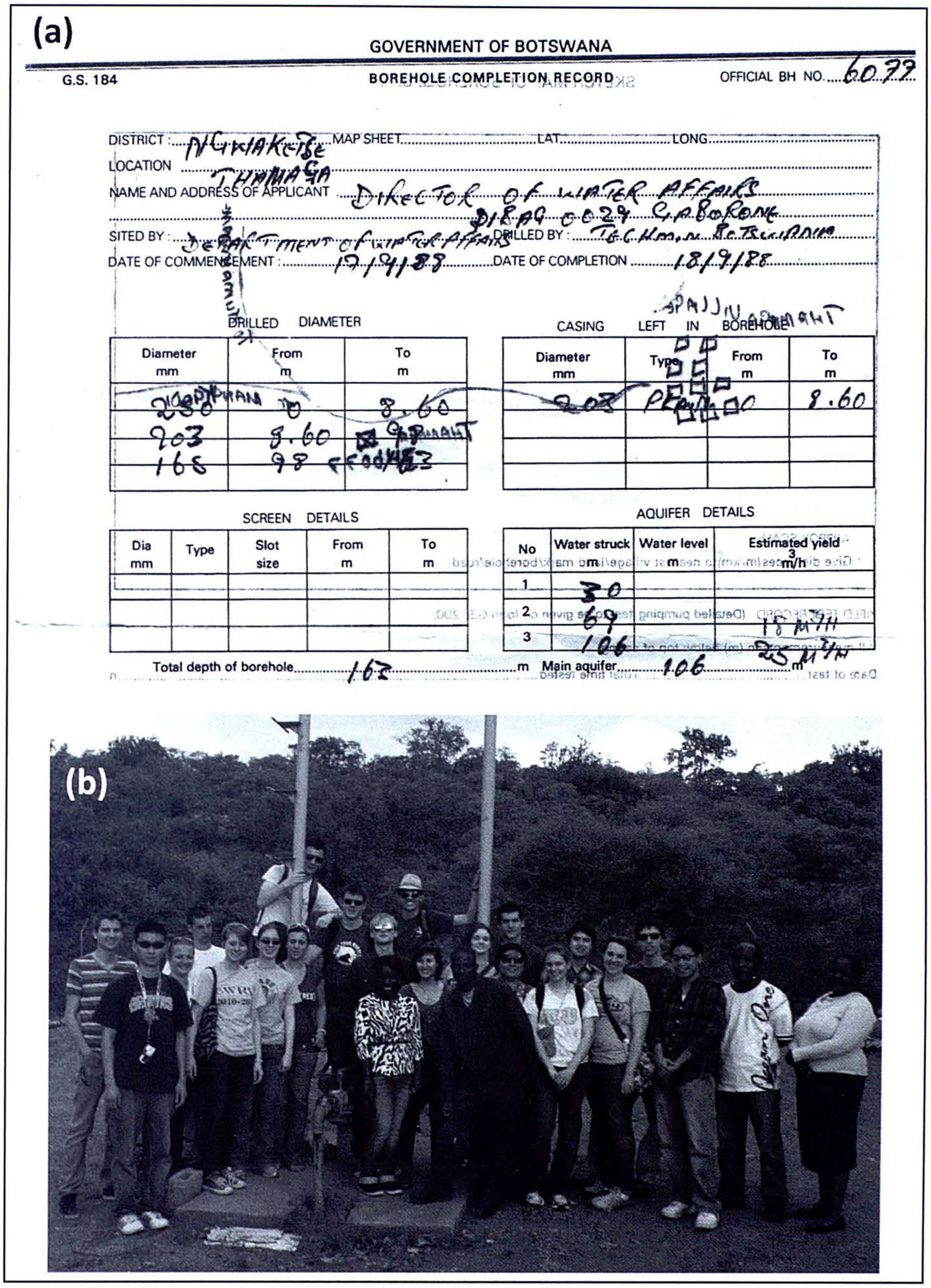

Figure 3. (a.) Specifications of borehole well in Thamaga village, Botswana. (b.) Class visit to the well, guided by engineer from the Botswana Water Authority (at front center).

ance for flowing incompressible fluids, which leads to the expression for the power needed to pump a fluid from point 1 to point 2,

$$\dot{W} = \left(\left[\frac{1}{2}\dot{m}v_2^2 + \dot{m}gh_2 + \frac{1}{\rho}\dot{m}P_2 \right] - \left[\frac{1}{2}\dot{m}v_1^2 + \dot{m}gh_1 + \frac{1}{\rho}\dot{m}P_1 \right] \right) + \dot{E}_{loss} \qquad (2)$$

where $\dot{m}$ is the mass flow rate, and v_i, h_i, and P_i are the velocity, elevation, and pressure at point i, ρ is the density, g is the gravitational constant, and $\dot{E}_{loss}$ is the rate of frictional energy loss.

In regard to the use of concrete experiences related to a foreign culture, the students overwhelmingly felt that this experience got them more interested in the technical content . . . .

We follow the development of the model with active experimentation—we estimate how much power would be needed to pump water from this well, using the parameters given in the well data sheet (frictional losses were neglected at this point). We find that 7 kW of power is required to pump water at 25 m^3/h. Since the cost of electricity in Botswana is 0.6 Botswana Pula (BWP) per kWh,[14] the cost to pump the water is approximately 0.2 BWP per cubic meter of water (1 BWP ≈ 0.15 USD).

The same day, the class travels to visit this well, guided by an engineer from Botswana Water Authority (Figure 3b). As further concrete experience, the students see first-hand the well they analyzed earlier in the day (and also learn about other aspects of water systems in Botswana). Thamaga village is charged 1 BWP per cubic meter of water. Our calculation of the cost required to pump the water from the well accounts for about 1/5 of this charge; other factors contributing to the charge include the inefficiency of the pump, water treatment (we visit the water treatment plant), and transport of the water from the well to the village.

The visit to a second water well near Thamaga, which provides 20 m^3/h of water to a village approximately 40 km away via a 90 mm diameter pipeline, provides concrete experience for the role of frictional losses in fluid flow—power is required to pump the water through the pipeline, even though there is no significant change in elevation. In class the next day, we discuss how this power is needed to overcome frictional losses due to the moving fluid interacting with the stationary pipe wall (reflective observation). An abstract conceptual model for fluid losses is introduced,

$$\dot{E}_{loss} = \frac{\dot{m}}{\rho} f\left(\frac{L}{D}\right)\frac{\rho v^2}{2} \tag{3}$$

where L is the length of the pipe, D is the pipe diameter, and f is the Darcy friction factor (f=64/Re for laminar flow, and $f=0.316/Re^{1/4}$ is the Blasius approximation for turbulent flow in smooth pipes). Active experimentation shows that frictional losses are negligible in the case of the first well, but significant in the case of the second well. For the second well, 18 kW of power is needed to overcome the frictional losses for 20 m^3/h of water, which corresponds to a cost of 0.6 BWP per cubic meter of water (this calculation was given as an exam problem).

ii. Victoria Falls

Fluid flow is also addressed in the context of Victoria Falls, one of the world's largest waterfalls. Victoria Falls is located on the Zambezi River between Zimbabwe and Zambia, about 80 km outside of Botswana. Active experimentation with the energy balance equation [Eq. (2)] shows that the falls release $\dot{W} \approx 1$ GW of power, based on a height of 100 m (the highest point is 108 m) and a flow rate of 1100 m^3/s (the annual average). Reflective observation puts this value into context: the available energy could power *10 million* 100 W light bulbs. The class visits Victoria Falls as part of a three-day excursion to the north of Botswana midway through the course (Figure 4)—this visit provides concrete experience of the power corresponding to 10 million light bulbs.

Thermodynamics

i. Thermodynamics of diamonds

The high standard of living in Gaborone, the capital of Botswana, is obvious to our students. For example, shopping malls in Gaborone are indistinguishable from "upscale" malls in the United States. This wealth is recent. When Botswana became independent in 1966, it was among the poorest countries in the world. In 1967, diamond was discovered in Botswana, and diamond mining began a few years later. Today, Botswana is the world's largest producer of diamonds (by value),[15] and the diamond industry has transformed the country to one of the richest in Africa. The students visited the diamond mine in Jwaneng (Figure 5), which produced over 10 million carats of diamond in 2009 and is the richest diamond mine in the world.[16]

These concrete experiences motivate reflective observation on diamond. Diamond and graphite are both forms of carbon; graphite is the thermodynamically stable phase at low pressures, while diamond is the thermodynamically stable phase at high pressures. If diamond thus forms only at very high pressures, and such high pressures exist deep inside the earth, at what depth does the pressure become high enough for diamonds to form?

We develop an abstract conceptual model to determine the thermodynamic stability of diamond as a function of depth inside the earth. Diamond is thermodynamically stable with respect to graphite at the depth where the Gibbs free energy of diamond relative to graphite is negative, $\Delta G(h) < 0$. While ΔG depends directly on pressure (P) and

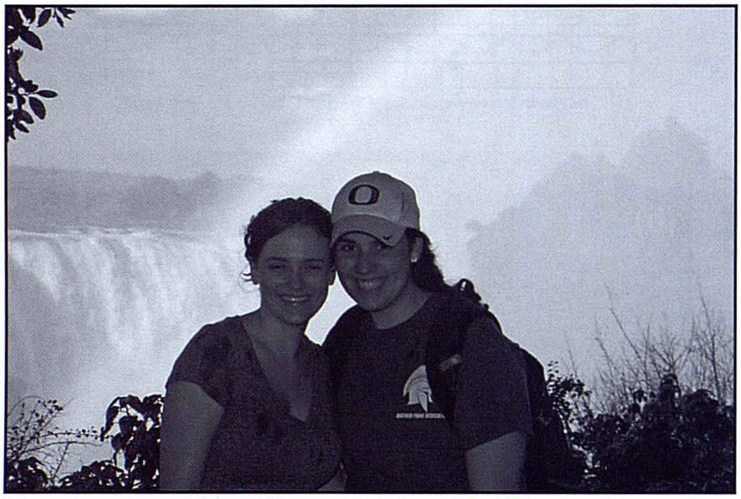

Figure 4. *Two of our students at Victoria Falls, with its permanent rainbow. A calculation carried out in class showed that the energy of the falling water at Victoria Falls could power 10 million 100 W lightbulbs.*

temperature (T), P and T depend on h—P increases with depth due to the gravitational force from the material above, and temperature increases with depth due to the presence of radioactive material in the earth. The relevant equations are

$$\Delta G(h) = \Delta G^0 + \left[P(h) - P^0\right]\Delta V^0 - \left[T(h) - T^0\right]\Delta S^0 \tag{4}$$

$$P(h) = P^0 + \rho g h \tag{5}$$

$$T(h) = T^0 + bh + ch^2 \tag{6}$$

where ΔV and ΔS are the differences in molar volume and molar entropy of diamond relative to graphite, the designation '0' implies evaluation at P=1 atm and T= 25 °C, ρ is the density, g is the gravitational constant, and b and c are empirical constants. These equations include approximations: Eq. (4) neglects changes of ΔV and

ΔS with P and T, Eq. (5) assumes constant ρ, and Eq. (6) is the polynomial fit of experimental results for the temperature profile under South Africa.[17]

Active experimentation with this model is used to estimate the depths at which diamond becomes stable, using Eqs. (4)-(6). A comparison of the pressure as a function of depth with the diamond-graphite stability range, shown in Figure 5, leads to the estimate that diamond is more stable than graphite for h>110 km (a more rigorous treatment would use more accurate pressure and temperature distributions in earth, and account for changes of ΔV, ΔS with P and T).

The students see that the diamond mine is only 300 m deep, far less than the >110 km depths at which diamonds are formed. In fact, diamonds are brought to near the surface by volcanic activity, whereby magma from deep in the earth ("Kimberlite") carries the diamonds from deep inside the earth to near the surface, where they can be collected and purified by mining operations.

ii. Energy from cow dung

Most African villages are not connected to national electrical and telephone grids. Portable devices such as cell phones are useful, but electricity is needed to charge the batteries (about 5 W-h per battery). A sustainable and essentially free source of energy in Botswana villages is cow dung—Botswana has more cows than people![18] Our trips outside Gaborone give students concrete experience with villages having no electricity but plenty of cattle (Figure 6).

Reflective observation is stimulated by a seminar describing research at UB using a calorimeter to determine the energy content of cow dung under various conditions. The abstract conceptual model underlying calorimeter involves the equation

$$\Delta E = MC\Delta T \tag{7}$$

where M and C are the mass and heat capacity of the water, and ΔE and ΔT are the changes in the internal energy and temperature of the water. As active experimentation, students are asked (on an exam) to determine how many cell phone batteries could be charged with 1 kg of cow dung, using the experimental result that the combustion of 206 g of cow dung increases the temperature of 2226 g of water from 16.8 °C to 52.1 °C. The calculation shows that 89 cell phone batteries could potentially be charged from the energy in 1 kg of cow dung.

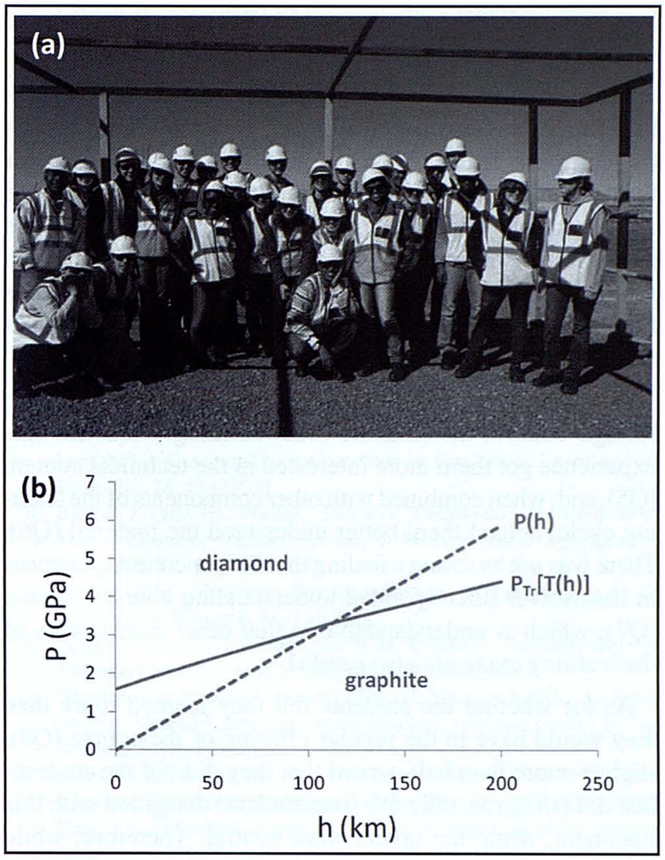

***Figure 5.** (**a.**) Our students at the richest diamond mine in the world in Jwaneng, Botswana. (**b.**)Graphite-diamond stability curves as a function of depth inside of the earth. Results of our analysis show that diamond is thermodynamically more stable than graphite at depths below ~110 km in the earth. The model was evaluated with the parameters ΔG^0=2900 J/mol, ΔV^0= −1.88 cm³/mol, ΔS^0= −3.36 J/mol. K,ρ = 3000 kg/m³, b= 11 °C/km and c = −0.023 C/km².*

***Figure 6.** The students saw that there are many cattle in Botswana, and villages without electricity. Calculations carried out in class, using data from University of Botswana research labs, showed that 1 kg of cow dung can provide the energy to recharge 89 cell phone batteries.*

ASSESSMENT

Our assessment of the 2011 implementation of our course aimed to evaluate the effectiveness of two "nontraditional" aspects of our course—the one-course-at-a-time format and the relationship of technical course content to societal issues in a foreign culture. A questionnaire was given to the students after they returned to the United States (and after grades had been assigned). All students completed the questionnaire, and results are shown in Table 1.

The students overwhelmingly felt that the one-course-at-a-time format was effective in allowing for activities throughout the complete learning cycle (question Q1). The modular format had additional favorable features, in that the absence of other classes allowed the students to focus better (Q2), and that problem-solving activities during the class time catalyzed group work that helped learning (Q3). Only 10% of the class felt that the short duration of the course detracted from their learning (Q4).

In regard to the use of concrete experiences related to a foreign culture, the students overwhelmingly felt that this experience got them more interested in the technical content (Q5), and, when combined with other components of the learning cycle, helped them better understand the material (Q6). There was not as strong a feeling that the concrete experiences in themselves directly aided understanding course material (Q7), which is understandable in that other components of the learning cycle are also needed.

As for whether the students felt they learned more than they would have in the regular offering of the course (Q8), slightly more than half agreed that they did. Of the students that did not agree, only 5% (one student) disagreed with this statement, while the others were neutral. Therefore, while the students as a whole may not have felt they learned more in our course compared to the regular offering, they did not feel that they learned less.

Finally, all students felt that the course in Botswana gave them a global perspective that many people in the United States do not have the opportunity to obtain (Q9).

DISCUSSION AND CONCLUSIONS

Our goal is to create a course that overcomes the dry and often ineffective learning environment in traditional engineering courses. The approach follows the ideas of experiential learning, where students actively participate in a cycle of learning processes that tackle the problem in different ways (the Learning Cycle). The novelty of our approach is to intertwine the technical content with societal issues in a foreign culture to initiate the experiential learning. The course is taught at a university in a foreign country, in an intensive three-week format, to facilitate the experiential learning activities.

Based on the results of our assessment of our initial implementation of the course, we believe the approach met its intended goals. In particular, the students felt that experiential learning approach was successful—the connection of technical content to societal issues in a foreign culture generated interest in the technical content, and the use of activities throughout the Learning Cycle helped them better understand the material. Further, the students felt that the one-course-at-a-time format facilitated the experiential learning approach, and allowed them to focus better on the course.

Surprisingly, the cost for students to take our course is comparable to the cost for taking the same course on the CWRU campus during the regular (eight-week) summer session.

TABLE 1
Results of Assessment Survey

Assessment Questions	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. The intermixing of lecture with problem solving in a single (long) class period helped me learn the material better	75	20	5	0	0
2. The course format allowed me to work with others in the course more effectively, which in turn helped me learn the material better	50	45	5	0	0
3. I was able to focus better on this course because I didn't have to devote time to other courses	85	15	0	0	0
4. The course was too condensed in time and this prevented me from learning the material as well as I could have	0	10	25	40	25
5. The connection of course content to African life made me more interested in the course material	50	40	5	5	0
6. The opportunity to, within a day or two, actually see instances of a phenomenon (*e.g.*, water well, water fall, diamond mine, African hut), derive the relevant equations, and apply these equations helped me understand the material better	40	50	5	5	0
7. The connection of course content to African life clarified technical content and helped me learn the material better	25	45	25	5	0
8. I learned more than if I took the regular ENGR 225 course	35	25	35	5	0
9. The program in Africa gave me a global perspective that most people in the United States don't have	70	30	0	0	0

The costs for students in our course consists of three parts: (a) \$3,100 for tuition, which is the standard tuition rate for a 4-credit summer course on the CWRU campus; (b) \$650 for room and board (single room and all meals); (c) ~\$1,500 for the flight to and from Botswana (the flights are booked directly by the students, and most students travel from their hometowns to Botswana). Thus the total cost for a student is approximately \$5,250. In comparison to taking the same course on the CWRU campus during the eight-week summer session, the cost of the flight to Botswana is largely offset by the much-higher room and board costs at CWRU (over eight weeks). The tuition income from the course generated a surplus of funds after covering all course expenses (salaries and travel for two instructors and a teaching assistant from CWRU, all activities including a three-day safari excursion, and local costs at UB).

We realize that this type of approach cannot become the general solution to the inadequacies in engineering education due to "scale-up" issues. At CWRU, approximately 400 students take this core course every year, and it would not be possible to teach them all with the approach we describe here. We believe this is the only real shortcoming of the approach. Nevertheless, our approach can provide a great (and memorable) impact on a smaller scale.

ACKNOWLEDGMENT

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REFERENCES

1. Rugarcia, A., R.M. Felder, D.R. Woods, and J.E. Stice, "The Future of Engineering Education I. A Vision for a New Century," *Chem. Eng. Ed.*, **34**(1), 16 (2000)
2. Hake, R.R., "Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses," *Am. J. Phys.*, **66**, 64 (1998)
3. Felder, R.M., G.N. Felder, and E.J. Dietz, "A Longitudinal Study of Engineering Student Performance and RetentionV. Comparisons with Traditionally Taught Students," *J. Eng. Ed.*, **87**, 469 (1998)
4. Kolb, D.A., *Experiential Learning: Experience as the Source of Learning and Development*, Englewood Cliffs, NJ, Prentice-Hall (1984)
5. Kolb, D.A., R.E. Boyatzis, and C. Mainemelis, "Experiential Learning Theory: Previous Research and New Directions," in R.J. Sternberg and L.F. Zhang (Eds.), *Perspectives on Cognitive, Learning, and Thinking Styles*, Lawrence Erlbaum, Prentice-Hall, NJ (2000)
6. Kolb, D.A., I.M. Rubin, and J.M. McIntyre, *Instructors Manual, Organizational Psychology: An Experiential Approach to Organizational Behavior*, Prentice-Hall, NJ (1984)
7. van Scyoc, L.J., and J. Gleason, "Traditional or Intensive Course Lengths? A Comparison of Outcomes in Economics Learning," *J. Econ. Ed.*, **24**, 15 (1993)
8. Burton, S., and P.L. Nesbit, "Block or Traditional? An Analysis of Student Choice of Teaching Format," *J. Management & Organization*, **14**, 4 (2008)
9. Davies, W.M., "Intensive Teaching Formats: A Review," *Issues In Educational Research,* **16**, 1 (2006)
10. Cengel, Y.A., J.H. Turner, and R.M. Cimbala, *Fundamentals of Thermal-Fluid Sciences*, 3rd ed., McGraw Hill (2008)
11. "Research on Sustainable Energy for sub-Saharan Africa," an International Research Experiences for Students program funded by the National Science Foundation
12. Rives, C., and D.J. Lacks, "Teaching Process Control With a Numerical Approach Based on Spreadsheets," *Chem. Eng. Ed.*, **36**(4), 242 (2002)
13. Etuk, S.E., I.O. Akpabio, and E.M. Udoh, "Comparison of the Thermal Properties of Clay Samples as Potential Walling Material for Naturally Cooled Building Design," *J. Environ. Sci.*, **15**, 65 (2003)
14. <http://www.bpc.bw/doc/power_tariff_leaflet_eng.pdf>
15. Stark, A., J.M. Peralta, and L. Arendse, "Botswana: The World's Largest Diamond Producer By Value," *Eng. Mining J.*, May 2007, 70 (2007)
16. "Jwaneng—the de Beers Group," <http://www.debeersgroup.com/Exploration-and-mining/Mining-operations/Jwaneng/>
17. Rudnick, R.L., W.F. McDonough, and R.J. O'Connell, "Thermal Structure, Thickness and Composition of Continental Lithosphere," *Chem. Geol.*, **145**, 395 (1998)
18. "Botswana," U.S. Department of State, 4/18/2011, <http://www.state.gov/r/pa/ei/bgn/1830.htm> ❒

TOWARDS A SUSTAINABLE APPROACH TO NANOTECHNOLOGY

by Integrating Life Cycle Assessment into the Undergraduate Engineering Curriculum

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Nanotechnology is poised to become a critical driver of economic growth and development for the early 21st century. It emerges from the physical, chemical, biological, and engineering sciences, where novel techniques are being developed to probe and manipulate single atoms and molecules. At a worldwide scale, most scientists and engineers are now confident that nanoscience and nanotechnology will revolutionize medical, industrial, agricultural, and environmental research.

Because of the expected impact of nanotechnology, aspects of the field are being actively incorporated into undergraduate curricula at various colleges and universities. Strategies employed in the integration of nanotechnology range from incorporation of modules on nanotechnology into existing courses[1,2] and development of new courses[3,4] to establishment of nanotechnology concentration areas within traditional engineering programs[5] and even creation of nanotechnology departments offering degrees in nano-engineering.[6,7]

Most individual courses on nanotechnology focus on manufacturing and application aspects of nanotechnology, while its environmental impacts are either discussed very briefly or not at all. It is increasingly recognized, however, that the development of nanotechnology should be accompanied by parallel efforts to investigate its potential health and environmental effects.[8] Although research on the health and environmental impacts of engineered nanomaterials (ENMs) is still in its infancy, it is fast growing[9-20] and it is imperative that engineering students are exposed to its most current findings.

Impacts of nanotechnology on the environment and health are discussed in comprehensive nanotechnology programs, such as the Nanotechnology Processes track offered by the Chemical Engineering Department at the Oregon State University[5] and the NanoEngineering B.S. program offered by the Department of Nanotechnology at UC San Diego.[6] Participation in these programs requires a long-term commitment from the students and it would be desirable to offer

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a single course or a short course sequence that would expose interested students to manufacturing and application of ENMs, as well as their environmental impact.

To meet this objective, we developed a sequence of two courses that introduce engineering students to different life-cycle stages of ENMs. The courses were offered in the Fall 2008 and Spring 2009 semesters and provided students with a solid foundation of nanoscale science and technology as well as the anticipated environmental challenges associated with their development. The ultimate goal of these courses, however, is to prepare the undergraduate engineer to not only recognize the need but also to be able to design nanomaterials into commercial products with the environment and public health in mind.

In these courses, the environmental aspects of nanotechnology are introduced using the life-cycle assessment (LCA) framework. LCA is a systematic method of assessing the environmental and health impacts of product systems and services, accounting for the emissions and resource uses during the extraction and processing of raw materials and the design, production, distribution, use, reuse, recycle, and disposal of a product or function.[21-24] The LCA approach includes the following steps:

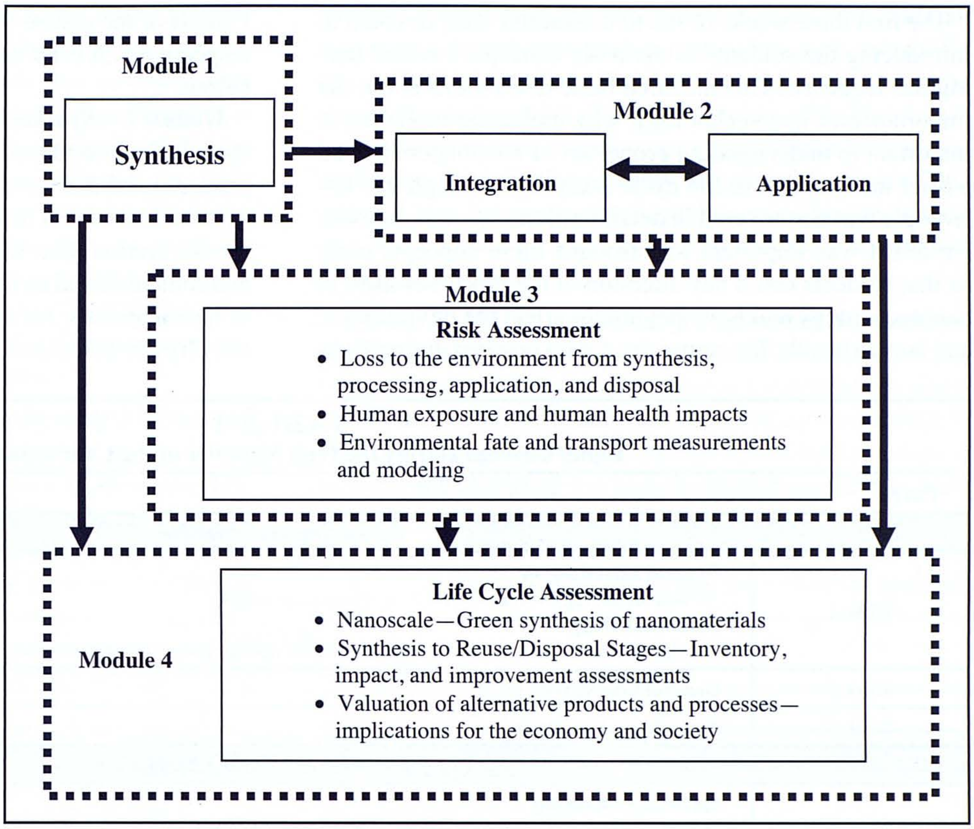


Figure 1. *Conceptual model for the development of learning materials. Module 1 focused on the synthesis of ENMs; Module 2 emphasized the integration and application of ENMs; Module 3 dealt with the environmental and health risks (i.e., exposure, toxicity, fate, and transport); and Module 4 defined the life cycle assessment (LCA) framework for the developed courses.*

- *Scoping and goal definition (establishing the boundaries and objectives of the model),*
- *Inventory analysis (acquiring necessary inputs and outputs),*
- *Impact assessment (computation of the environmental and health effects),*
- *Improvement analysis (determination of the sensitivity of the variables in the model on the impacts and assessment of model robustness), and*
- *Valuation and decision-making (interpreting the results transparently).*

The U.S. EPA recently expressed the need for LCA in the design stage of nanomaterials[25] and many corporations and non-government organizations are following suit.[26] Introducing a life-cycle view of ENMs into the undergraduate curriculum allows students to become exposed to an environmentally conscious design, environmental literacy, and the beyond-the-plant aspects of this new technology just before they enter the job market or graduate school. Although LCA was incorporated into some chemical engineering courses, such as the Heat Transfer course,[27,28] to the best of our knowledge, the LCA framework has not been applied to any courses on nanotechnology.

COURSE DESCRIPTION

Figure 1 shows the organization of the course sequence. The sequence is focused on four conceptual modules: (1) Synthesis of nanomaterials; (2) Integration of nanomaterials and their applications; (3) Risk assessment; and (4) Life cycle assessment. The first semester (Part I) primarily covered the concepts in module 1 and the integration aspects of module 2. The goal of the first semester was to provide students with the scientific foundation of nanomaterial properties and the forces that act on nanoparticles. The second semester consisted of the remaining modules, which emphasized environmental and health implications of nanotechnology, as well as an understanding of LCA approaches and sustainable development of this emerging technology. More importantly, the LCA component pulled together the different course components by modeling the impacts from the entire life cycle.

The first three weeks of the first semester were devoted to introducing the students to the basic concepts covered during the sequence. This included basic discussions about the importance of nanotechnology, why molecular modeling is important to understanding properties of nanomaterials, and a brief introduction to life cycle analysis. Although this latter topic was not covered in detail until the second semester, we felt it was important to introduce these concepts early so that students could pay attention to the processes used in nanotechnology and how they might affect the environment and human health. The remaining topics covered during Parts I and II of the course sequence are shown in Tables 1 and 2, respectively. A brief description of each module is provided below.

Module 1—Synthesis of Engineered Nanomaterials: This module first introduced students to the unique size-dependent properties of nanomaterials and their qualitative difference from bulk materials in the *Physiochemical & Modeling Background section*. The students were introduced to experimental and computational techniques for characterizing the properties of nanomaterials. An emphasis was placed on understanding the physics associated with the materials' properties. Once

TABLE 1
Topics Covered During the First Semester of the Course Sequence

Part I	
	Course Sequence Overview
Week 1	**General Introduction** • Nanotechnology within life cycle assessment principles **Nanotechnology** • Why nanotechnology • Length scales • Bottom-up/top-down • Characterization
Week 2	**General Concepts of LCA**
Week 3	**Toxicological methods**
	Physicochemical & Modeling Background
Week 4	**Molecular Modeling** • Equations of motion-continuum vs. molecular models • Potential functions • Types of intermolecular and interatomic interactions
Week 5	**Analysis of Simulations and Overcoming Timescale Limitations** • Probability distributions and correlation functions • Potential of mean force (PMF) • Methods for calculation of PMF
Week 6	**Interactions Between Particles in Solution** • Van der Waals and Electrostatic Interactions • DLVO Theory • Solvation and Steric Forces
Week 7	**Introduction to Quantum Mechanics** • Photoelectric effect • Wave-particle duality • Schrödinger equation • Particle in a well
Week 8	**Solid State Physics** • Confinement effects • Quantum wells, wires, and dots • Semiconductors • Band structure
Week 9	**Optical Properties** • Bandgap • Exciton • Emission spectra
	Synthesis of Nanoengineered Materials
Week 10	**Surfactant Self-assembly** • Thermodynamics • Packing considerations • Preparation of templates • Relevance to biomembranes
Week 11	**Nanoparticle Growth** • Desired traits • Thermo/kinetic approaches • Aerosol • Microemulsion • Templates • Sol-gel • Arrested growth
Week 12	**Nucleation and Growth** • Chemical potential • Phase diagrams • Supersaturation • Homogeneous nucleation • Heterogeneous nucleation • Nucleation of crystals • Nucleation rate • Ostwald Ripening
Week 13	**Nanowire Growth** • VLS • Templates • Heterostructures
Week 14	**Carbon Nanotubes** • Relationship between geometric structure and electronic properties of nanotubes • Growth methods • Functionalization
	Integrating Nanomaterials
Week 15	**Dispersion** • Stability **Separations** • Purification • Size fractionation • Separation of carbon nanotubes
Week 16	**Nanomaterial Properties and Toxicity Implications**

the students had an adequate understanding of the physio-chemical properties, the *Synthesis of Nanomaterials* for use in engineered devices and applications was covered. This section built upon the fundamental knowledge covered in chemistry and physics courses as well as strengthening the students' knowledge of reaction kinetics, diffusion, and fluid and heat flow in their application to problems unique to the synthesis of nanomaterials. New concepts, such as crystallization, were also introduced. The students were introduced to a wide variety of nano-sized building blocks, including micelles and microemulsions, nanoparticles, and 1-D nanostructures, such as nanowires and carbon nanotubes.

Module 2—Integration and Application of Engineered Nanomaterials: This module focused on the manipulation and integration of ENMs into devices and applications. The first section, *Integrating Nanomaterials*, strengthened the student's knowledge on separations, diffusion, and self-assembly processes while introducing the new concepts of interfacial phenomena, dispersion, and colloids, which play an important role in the integration of nanomaterials into useful devices and applications. Students were later exposed to the nanotechnology potential in a wide variety of fields, including microelectronics, manufacturing, information technology, healthcare, biotechnology, energy, and materials science. This material was covered in the *Applications of Nanomaterials and Implications for Human Health and the Environment* section (see Table 2).

Module 3—Risk Assessment of Engineered Nanomaterials: Understanding the effects of exposure to nanomaterials and their environmental fate and transport is fundamental in determining the overall environmental impact of nanotechnology.[8] This is challenging, however, as the industrial landscape is growing and changing very rapidly. In addition, ENMs could enter the environment from different stages along their life cycle. The *Potential Fate & Transport of Nanomaterials* in the Environment section of Module 3 was focused on the potential

TABLE 2
Topics Covered During the Second Semester of the Course Sequence

Part II	
	Potential Fate & Transport of Nanomaterials in the Environment
Week 1	**Environmental Pollution and Concepts in Pollutant Behavior** • Introduction • Connectedness of the geospheres and fate of pollutants
Week 2	**Physicochemical Parameters** • Aqueous solubility and factors influencing solubility • Phase partitioning • Physical/chemical interactions
Week 3	**Nanoparticle Transport in Porous Media**
Weeks 4 & 5	**Properties of Materials and Environmental Fate** • Transport in aqueous and soil systems • Pollutant interactions with cell membranes • Predictive approaches/tools • Bioaccumulation, biotransformation, bioepuration • Food transfer and biomagnification
Week 6	**Framework for Environmental Toxicology and Toxicity of Nanomaterials** • Toxicity testing • Typical toxicity methods • Routes of exposure and mode of action
Weeks 7 & 8	**Possible Mechanisms of Nanoparticle Toxicity** • Toxicity of nanomaterial synthesis • Physicochemical characteristics of nanomaterial and potential toxicity • Predictive approaches/tools • Green nanomaterial manufacturing and toxicity elimination
	Applications of Nanomaterials and Implications for Human Health and the Environment
Week 9	**Nanocomposites** • Dispersion • Polymerization (carbon nanotubes) **Thermoelectrics** • Nanowire- and quantum-dot based nanomaterials **Solar Cells** • CdSe hybrid • Dye-sensitized solar cells (TiO_2, ZnO) **Medical Applications** • Gold nanoshells • Carbon nanotubes • Sensors **Green Design and Environmental Implications**
	Life Cycle Assessment (LCA): Overview and Methodology
Weeks 10 – 12	**Metrics of Sustainability** **Stages of LCA** • Inventory analysis • Impact analysis • Sensitivity analysis **Case Studies**
Weeks 13 & 14	**Modeling Approaches** • Manual Approaches • Software (Simapro, TRACI, GaBi, Athena, Umberto) • Limitations of Modeling
Weeks 15 & 16	**LCA Application to Nanotechnology** • Nanotechnology-related Case Studies • Closing the Loop • Defining "Sustainable Nanotechnology" • Nanomaterial design and modeling

impacts of ENMs on the environment, their environmental mobility, reactivity, bioavailability, and toxicity. Specifically, the available experimental models to characterize the toxic potentials of ultrafine particles and the fate of nanomaterials after their intentional and/or non-intentional introduction to soils and aquatic systems were discussed. This subsection emphasized both the dispersal and ability of nanomaterials to move from points of release to far away locations and to encounter living organisms. The physicochemical properties that make ENMs commercially attractive were also evaluated for their potential risks to environmental and human health. Finally, the students were introduced to the lack of adequate experimental data to understand the nano-toxicological effects and how molecular modeling can play an important role in advancing our knowledge of these effects.

Module 4—Life Cycle Assessment (LCA): This module taught students the fundamentals and methodology of LCA construction with a specific emphasis on the synthesis, processing, application, and disposal life-cycle stages of ENMs addressed in modules 1 – 3. The introductory material educated students in LCA development and reinforced the connection between the synthesis, processing, application, and disposal stages with potential environmental concerns. Students also learned how impacts are calculated using various methods, including the Environmental Risk Evaluation method presented by Allen and Shonnard,[29] the Argonne National Laboratory GREET model that deals with transportation impacts,[30] and other methods included in the modeling software discussed below. All steps of LCA recommended in the ISO 14040 guidelines[21] were thoroughly discussed with case studies of existing LCAs, along with development of an LCA framework to compare traditional processes with alternative green nanotechnologies reported in the recent literature (*e.g.*, see References 31 and 32). Students were then introduced to various LCA modeling software packages, including SimaPro (Pré Associates, The Netherlands) and TRACI (developed by the U.S. EPA and available as freeware from the agency's website, <www.epa.gov>). As a final section in this module, the implications of nanotechnology were discussed from a life cycle perspective. As data from many stages of the life cycle of nanomaterials were limited and not all impacts of these materials can be predicted, the students were challenged to construct wise approaches for handling these technologies throughout their life cycle and for developing wise policies and regulations.

COURSE IMPLEMENTATION

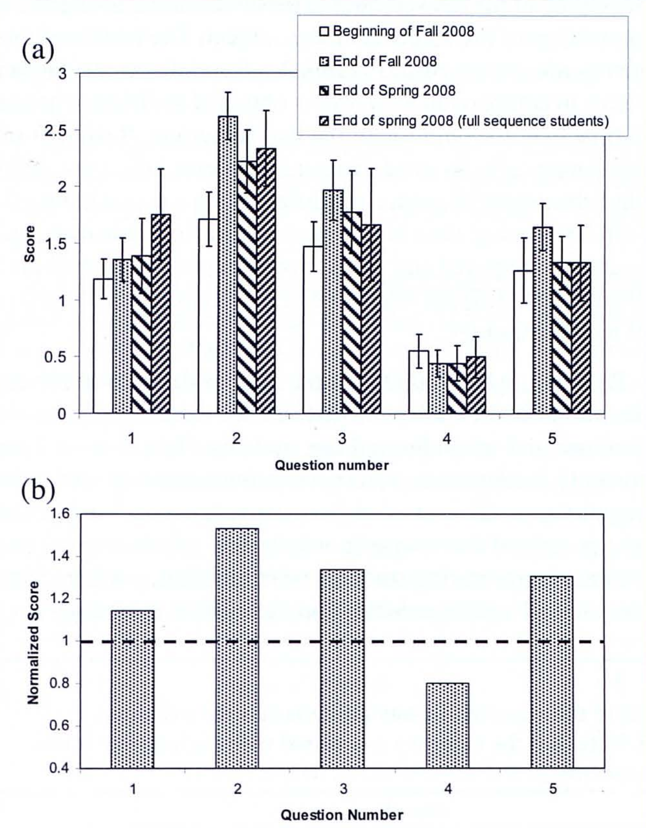
The course sequence was offered during the 2008–2009 academic year. Course materials were developed to target senior undergraduate students, because, at this stage in the curriculum, engineering students from all disciplines have been exposed to the necessary fundamental concepts in chemistry, physics, thermodynamics, heat transfer, transport phenomena, mechanics, numerical methods, and computer programming. Therefore, developed course modules were designed to build upon these concepts and expand students' mastery of these subjects into this emerging discipline. Although the developed courses were designed for undergraduate students, interested graduate students were also allowed to enroll. A textbook on basic nanotechnology principles[33] was required for Part I while research articles and case studies were used for Part II.

All four instructors attended the first two weeks of the semester to emphasize the course's framework and the connectedness of the different modules. After this general introduction section, each of the two developed courses was taught primarily by two instructors (*e.g.*, Ziegler and Kopelevich for Part I and Bonzongo and Lindner for Part II). The instructors attended lectures during both semesters, except when lecture times conflicted with other professional events. A student-centered teaching approach was used in both courses. This method varies from the traditional approach that relies on the belief that ideas can be successfully transferred by simply telling them to the students. The student-centered approach is based on the premise that students have better retention when they are actively engaged and the approach relies on self-managed teams that work collectively on Process-Oriented Guided-Inquiry Learning (POGIL) activities. The POGIL approach helps students develop teamwork, communication, and management skills while engaging in critical thinking and assessment as they sharpen their problem-solving skills. This focus on soft skills is particularly effective at educating students on the higher-order cognitive tasks of the Bloom taxonomy.[34]

The following POGIL activities were incorporated into the course sequence:

Computational Experiments to Explore Nanoscale Phenomena. These phenomena are not familiar to the students from everyday experience or from the core chemical and environmental engineering classes that traditionally focus on macroscopic phenomena. In order to provide students a hands-on experience with nanoscale systems, we introduced molecular dynamics simulations (MD) into Part I of the course sequence. MD simulations were performed using the Molecular Workbench software package.[35] This open-source package was specifically designed for educational purposes. It enables students to start performing MD simulations with minimum background. It employs a simplified molecular model that nevertheless retains relevant physics. This enables students to (i) perform simulations on their personal computers within a reasonable amount of time and (ii) explore effects of various molecular properties (such as charge, degree of hydrophobicity, etc.) without being overwhelmed with details of more accurate models. The students performed molecular dynamics simulations to investigate nanoparticle nucleation, interactions between colloidal nanoparticles, and self-assembly in solution.

Open-ended Design Problems. Several open-ended assign-



A1. What is special about the nanosize of particles?
A2. What types of forces dominate at nanoscale? List as many as you can.
A3. What new challenges arise in manufacturing of nanomaterials?
A4. What are the main differences between macro- and nano-scale transport processes?
A5. What are the benefits and limitations of modeling versus experimental approaches?

Figure 2. *(**a.**) Average scores corresponding to each question over the two semesters. Answers to questions were lists of various nanomaterial properties. Therefore, the grading scale was 1 point for every correct item on the list. Here and in the following plots, "full sequence students" refers to the students who have taken both semesters of this class. (**b.**) Score of each question at the end of the fall semester normalized to the beginning of the sequence.*

ments asked students to design a novel device or an experiment. For example, in order to reinforce students' knowledge of interparticle interactions, the students were asked to investigate possible applications of nanorod electrodes as computer memory elements and nanorelays. In another assignment, the students were asked to design an experiment to investigate production of the reactive oxygen species (ROS) by fullerene nanoparticles and the ROS effects on living organisms.

Critical Literature Reviews and In-Class Discussions. In Part I of the course sequence, the students were asked to perform a critical review, write a report, and make a presentation on various methods of nanoparticle synthesis. The synthesis aspects discussed by the students included raw materials, physical conditions, quality of the final product, and potential health and environmental hazards. In Part II of the course sequence, the students prepared and delivered presentations based on peer-reviewed papers related to LCA of nanomaterials. Some of the papers assigned by the instructor did not address LCA directly and the students were asked to identify and comment on aspects of the paper relevant to LCA. We also organized an in-class discussion regarding viability of nanobots following the Smalley-Drexler debate.[36] The discussion was guided with specific questions that forced the students to argue about the scientific merits of the ideas.

ASSESSMENT METHODS

While no one single effective tool for assessing learning and/or evaluating innovations in higher education exists, a combination of several methods can be used to capture data from both cognitive and affective domains and provide unique information that bridges that of traditional assessment tools, such as exams, quizzes, and student evaluations. Many of these traditional assessment tools generally cover only a narrow range of course content and are not well suited for assessing higher-level understanding and skills. Ideally, an efficient assessment tool should provide[37]: (i) formative assessments of student understanding; (ii) reliable, quantifiable data about student understanding; and (iii) data useful to students' cognitive and meta-cognitive growth. In addition, faculty should be able to use such a tool to evaluate their effectiveness and the advantage of additions or changes to existing curricula or programs.

The following two approaches were used to assess the outcomes from the course sequence:

Evaluation via knowledge surveys: Knowledge surveys consisted of numerous items that covered the full breadth of course learning objectives and levels of understanding. Students completed the survey at the beginning of the first 2008 semester and at the end of each semester. Surveys at the beginning of a course provided information on students' background and preparation. During the course, surveys became learning guides for the instructors, helping them make necessary adjustments on both teaching style and exam format/content to improve student learning.

Student course evaluation: In general, the focus of this tool is on whether or not students are satisfied or dissatisfied with the entire course and/or individual modules. While this is useful information, this process can also be used to explore more complex and, perhaps more relevant issues, such as what students are learning, what aspects are more useful, what could be improved, etc.

ASSESSMENT RESULTS

Student enrollment: The two courses attracted a larger number of students than originally expected. We also admitted students who could not commit to the entire sequence of two courses due to graduation and other scheduling conflicts (see below). The latter had a negative impact on the number of students providing feedback on the course sequence as a whole. Further details on student enrollment are provided below.

PART I: Fall 2008 – A total of 19 students registered for the fall course of the sequence. Enrolled students included eight graduate and 11 undergraduate students. The graduate students attracted by this offering were those conducting research on different aspects of nanotechnology and all were environmental engineering majors. The undergraduate group included four students from environmental engineering and seven from chemical engineering. The first survey was administered at the beginning of the fall semester to probe the initial background knowledge of the students on the subject. The results of this survey are presented in Figures 2 – 5 and discussed further below in comparison with results obtained at different points in time over the duration of the two semesters. Results from this survey also showed that some students could not complete the course sequence for different reasons, including (i) Fall 2008 being their last semester prior to graduation, (ii) course not required and would not fit in pre-established plan of study, and (iii) not interested in the environmental aspects of nanotechnology.

PART II: Spring 2009 – At the start of the second semester, a total of 12 students registered for the course, with six graduate and six undergraduate students. Only nine of these students participated in surveys administered at either the beginning or the end of the semester, however. Unlike the first portion of the course in which only environmental and chemical engineering students were enrolled, students from electrical (1 undergraduate) and agriculture & biological (1

TABLE 3
Students were asked to assess their own ability to address each of these aspects in solving unstructured problems. Students' responses to these questions are summarized in Figure 5. Note that the category associated with each question was not given to the students.

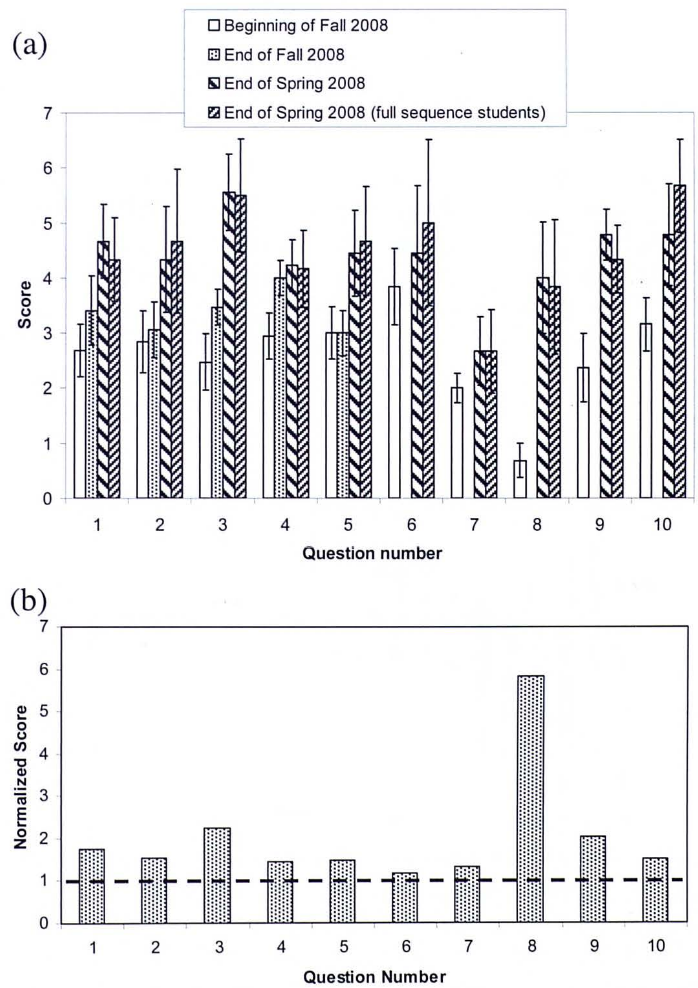
Question #	Categories	Questions
D1	Need recognition	State the needs of the problem in clear and explicit terms
D2	Need recognition	Recognize the needs to be addressed by the problem
D3	Problem definition	List the performance requirements that a solution must satisfy
D4	Problem definition	Establish criteria for evaluating the quality of a solution
D5	Planning	Develop a solution strategy given a model of the design process
D6	Planning	Divide a problem into manageable components or tasks
D7	Information gathering	Identify the knowledge and resources needed to develop a solution
D8	Information gathering	Ask probing questions to clarify facts, concepts, or relationships
D9	Idea generation	Describe procedures or techniques to search for and generate solutions
D10	Idea generation	Generate possible alternative solutions
D11	Modeling	Select a mathematical model that can be used to characterize a solution
D12	Evaluation	Identify the pros and cons of possible solutions
D13	Evaluation	Compare a set of solution alternatives using a specified set of criteria
D14	Feasibility analysis	Analyze the feasibility of a solution
D15	Selection	Select a solution that best satisfies the problem objectives
D16	Documentation	Document your solution process
D17	Communication	Understand the different roles and responsibilities of being an effective member in a team
D18	Communication	Resolve conflict and reach agreement in a group
D19	Communication	Identify the characteristics of effective communication
D20	Iteration	Recognize when changes to the original understanding of the problem may be necessary
D21	Iteration	Suggest modifications or improvements to a final solution
D22	Iteration	Develop strategies for monitoring and evaluating progress
D23	Implementation	Build a prototype or final solution

graduate) engineering departments registered for the course as well. Four out of nine students who participated in the surveys during the spring semester (Part II) did not take Part I of the course sequence.

Course objectives: Questions related to the general aspects of the course sequence and students' responses at various points during the sequence are shown in Figures 2 – 5 and Table 3.

A. Properties of engineered nanomaterials and modeling of nanoscale processes (Figure 2, page 123) – These topics were covered in Part I of the course sequence. Therefore, the students who took only Part II had limited knowledge of these topics. Hence, we focus on comparison of the students' knowledge at the beginning and the end of the fall semester. With the exception of question A4 (differences between macro- and nano-scale transport processes), the results shown in Figure 2a indicate clear knowledge improvement by the end of the first semester. The most significant improvements were observed in the students' understanding of the forces acting on nanostructures and manufacturing challenges, as seen in Figure 2b.

B. Biological implications on engineered nanomaterials (Figure 3) – For this nanotoxicity component, 10 questions were asked. Questions B6-B10, however, were limited to surveys administered only at the beginning of the Fall 2008 semester and the end of the Spring 2009 semester (full course sequence). Questions B1-B5 were asked in all four surveys. The corresponding average scores graded on a 0 to 10 scale are shown in Figure 3a. Overall, an increasing trend in knowledge improvement was observed from the start to the end of the fall semester. The observed improvement in questions B1, B3, and B4 was related primarily to the introductory section of the course with subsequent reinforcement of these ideas during the discussion of ENM synthesis and integration. In contrast, answers to questions B2 and B5, which were not covered in the first course of the sequence, showed no knowledge improvement. When scores obtained at the end of spring semester are compared to scores recorded at the beginning of



B1. How would one combine chemical synthesis, modeling, & toxicology to produce green ENMs?

B2. Discuss very briefly the potential for the release of engineered nanomaterials to different environmental compartments as they are processed from cradle to grave.

B3. What properties of ENMs may affect their toxic effects? Name as many properties as you can.

B4. Based on the size and physicochemical properties of ENMs, could you list potential negative impacts of ENMs on the environment?

B5. Why do we need to assess the environmental and health impacts of ENMs separately from their bulk counterparts – In other words, why can't we simply use knowledge of toxicity of bulk materials to predict the toxicity of ENMs?

B6. What is environmental chemodynamics and how does it apply to ENMs?

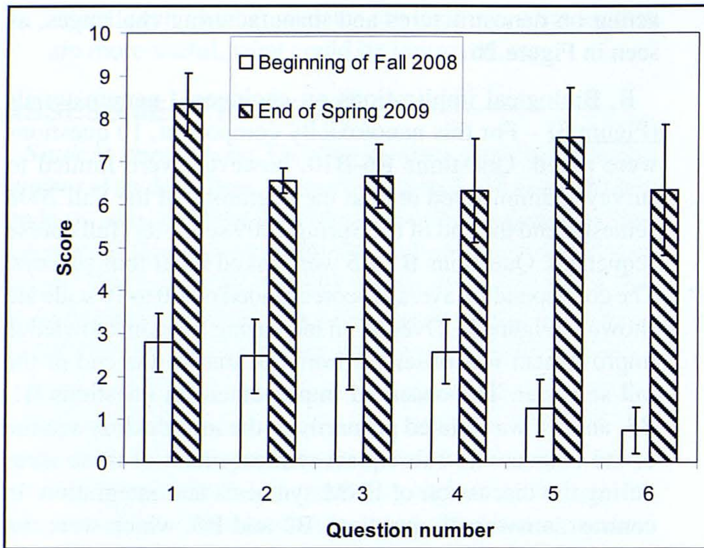
B7. What types of transformations ENMs might undergo if released to the environment?

B8. Solvent partitioning has been used to predict the potential for bioaccumulation and toxicity of xenobiotics. What difficulties would you anticipate from the use of solvent/water distribution in assessing the potential for bioavailability and toxicity of ENMs?

B9. What key factors affect toxicity measurements? Name as many as you can.

B10. What could be the potential targets of ENMs in (i) animal, (ii) plant, and (iii) microbial cells? Explain.

***Figure 3.** (**a.**) Average scores for answers related to the toxicity aspects of engineered nanomaterials. The grading scale for these questions is 0 to 10. (**b.**) Score of each question at the end of the spring semester normalized to the beginning of the sequence.*



C1. Name the three stages of life cycle assessment (LCA) development.
C2. Select a specific nanomaterial and list the life cycle stages of this ENM.
C3. Identify, even in general terms, the relevant inputs and outputs of each life cycle stage.
C4. Identify the environmental impacts of interest and defend your selection.
C5. Identify the primary uncertainty of your LCA model for your selected nanomaterial.
C6. What would be the best software to use in performing the LCA of your ENM? Explain why.

Figure 4. *Average scores for answers on LCA questions. The grading scale for these questions is 0 to 10.*

fall semester, a significant knowledge improvement is observed as shown in Figure 3b.

C. Life-cycle assessment (Figure 4) – This section of the course sequence offered the opportunity for students to discuss the implications of nanotechnology from a life cycle perspective. Students considered the ethics of nanomaterials use, regulatory needs, international policies on nanomaterial use, and best practices for corporations in making decisions concerning nano-products, with the ultimate challenge of how to produce high-performance materials that pose no risk to the environment or public health. Only questions emphasizing knowledge of the basic steps of the LCA approach and tools used in LCA studies were asked in the survey administered at the beginning of the fall semester and at the end of the spring semester, however. These questions and the average scores corresponding to correct answers (graded on a 0 to 10 scale) are shown in Figure 4.

Unlike most physicochemical and biological concepts that are familiar to engineering students, LCA was a rather new topic to students enrolled in this sequence of courses. In fact, besides the few hours of LCA lectures as part of the general introduction during fall semester, most students enrolled in the course had no prior background in life cycle assessment. Therefore, they did not know how this discipline could be used to study the environmental implications of materials from cradle to grave. Accordingly, students' answers to the above questions were simply mere speculations and best guesses at the beginning of the fall semester. Answers to the same questions at the end of the course sequence (Spring 2009) show a significant knowledge im-

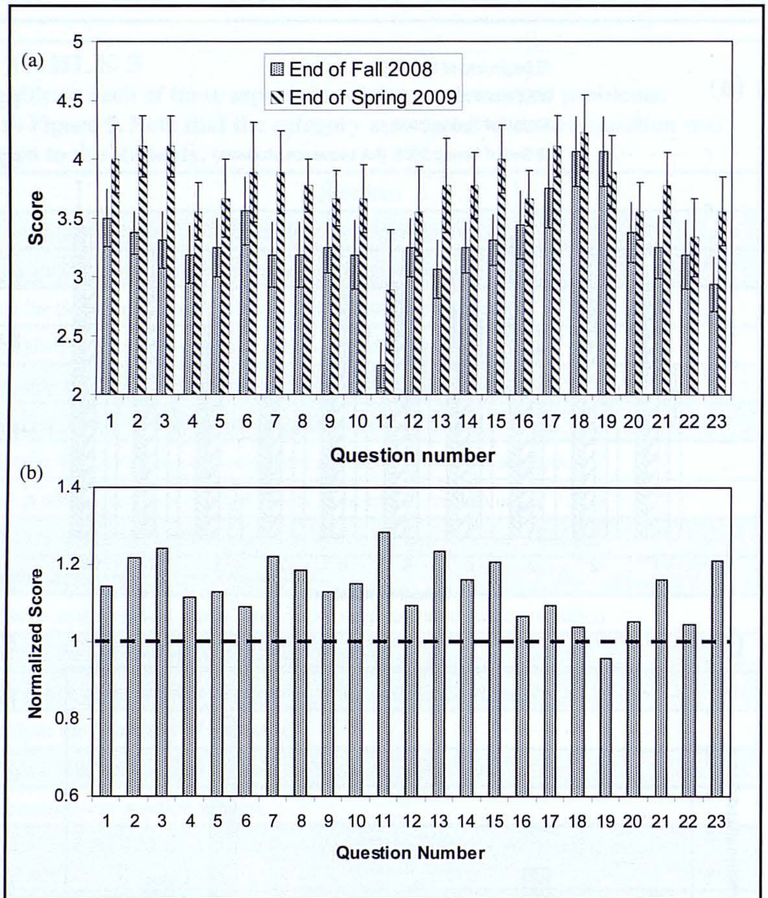


Figure 5. *(**a.**) Average scores for the survey on solving unstructured problems. Since no significant differences between the beginning and end of the fall semester were observed, only the survey results for the end of the fall semester are shown in this chart. The grading scale for these questions is 1 to 5. The questions are listed in Table 3. (**b.**) Score of each question at the end of the spring semester normalized to the beginning of the sequence.*

TABLE 4
Student comments taken from surveys and teaching evaluations and the end of the course sequence.

Example comments:	• *Concepts covered in this class will be used in future research endeavors (9 votes out of 9)*
	• *Have been inspired to dig deeper into the concepts learned in this course sequence (9 votes out of 9)*
	• *The overall content of the class can be considered "Good" (5 votes) to "Very Good" (4 votes).*
	• *"I learned the most from the take home tests and presentations. These were excellent ways to understand the materials. But this was a great class! I learned a lot and am very glad to have taken it."*
Example recommendations:	• *"The instructors need to improve the integration of course materials to make it more concise and fluid, especially in Part I of the course. Make sure that the big picture is not lost."*
	• *"Part I of the course needs room for a learning curve on homework sets."*
	• *"A better integration of environmental and chemical concepts is needed. This could be achieved by a 'step-up' program, which provides a quick overview of the relevant concepts to build a common foundation for all, regardless of student initial background."*
	• *"Need to have more class resources (books, etc.). The textbook used in Part I should be replaced."*

provement, however. This net separation between the fall and spring can be explained by at least two factors. First, as stated above, most students enrolled in this course had very little to no prior knowledge of LCA. Second, this portion of the course was well-received by students for its integrative capacity, and the group projects allowed for interactive and hands-on activities that developed problem-solving skills.

D. Solving unstructured problems (Figure 5) – A total of 23 questions was asked about various aspects of working on unstructured problems in groups. The questions were asked at the beginning of the Fall 2008 semester and at the end of the fall and spring semesters. The questions are divided into various design attributes, as described by Safoutin, et al.[38] The questions are shown in Table 3 and the corresponding average scores graded on a 1 to 5 scale are shown in Figure 5a, where 1 = Poor, 2 = Fair, 3 = Good, 4 = Very good, and 5 = Excellent.

The results show no significant differences between the beginning and end of the fall semester (not shown). This might have been expected since the unstructured group activities were largely part of the Spring 2009 semester. Figure 5 shows comparative trends of students' scores with regard to their ability to adequately address various attributes of solving unstructured problems at the end of each of the two semesters. Overall, the students felt better prepared to handle unstructured problems at the end of the sequence (Spring 2009). As shown in Figure 5b, the largest improvements are observed in the need recognition (D2), problem definition (D3), information gathering (D7 – D8), modeling (D11), evaluation (D13), selection (D15), and implementation (D23) attributes. The smallest changes were observed in the documentation (D16), communication (D17 – D19), and iteration (D20, D22) processes, although the students were already confident in their ability to communicate. Interestingly, the students were clearly not confident with modeling a solution to a problem (D11) in the beginning. The students were more confident at the end of the sequence but this attribute of solving unstructured problems clearly remains lower than other attributes.

CONCLUDING REMARKS

The ultimate goal of this course development was to increase the awareness of engineering undergraduates to the life cycle stages of nanomaterials and of the importance of considering engineering design impact on the environment and public health during the design stage of processes and products incorporating nanotechnologies. The initial offering of the two courses led us to believe that our comprehensive approach to incorporating a life cycle assessment of nanotechnology into the engineering undergraduate curriculum has been well received by students. Table 4 shows some example comments and recommendations taken from the surveys and teaching evaluations during the spring semester. The students clearly enjoyed the topics covered in the course sequence. Students sometimes had difficulties making connections between the various parts of the course sequence, however. This sentiment is probably best reflected in the recommendation for a "step-up" program, which would provide tutorial sessions in areas where students had deficiencies in the course. For example, environmental engineering students would likely benefit from tutorials on transport, kinetics, and calculus while chemical engineering students may require sessions on analytical chemistry and biology. The instructors did find it difficult at times to balance the depth of the course material to the varied background of students from different disciplines. Therefore, we would recommend that a "step-up" program be included to establish better baseline knowledge for all students.

Further details on this course sequence, including slides for lectures, references to supplemental literature, and assignments, can be found at the course website, <http://www.che.ufl.edu/courses/SustainableNanotechnology/>.

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REFERENCES

1. Allam, Y., D.L. Tomasko, B. Trott, P. Schlosser, Y. Yang, T.M. Wilson, and J. Merrill, "Lab-on-a- chip Design-Build Project with a Nanotechnology Component in a Freshman Engineering Course," *Chem. Eng. Ed.*, **42**(4), 185 (2008)
2. Heitsch, A.T., J.G. Ekerdt, and B.A. Korgel, "NANOLAB at the Uni-

versity of Texas at Austin: A Model for Interdisciplinary Undergraduate Science and Engineering Education," *Chem. Eng. Ed.*, **43**(3), 225 (2009)
3. Smith, T.F., D. Baah, J. Bradley, M. Sidler, R. Hall, T. Daughtrey, and C. Curtis, "A Synchronous Distance Education Course for Non-Scientists Coordinated Among Three Universities," *Chem. Eng. Ed.*, **44**(1), 30 (2010)
4. Smith, Y.R., A. Fuchs, and M. Meyyappan, "Industrial Scale Synthesis of Carbon Nanotubes Via Fluidized Bed Chemical Vapor Deposition: A Senior Design Project," *Chem. Eng. Ed.*, **44**(2), 166 (2010)
5. Koretsky, M.D., A. Yokochi, and S. Kimura, "A Nanotechnology Processes Option in Chemical Engineering," *Chem. Eng. Ed.*, **43**(4), 265 (2009)
6. University of California, San Diego, Department of Nanoengineering, <http://ne.ucsd.edu> (2011).
7. University of Waterloo, Department of Nanotechnology Engineering, <http://www.nanotech.uwaterloo.ca> (2011)
8. Guzman, K.A.D., M.R. Taylor, and J.F. Banfield, "Environmental Risks of Nanotechnology: National Nanotechnology Initiative Funding, 2000-2004," *Environ. Sci. Technol.*, **40**(5), 1401 (2006)
9. Hurt, R.H., M. Monthioux, and A. Kane, "Toxicology of Carbon Nanomaterials: Status, Trends, and Perspectives on the Special Issue," *Carbon*, **44**(6), 1028 (2006)
10. Borm, P.J.A., R.P.F. Schins, and C. Albrecht, "Inhaled Particles and Lung Cancer, Part B: Paradigms and Risk Assessment," *Int. J. Cancer*, **110**(1), 3 (2004)
11. Cheng, J.P., E. Flahaut, and S.H. Cheng, "Effect of Carbon Nanotubes on Developing Zebrafish (Danio rerio) Embryos," *Environ. Toxicol. Chem.*, **26**(4), 708 (2007)
12. Davoren, M., E. Herzog, A. Casey, B. Cottineau, G. Chambers, H.J. Byrne, and F.M. Lyng, "In vitro Toxicity Evaluation of Single Walled Carbon Nanotubes on Human A549 Lung Cells," *Toxicol. in Vitro*, **21**(3), 438 (2007)
13. Koyama, S., M. Endo, Y.A. Kim, T. Hayashi, T. Yanagisawa, K. Osaka, H. Koyama, H. Haniu, and N. Kuroiwa, "Role of Systemic T-cells and Histopathological Aspects after Subcutaneous Implantation of Various Carbon Nanotubes in Mice," *Carbon*, **44**(6), 1079 (2006)
14. Oberdorster, G., "Toxicology of Ultrafine Particles: in vivo Studies," *Philos. T. Roy. Soc. A*, **358**(1775), 2719 (2000)
15. Roberts, A.P., A.S. Mount, B. Seda, J. Souther, R. Qiao, S.J. Lin, P.C. Ke, A.M. Rao, and S J. Klaine, "In vivo Biomodification of Lipid-Coated Carbon Nanotubes by Daphnia Magna," *Environ. Sci. Technol.*, **41**(8), 3025 (2007)
16. Smith, C.J., B.J. Shaw, and R.D. Handy, "Toxicity of Single Walled Carbon Nanotubes to Rainbow Trout (Oncorhynchus mykiss): Respiratory Toxicity, Organ Pathologies, and Other Physiological Effects," *Aquat. Toxicol.*, **82**(2), 94 (2007)
17. Templeton, R.C., P.L. Ferguson, K.M. Washburn, W.A. Scrivens, and G.T. Chandler, "Life-Cycle Effects of Single-Walled Carbon Nanotubes (SWNTs) on an Estuarine Meiobenthic Copepod," *Environ. Sci. Technol.*, **40**(23), 7387 (2006)
18. Wick, P., P. Manser, L.K. Limbach, U. Dettlaff-Weglikowska, F. Krumeich, S. Roth, W.J. Stark, and A. Bruinink, "The Degree and Kind Of Agglomeration Affect Carbon Nanotube Cytotoxicity," *Toxicol. Lett.*, **168**(2), 121 (2007)
19. Gao, J., S. Youn, A. Hovsepyan, V.L. Llaneza, Y. Wang, G. Bitton, and J.C.J. Bonzongo, "Dispersion and Toxicity of Selected Manufactured Nanomaterials in Natural River Water Samples: Effects of Water Chemical Composition," *Environ. Sci. Technol.*, **43**(9), 3322 (2009)
20. Griffitt, R.J., J. Luo, J. Gao, J.C. Bonzongo, and D.S. Barber, "Effects of Particle Composition and Species on Toxicity of Metallic Nanomaterials in Aquatic Organisms," *Environ. Toxicol. Chem.*, **27**(9), 1972 (2008)
21. International Organization for Standardization 14040, Environmental Management—Life Cycle Assessment: Principles and Framework, Geneva (1997)
22. Ciambrone, D.F., *Environmental Life Cycle Analysis*, Lewis Publishers, Boca Raton, FL (1997)
23. Graedel, T.E., *Streamlined Life-Cycle Assessment*, Prentice Hall, Upper Saddle River, NJ (1998)
24. Hertwich, E.G., "Life Cycle Approaches to Sustainable Consumption: A Critical Review," *Environ. Sci. Technol.*, **39**(13), 4673 (2005)
5. U.S. Environmental Protection Agency, Nanotechnology White Paper EPA-HQ-ORD-2005-0504 (2005)
26. Thayer, A.M., "Chance of a Lifetime," *Chem. & Eng. News*, **84**, 10 (2006)
27. Flynn, A.M., M.H. Naraghi, and S. Shaefer, "The Greening of a Design-Oriented Heat Transfer Course," *Chem. Eng. Ed.*, **39**(3), 216 (2005)
28. Flynn, A.M., "Assessing the Incorporation of Green Engineering into a Design-Oriented Heat Transfer Course," *Chem. Eng. Ed.*, **39**(4), 320 (2005)
29. Allen, D., and D. Shonnard, *Green Engineering: Environmentally Conscious Design of Chemical Processes*, Prentice-Hall PTR, Englewood Cliffs, CA (2002)
30. Argonne National Laboratory, The greenhouse gases, regulated emissions, and energy use in transportation (GREET) model. Available at <http://greet.es.anl.gov/> (2006)
31. Sweeney, S.F., G.H. Woehrle, and J.E. Hutchison, "Rapid Purification and Size Separation of Gold Nanoparticles Via Diafiltration," *J. Am. Chem. Soc.*, **128**(10), 3190 (2006)
32. Wang, Y.B., Z. Iqbal, and S. Mitra, "Rapidly Functionalized, Water-Dispersed Carbon Nanotubes at High Concentration," *J. Am. Chem. Soc.*, **128**(1), 95 (2006)
33. Rogers, B., S. Pennathur, and J. Adams, *Nanotechnology: Understanding Small Systems*, CRC Press (2008)
34. Bloom, B.S., ed., *Taxonomy of Educational Objectives: The Classification of Educational Goals*, McKay, New York (1956)
35. The Concord Consortium, Molecular Workbench Software Package, available at <http://mw.concord.org/modeler/> (2004)
36. "Point-Counterpoint. Drexler and Smalley Make The Case For and Against 'Molecular Assemblers'," *Chem. & Eng. News*, **81**(48), 37 (2003)
37. Wirth, K.R., D. Perkins, and E. Nuhfer, "Knowledge Surveys: An Ideal Tool For Assessing Learning and For Evaluating Instructional Practices and Curricula," *Geological Society of America, Abstracts with Programs*, **37**(7), 119 (2005)
38. Safoutin, M.J., C.J. Atman, R. Adams, T. Rutar, J.C. Kramlich, and J.L. Fridley, "A Design Attribute Framework For Course Planning and Learning Assessment," *IEEE T. Educ.*, **43**(2), 188 (2000) ❐

AN APPROACH TO HELP DEPARTMENTS MEET THE NEW ABET PROCESS SAFETY REQUIREMENTS

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This paper has two sections: the first provides a brief history of the new ABET process safety requirements; the second describes a SAChE Product that has been prepared to help departments meet and document these process safety requirements through their senior capstone design project. The paper concludes with a summary of how departments can combine SAChE products and the SAChE Safety Certificate Program to effectively teach fundamental process safety awareness to undergraduates.

A BRIEF HISTORY

For the last two decades, industrial and academic process safety experts have been creating products describing many of the fundamental process safety risk-reduction concepts. These products are free to chemical engineering department students and instructors through AIChE's "Safety and Chemical Engineering Education (SAChE)" Program. SAChE was formed in 1992 as AIChE's link between industrial process safety experts in the Center for Chemical Process Safety (CCPS) and universities. The SAChE website contains more than 100 process safety-related products to assist instructors.[1] In addition, SAChE program members also organize faculty workshops that help share best industrial practices with academic instructors.[2]

In 2007, the fatal explosion at the T2 Laboratories, Inc., triggered an investigation by the U.S. Chemical Safety Board (CSB) and resulted in several findings.[3] One of these findings included the following statement:

> *Chemical engineer (part owner) killed because of lack of proper understanding of reactive chemistry hazards and process safety and risk reduction design.*

As a result of their investigation, the CSB recommended to the AIChE:

> *"Work with the Accreditation Board for Engineering and Technology, Inc., (ABET) to add reactive hazard awareness to baccalaureate chemical engineering curricula requirements."*

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TABLE 1
AIChE/SAChE Guidelines for Teaching Safety and Design

1	The graduate must understand the importance of process safety and the resources and commitment required. This should include the important incidents that define process safety, and how these incidents affected the practice of chemical engineering.
2	The graduate must be able to characterize the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards.
3	The graduate must understand and be able to apply concepts of inherently safer design.
4	The graduate must understand how to control and mitigate hazards to prevent accidents. This should include generally accepted management systems, plant procedures, and designs to prevent accidents.
5	The graduate should be familiar with the major regulations that impact the safety of chemical plants.
6	The graduate should understand the consequences of chemical plant incidents due to acute and chronic chemical releases and exposures.
7	The graduate should be reasonably proficient with at least one hazard-identification procedure.
8	The graduate should have an introduction to the process for hazard evaluations and risk.

Since the report, AIChE has developed and proposed guidelines to ABET for teaching safety to undergraduates. These guidelines are shown in Table 1.

This paper presents the basic concepts for a SAChE Product that provides guidance to engineering design teams to help them meet the combined process safety guidelines of both academia and industry.[4,5] A department can "prove" its process safety awareness efforts for an ABET auditor by documenting its efforts in the senior capstone design report. This approach, described in this product, will help ensure that students graduate with, at minimum, an awareness of the different hazards analysis techniques that must be used when they design their risk-reduction controls, preventing irreversible life-changing process-related incidents from affecting them or their coworkers.

Please recognize the distinction between "process safety" and "personal safety." Process safety requires a thorough hazards evaluation that identifies and controls all potential risks associated with a chemical process. The consequences of these process hazards, such as runaway reactions, toxic releases, fires or explosions, must be understood and reduced as much as is practical through adequate process design—this is known as the "first line of defense." On the other hand, personal health and safety may require students in a unit operations laboratory to wear personal protective equipment (PPE), such as safety glasses, hard hats, and gloves. PPE is required to address any residual risks associated with the chemical process—the PPE is the "last line of defense."

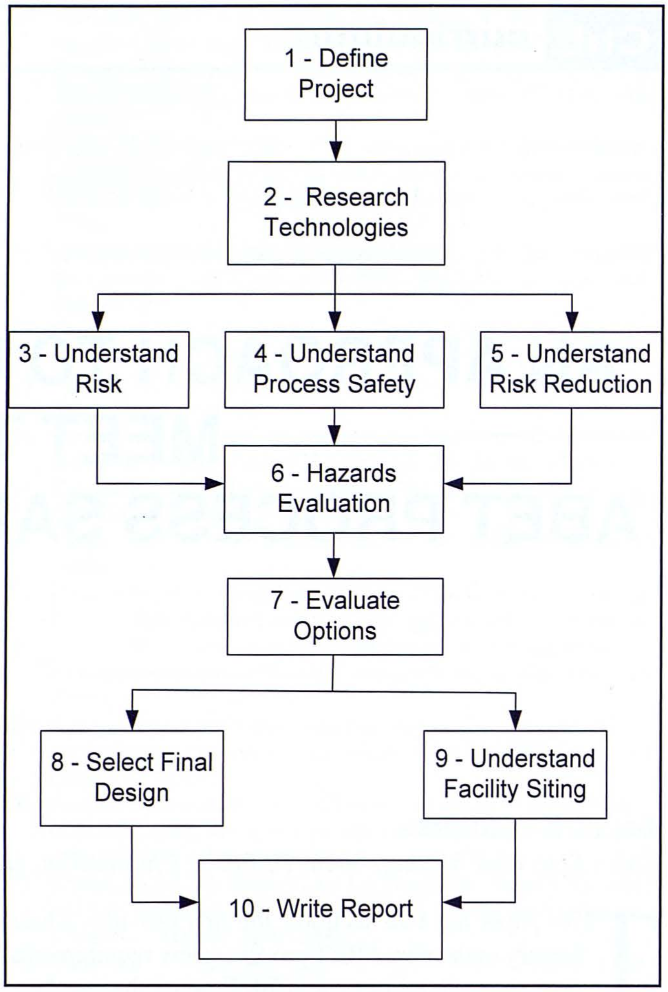

***Figure 1.** The Design Project Road Map.*

THE SAChE PRODUCT

The SAChE product, "Safety Guidance for Design Projects," combines the steps in a senior design project (the basis) with the AIChE Process Safety Guidelines and the principles of Process Safety Management (PSM). As is shown in the "Road Map" in Figure 1, the design team's project has 10 basic steps:

1. *Define Project*
2. *Research Technologies*
3. *Understand Risk*
4. *Understand Process Safety*
5. *Understand Risk Reduction Strategies*
6. *Hazards Evaluation*
7. *Evaluate Options*
8. *Select Final Design*
9. *Understand Facility Siting*
10. *Write Final Report*

The flow of the blocks noted in Figure 1 helps the design team organize their efforts to meet their academic and industrial process safety requirements, including references to the industry's basic principles of Process Safety Management (PSM).

The connections between the process safety Guidelines listed in Table 1 and the Road Map in Figure 1 are shown in Table 2. The steps shown in Figure 1 that are focused on safety include steps 3, 4, 5, 6, and 9. These process safety-related steps are described in more detail below.

The SAChE Product provides guidance for engineering design teams to help them meet the combined process safety requirements of education and industry.[4] It can be used by professors, industrial trainers, and students who are working on a process design project, as well.

The Product includes:

1. *An Overview document written to assist the instructor on how to use the module,*
2. *A PowerPoint presentation (the module), and*
3. *Handouts that are used with the PowerPoint presentation.*

The presentation begins with a brief description of the T2 accident that was the genesis of the CSB recommendation

TABLE 2
The Design Project Steps Linked to the AIChE/SAChE/ABET Guidelines

Design Project Steps		Description of Project Steps (with referenced AIChE/SAChE/ABET guidelines—see Table 1.
1	Define Project	Project Proposal - must have clear understanding of objectives and business case (what is the benefit of making this product?) Will it make a profit? Must be clearly written and understood by all Team members.
2	Research Technologies	Research and locate potential technology options that will meet project goals. (Literature review) Establish high-cut types of Process Safety Information (see step 4 below)
3	Understand Risk	The graduate should have an introduction to the process for hazard evaluations and risk assessments [Guideline 8].
4	Understand Process Safety	a. The graduate must be able to characterize the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards [Guideline 2]. Understand Process Safety Information (PSI) required to manufacture product. Includes basic description of Hazards of Materials, Process Design Technology and Equipment Design Technology [part of Guideline 2]. b. The graduate should understand the consequences of chemical plant incidents due to acute and chronic chemical releases and exposures [Guideline 6]. c. The graduate must understand the importance of process safety and the resources and commitment required. This should include the important incidents that define process safety, and how these incidents affected the practice of chemical engineering [Guideline 1]. d. The graduate should be familiar with the major regulations that impact the safety of chemical plants [Guideline 5].
5	Understand Risk Reduction Strategies a. Understand Engineering and Administrative Controls b. Understand Inherently Safer Design c. Understand Human Factors	a. The graduate must understand how to control and mitigate hazards to prevent accidents. This should include generally accepted management systems, plant procedures and designs to prevent accidents [Guideline 4]. b. Reduce the Frequency as much as is practical. Note for US - Design Project Steps (Road Map) Description of Project Steps [with referenced AIChE/SAChE/ABET Guidelines – see Table 1] Required for OSHA PSM [parts of Guidelines 4 and 5]. c. The graduate must understand and be able to apply concepts of inherently safer design [Guideline 3]. d. Improve the "Human Factors" term in the risk equation ("Operating Discipline," "Conduct of Operations," etc.) - improvement in human factors will reduce risk. Note for US - Required for OSHA PSM [part of Guideline 5].
6	Hazards Evaluation	The graduate should be reasonably proficient with at least one hazard identification procedure [Guideline 7].
7	Evaluate Options	Evaluate overall risk associated with chosen technologies (effect of safety, health, environmental and business) to select final design project. Perform a risk gap analysis.
8	Select Final Design	Must define final Process Safety Information (PSI) required to manufacture product. Includes Hazards of Materials, Process Design Technology and Equipment Design Technology. Analyze Cost / Benefit for Final Design.
9	Understand Facility Siting	Must understand impact on personnel and communities. The difficulty for a design project is that design concepts do not have a site layout. An option for Design Team could be to identify a part of their hazardous process (if any), propose a site layout and then define their worst case scenario using a facility siting hazards analysis checklist. Note for US - This analysis is required for OSHA's PSM standard (29 CFR 1910.119) and is essential for the EPA's Risk Management Plan (RMP) [Guideline 5].
10	Write Final Report	Use a report template. Note that a chapter could be included to address findings discovered later that could affect the final choice (such as "Directions for Future Efforts" - an important chapter when deadlines approach)

to AIChE and ABET. The design project "Road Map" is presented next, helping the design team visualize how the elements of Process Safety Management (PSM) used in industry are incorporated into their project.

The handouts include four tables. Table 1 describes the AIChE/SAChE/ABET proposed process safety guidelines; Table 2 compares the steps in a design project that meet part of the process safety guidelines. Note that the team's final written design report helps departments document that their students meet the AIChE/SAChE process safety guidelines. Specific SAChE products and SAChE Safety Certificates are referenced in Tables 3 and 4 to point the student to additional resources for learning and understanding how to develop a safe design.

The product helps describe the process safety-related steps shown Figure 1:

Step 3: Understanding Risk. *The module starts with a definition of risk and includes an example of a risk matrix. The matrix consists of a frequency term and a consequence term. The term "unacceptable risk," with its high frequency and high consequence is compared to the term "acceptable risk," with its correspondingly low frequency and low consequence. Each team must establish its own risk tolerance levels before proceeding with its analysis – just like any business must do before allocating resources to reduce its process safety-related risks.*

Step 4: Understanding Process Safety. *The types of process safety hazards are: fires, explosions, runaway reactions, and toxic releases. A simplified PSM definition is included in the SAChE PowerPoint charts. PSM's goals are to reduce the process safety risk to people, the environment, and the business.*

Step 5: Risk-Reduction Strategy. *The risk-reduction strategies include lowering the expected frequency with engineering or administrative controls and/or lowering the consequence with inherently safer designs. Engineering design considerations include alarms and interlocks (safety instrumented systems, or SIS). Administrative controls include written operating procedures. Inherently safer design considerations (especially crucial at this point!) include, for example, less hazardous materials or reduced processing temperature or pressure extremes. Consequence*

TABLE 3
SAChE Products Linked to Design Project Steps (Online via sache.org)

Design Project Step	SAChE Product (Development year via sache.org)
1. Define Project	The Product described in this paper: a. Safety Guidance in Design Projects (2011) These Products help with Steps 3, 4, 5, 6 and 9 below: b. A Process Safety Management Overview (2012) c. Conservation of Life: Application of Process Safety Management (2012)
2. Research Technologies	
3. Understand Risk	a. Risk Assessment (2008) b. Green Engineering Tutorial (2004) c. Project Risk Analysis (2009) d. Understanding Atmospheric Dispersions of Accidental Releases - CCPS book (2010) e. Dow Fire and Explosion Index (F&EI) and Chemical Exposure Index (CEI) Software (2011)
4. Understand Process Safety	a. Chemical Process Safety (2006) b. Seminar on Fires (2009) c. Explosions (2009) d. Dust Explosion Control (2006) e. Chemical Reactivity Hazards (2005) f. Properties of Materials (2007) g. Fire Protection Concepts (2010) h. Introduction to Biosafety (2005)
5. Understand Risk Reduction Strategies	a. Runaway Reactions – Experimental Characterizations (2005) b. Design for Overpressure and Underpressure Protection (2006) c. Safety Valves: Practical Design Practices for Relief Valve Sizing (2003) d. Compressible and Two-Phase Flow with Applications Including Relief System Sizing (2011) e. Inherent Safety (2006) f. Fundamentals of Chemical Transportation with Case Histories (2012)
6. Hazards Evaluation	a. Layers of Protection Analysis (2011) b. Static Electricity as an Ignition Source (2008) c. Process Hazard Analysis (2009)
7. Evaluate Options	Inherently Safer Design Conflicts and Decisions (2008)
8. Select Final Design – Risk Based	
9. Understand Facility Siting	
10. Write Final Report	Improving Communication Skills (2004) Includes Oral Presentations

reduction strategies could include quick detection of the potential event and a quick emergency response, such as smoke detectors, sprinklers, and then immediate action by an emergency response team.

NOTE: The important operational discipline (OD) concepts must be considered when applying risk evaluations in industry. For example: If people do not follow the process safety "rules" (i.e., *operating procedures, equipment codes or standards, or maintenance and reliability programs, etc.), then their risk is larger since their OD is less than 1 (where 1 equals perfect compliance to OD). This is shown in a "perceived risk" vs. "actual risk" chart when there is poor OD.*

Step 6: The Hazards Evaluation. *The elements of Process Safety Management (PSM) are briefly discussed in the module, with particular focus on reinforcing the importance of the Process Safety Information (PSI) and Process Hazards Analysis (PHA) elements and their considerations in the design process.*

Step 9: Facility Siting. *Please refer to more details of Facility Siting, which is industrially significant, in the notes written in Table 2, Step 9.*

The Product concludes by reminding the students of the process safety-related steps in the design team's project Road Map chart. The final two charts were influenced by the Deepwater Horizon disaster in early 2010 (the time when this Product was being prepared). Hopefully the students will understand: Although we have made progress in process safety, we still have work to do.

SUMMARY

Fatalities, such as those that occurred at the T2 Laboratory in 2007, could have been avoided with better understanding and implementation of the elements of Process Safety Management (PSM). Significant advances in industry have helped engineers reduce process safety risks with better design-related tools for understanding, analyzing, designing, and controlling hazardous processes. The SAChE Product described in this paper helps bridge a gap between universities and industry in process safety-related awareness and education. The SAChE product provides a Road Map (a framework) for organizing the existing SAChE products, combining the requirements of the design project with the PSM principles. The product can be used to improve the awareness of the PSM-related resources and techniques, with particular emphasis on locating the SAChE products that have been designed to be integrated within the chemical engineering curriculum. Using this Product will help ensure that students graduate with, at minimum, an awareness of different hazards analysis techniques that must be used when they design their risk-reduction controls.

A brief note on future efforts: These process safety-related education/design efforts described in this paper focus on the traditional studies of material and energy balances—conserving mass and energy. Industrial application of process safety requires two more concepts, however:

> *"Operational Discipline" and the "conservation of life."*[6-8] *These additional concepts help us achieve AIChE's first principle in our "Code of Ethics" [underlined below,* [9]*]:*
>
> *"Members of the American Institute of Chemical Engineers shall uphold and advance the integrity, honor and dignity of the engineering profession by:,*
>
>> *Being honest and impartial and serving with fidelity their employers, their clients, and the public;*
>>
>> *Striving to increase the competence and prestige of the engineering profession;*
>>
>> *Using their knowledge and skill for the enhancement of human welfare.*
>
> *To achieve these goals, members shall:*
>
>> *Hold paramount the safety, health and welfare of the public and protect the environment in performance of their professional duties."*

Expect to read more about how we will continue to meet this principle in the future.

REFERENCES

1. Safety and Chemical Engineering Education Program (SAChE), <http://www.sache.org>
2. Safety and Chemical Engineering Education Program (SAChE), Faculty Workshops: <http://sache.org/workshops.asp>. Examples of presentations from the SAChE Faculty Workshop in Baytown, TX, in August, 2010 include these presentations: 2.1 Schneider, R., "SAChE: What Exactly Is It and How Can It Help You?"; 2.2 Cox, K.R., "Process Safety in the Classroom"; 2.3 Chosnek, J., "Process Safety and Chemical Engineering Design"; 2.4 Edwards, V.E., "Develop and

TABLE 4
SAChE Safety Certificates Linked to the Design Project Steps (Online via sache.org)

Design Project Step	SAChE Product (Year via sache.org)
3. Understand Risk	Risk Assessment (2008)
4. Understand Process Safety	a. Safety in the Process Industries (2008) b. Chemical Reactivity Hazards (2008) c. Runaway Reactions (2008) d. Dust Explosion Control (2010) e. Process Safety 101 (2010)
5. Understand Risk Reduction Strategies	Inherently Safer Design (2009)

Design Inherently Safer Process Plants"
3. <http://www.csb.gov>; The U.S. Chemical Safety and Hazard Investigation Board (CSB) Investigation Report: "T2 Laboratories Inc. Reactive Chemical Explosion, Jacksonville, FL, Dec. 19, 2007" <http://www.csb.gov/investigations/detail.aspx?SID=8&Type=2&pg=1&F_InvestigationId=8>
4. Vaughen, B.K., "Safety Guidance for Design Projects," Safety and Chemical Engineering Education Program (SaChE), Product issued in 2011, SACHE.org. <http://www.sache.org/products.asp>
5. Vaughen, B.K., "A SAChE Module Designed to Bridge Process Safety's Troubled Waters: Meeting the New Academic Process Safety Requirements," the American Institute of Chemical Engineers (AIChE) 2010 Annual Meeting, Education Division, Salt Lake City, Utah, November 2010
6. Klein, J.A., and B.K. Vaughen, "Implementing an Operational Discipline Program to Improve Plant Process Safety," *Chemical Engineering Progress*, The American Institute of Chemical Engineers (AIChE), June 2011, pp. 48-52
7. Vaughen, B.K., and J.A. Klein, "Improving Operational Discipline to Prevent Loss of Containment Incidents," *Process Safety Progress*, The American Institute of Chemical Engineers (AICHE), in press, published online in Wiley Online Library (<wileyonlinelibrary.com>): DOI 10.1002/prs.10430
8. Klein, J., "Conservation of Life: Application of Process Safety Management," Safety and Chemical Engineering Education Program (SAChE), Product issued in 2012, <SACHE.org> (<http://www.sache.org/products.asp>)
9. American Institute of Chemical Engineers (AICHE) 3 Park Avenue, New York <http://www.aiche.org/About/Code.aspx> ❒

PBL: An Evaluation of the Effectiveness of AUTHENTIC PROBLEM-BASED LEARNING (aPBL)

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The acronym PBL has been used to describe a wide range of different educational interventions. At one end of the spectrum is the original or authentic version developed at McMaster University medical school in the 1960s,[1] which Barrows[2, 3] called aPBL. Barrows[4] distinguishes among some of the different versions of what one might refer to as "problem-based learning" based on 1) the outcomes, 2) the style of the problem presentation, and 3) the interaction and responsibilities of the teacher and the students. The outcomes he lists are: learning and using new knowledge, structuring the knowledge for use in future professional contexts, increased motivation for learning, and developing effective reasoning, problem-solving skills with the guidance of the tutor, team skills, skills in self-assessment, lifelong learning skills, and teaching skills. In aPBL the focus is on empowering the students with the learning process. Given a problem, students realize they don't know key knowledge, they contract with each other that different team members will learn new knowledge and return to the group and teach all the members the new knowledge. This medical school approach empowers the student with the learning process and has the following attributes:[1, 3, 5-7] small group (4 to 8 students), self-directed, self-assessed, interdependent problem-based learning. Self-directed means that, for the professionally significant problem, the students decide what they know already, what they need to know, receive approval from the tutor that their learning objectives are appropriate, contract with each other, research and prepare teach notes, teach, and assess the knowledge learned and problem solved. The faculty do not lecture; faculty are tutors. All students are responsible for learning all the new knowledge. aPBL is used for two different outcomes that Schmidt et al.[7] calls Type I and Type II. The outcome for Type I aPBL is knowledge acquisition. For Type II, the outcomes are acquisition of both knowledge and clinical skills.[8, 9]

At the other end of the spectrum is problem-based synthesis, sometimes called project-based learning. In this model students are asked to use previously learned knowledge to solve a problem. Samson University[10] uses a variation of problem-based synthesis where a problem is posed, the teacher lectures on the knowledge needed and then the students apply the knowledge. In this option, faculty lecture to set the context, and supply information and background material.[10] Versions of this lecture-style problem-/project-based learning are described by Kolmos et al.[11] Design projects are another example of problem-based synthesis. Here the students have already learned the fundamentals needed to solve the project. If the students need to learn additional knowledge to solve the project, they usually divvy up the parts of the project. Each learns the new knowledge needed to solve his/her part of the project. The other

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members of the team rarely learn the knowledge acquired by the other members of the team, however. "Project-based must not be confused with problem-based. The former is designed to reinforce what has already been taught and demonstrate the relevance of knowledge. PBL (problem-based learning) poses a problem that is set before the knowledge has been acquired, and the problem causes the students to acquire the knowledge they need to complete the task."[12] Mills and Treagust[13] also distinguish between problem-based and project-based experiences. The outcomes, the knowledge learned and the overall learning experience are different.

To evaluate the effectiveness of any learning environment, for clarity, we must study comparable educational interventions. Hence, articles describing learning that the authors call PBL but from their description are using problem-based synthesis, hybrid PBL, problem-assisted learning or project-based learning are not included in this analysis.

With a focus on aPBL, and this form alone, we review the literature in engineering and medical fields of the effectiveness of aPBL.

EFFECTIVENESS

The effectiveness of aPBL, compared to traditional lectures, has been reported for 12 claims. Some researchers used measures of performance; others used questionnaires about perceptions.

Comparable subject knowledge acquisition. Performance on exams has been used to determine differences in knowledge acquisition between students in aPBL and in conventional lecture-style instruction. Some of the earlier analyses of aPBL reported that marks in the subject knowledge of medical doctors, MDs, on the National Board Medical Examiners I, NBME I, (which tests factual knowledge) were statistically significantly lower than marks obtained by MDs from the traditional programs.[14, 15] Dochy et al.,[6] however, recently reconsidered that research in the medical area, and added more recent studies. They concluded that the marks by students in the aPBL programs were as good if not better, but not significantly so, than those obtained by graduates of the conventional programs. Schmidt et al.[7] in medicine, Mehta,[16] in a Mechanical Measurements course, and Mantri et al.,[17] for an externally set subject knowledge exam in a course in digital electronics, found no significant difference between marks of aPBL students and students in traditional courses. Mantri et al.[17] found that aPBL marks on internally set subject knowledge exams were statistically significantly better than traditionally educated students.

Improved clinical or troubleshooting skills. For Type II aPBL, clinical skills for graduates of the aPBL program were statistically superior to those graduating from the conventional program as measured by graduate's performance on four measures: NBME II, cases, simulations, and Modified Essay Questions.[6, 14, 15] For engineering students the skill is troubleshooting. Mantri et al.[17] found that the aPBL marks on a troubleshooting task on a circuit were statistically significantly better than lecture-based. In summary, for Type II aPBL where clinical skill development was explicitly built into the experience, statistically significant performance occurred.

Deep learning instead of surface learning. Students have preferred styles of learning. Deep learners search for meaning in what they are learning. Surface or rote learners ask "tell me what to learn and I'll learn it." Strategic learners will adapt their style of learning to the expectations of the course. Students who are given lectures throughout their college years show an increase in surface learning. They may enter universities with a preference for deep learning but that preference decreases and surface learning increases attributed mainly to their lecture experience. On the other hand, students experiencing aPBL show the opposite. Their initial use of surface learning decreases and their use of deep learning increases.[18-21] Indeed, there is a statistically significant increase in deep learning as measured by pre- and post tests using the Lancaster Approaches to Studying Questionnaire.[20-24]

High-quality learning environment. Ramsden and Enwistle[23] found the key factors in learning environments that promote deep instead of rote learning include good teaching, openness to students, the clarity of the goals and assessment, student's freedom in learning, the vocational relevance of the course, and the social climate. The negative factors are the workload and the degree of formal didactic lectures. These factors are used in the Course Perceptions Questionnaire, CPQ,[21-24] or sometimes called the Course Experience Questionnaire. The CPQ has been used as input for funding decisions by Higher Education Funding Agencies in Australia since the mid-1980s.[25, 26] For conventional lectures, the CPQ is about 18 to 23 with student/control-centred ratio < 1. For aPBL, CPQ values are usually between 30 and 45 with student/control-centred ratio > 1 (often 2 to 4).[23] A perception survey of over 20,000 Dutch students showed that aPBL students rated the quality of the learning environment superior especially in providing independent study, critical thinking, coherence of content, and preparation for the profession.[7] In aPBL the students feel more supported, less stress, and less alienation than students in conventional programs.[7]

Knowledge retention higher. We want our graduates to retain the knowledge they learn. Long term (2- to 4-year) knowledge retention was statistically significantly higher from students in aPBL programs compared with those from conventional program.[6, 7, 27, 29-32] Martenson et al.[29] reported 60% higher long-term retention after 2 to 4 1/2 years for graduates from aPBL over graduates from conventional MD programs. The aPBL students recalled five times more concepts than did students in conventional programs.[30] Confirming evidence from other researchers is summarized by Norman and Schmidt[31] and by Hung, Jonassen, and Liu.[32]

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In aPBL the focus is on empowering the students with the learning process. Given a problem, students realize they don't know key knowledge, they contract with each other that different team members will learn new knowledge and return to the group and teach all the members the new knowledge.

For the retention of skills acquired, first-year students at The University of Guelph[10] experienced a course run as aPBL, seminar, or lecture. In their third year, students from aPBL and the seminar course completed questionnaires about their skills that they retained. Those from aPBL rated their skills to be far superior, compared with those who had experienced the seminar-style course. A statistical analysis was not done.

Motivation higher. Student motivation, as measured by student response to learning environments, was statistically significantly higher for students in the aPBL program compared with those in conventional programs.[27,33]

Exit surveys and alumni: positive. Surveys and written feedback from graduates, alumni, and employers provide softer, yet nevertheless useful evidence. One useful survey has been the Queen's University's Exit Survey.[24,35] On this survey, students from McMaster's Chemical Engineering problem-solving-aPBL program rated problem solving, communication, and critical thinking as important skills that were developed in our program. Regrettably, life-long learning was not included in the original Queen's exit survey. McMaster also developed its own survey asking graduates to identify the most useful experience or courses. The results were that 58% identified the problem-solving aPBL sequence of courses as contributing to their career success.[34] Other courses or experiences cited were 25% "engineering fundamentals" and 10% project work.

The following two claims have, to my knowledge, no direct supporting research evidence, although they might be inferred from the foregoing evidence.

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Improved learning. aPBL includes most characteristics to improve learning. Chickering & Gamson[39] in their classic paper noted seven characteristics of effective learning environments: expect student success, strong teacher-student interaction, active, cooperative, prompt feedback, clear time-on-task, and accounts for different student learning styles. All are provided by aPBL with the exception of explicitly emphasizing expecting student success. Tutored groups provide strong teacher-student interaction, although tutorless groups do not explicitly.

In summary, evidence about the effectiveness of aPBL, compared with traditional lectures, was listed. Now consider the issues and steps to be addressed to implement aPBL.

IMPLEMENTING aPBL

The ABET accreditation criteria introduced in 2000 list 11 Criterion 3 outcomes for engineering programs.[40] Felder and Brent[41] suggest that "the instructional method known as problem-based learning (PBL) can easily be adapted to address all 11 outcomes of Criterion 3. Once problem-based learning has been adopted in a course, very little additional members of the team rarely learn the knowledge acquired by the other members of the team, however. "Project-based must not be confused with problem-based. The former is designed to reinforce what has already been taught and demonstrate the relevance of knowledge. PBL (problem-based learning) poses a problem that is set before the knowledge has been acquired, and the problem causes the students to acquire the knowledge they need to complete the task."[12] Mills and Treagust[13] also distinguish between problem-based and project-based experiences. The outcomes, the knowledge learned and the overall learning experience are different.

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In 1982 the McMaster Chemical Engineering Department implemented aPBL via tutorless, autonomous groups in the context of classes with 30 to 70 students and one instructor. To prepare students for aPBL, in the sophomore year they had one required, workshop-style course to develop the students' skill and confidence in those prerequisite skills needed for tutorless groups. Two required courses in the junior year developed more required skills. Then aPBL was used in one senior course that included engineering economics. The knowledge learned included interest and depreciation, investment, money flow in a company, financial attractiveness and capital and operating cost estimation. Typically we formerly used four weeks of lectures/tutorials to "cover" this material. We replaced the lecture class time with aPBL and considered one case each week. In addition to the students' self-assessment of the subject knowledge gained, faculty judged the students' performance on written exams on this topic to be as good as previous years when they "learned" the material from conventional lectures, although we did not do a rigorous statistical analysis. An alumni survey praised this approach and neither alumni nor employers suggested any deficiency in subject knowledge.[20,34] The student response was so positive to this way of learning, that, at their insistence, we replaced three weeks of traditional lectures with aPBL in a junior-level course on safety and process analysis. Details are available.[20,42-49] Based on this experience, plus that gained from giving numerous workshops on aPBL in different cultures, contexts, and subjects (English, Geography, Civil Engineering, Policing, Nursing) here are the initial implementation issue to address and the seven key decisions to make.

> ***The student response was so positive to this way of learning, that, at (student) insistence, we replaced three weeks of traditional lectures with aPBL in a junior-level course on safety and process analysis.***

1. Initial Decision: Tutored or tutorless Groups

A major initial issue is tutored vs. tutorless groups.[48] In my experience, if there is one instructor and a class of more than 20, then tutorless groups is the preferred option.[43,5] If the whole department or program is going aPBL, so that one faculty member can be a tutor for each group of five to eight students, then tutored aPBL is probably the best choice.[48] This tutored approach is described most extensively by Barrows[1,3] and Schmidt.[7,31,36,37] An intermediate approach uses one instructor and a "large class." The tutor circulates and, almost in a Guided Design[50] approach, facilitates all the groups concurrently. A disadvantage to this approach is that groups inevitably complete tasks at different times. This forces all the groups to follow the same timeframe. This option is not discussed in this paper. Another option is to provide guided questions,[51] which seems to be similar to the method used in Guided Design.

Whether the groups are tutored or tutorless affects three things, a) major student concerns, b) the possibility of including skill development (Schmidt's type II aPBL), and c) the problem format. *Student concerns:* Students in tutored and tutorless groups have different concerns. For the tutorless groups the major concerns relate to reliable student participation (all are not seen as pulling their weight, attendance, lack of trust, lack of cohesive goals, and hesitant to engage in accountability activities).[44] The presence of a tutor, by and large, eliminates this type of concern.[44] For tutorless groups, one approach to address the main concern in tutorless groups, namely, individuals contributing their share, is to use self- and peer assessment.[46,47]

Skill development outcomes: for tutored groups, besides the subject knowledge acquisition (type I aPBL), the program outcomes may include the development of skills specific to the profession (type II aPBL). For engineers, troubleshooting, product or process design, and process improvement might be the skills. For medical professionals, clinical skills would be developed.[6,8] If the aPBL outcomes include skill development, then most institutions use a tutored group. The tutor's role is primarily to facilitate the development of thinking skills and problem-solving/clinical/troubleshooting/ detective skills. Guidance is given by Hmelo-Silver and Barrows.[52] On the other hand, for tutorless groups,

- *the questioning to prompt critical thinking can be handled by a student in the group using questions summarized by Hmelo-Silver and Barrows,*[52]
- *the task and morale aspects of group work are facilitated by the chair,*
- *the development of clinical/troubleshooting/detective skills is probably best developed using separate triad workshops.*[53]

Problem format. For type I aPBL, a single page, single problem is usually used. For type II aPBL developing clinical/troubleshooting/detective skills, the group receives, over the weeks, a sequence of related problem statements representing the stages of the process.

The resources and the university culture often dictate whether to use tutored or tutorless groups. This decision affects the student issues we need to address; whether clinical, troubleshooting, or procedural skills can be included as a target outcome for aPBL and the type of problems created and their sequence.

2. Some of what it takes to implement aPBL

Here are seven issues to consider.

2-1. Prepare the students before aPBL with skill in problem solving, teamwork and self-assessment. Many[20, 30, 33, 54-56] have found it vital to provide workshop-style training or to ensure students have skill in such areas as problem solving, self-assessment, and group skills before they engage in aPBL. For example, at the McMaster University Medical School one of the five criteria for admission is successful performance on problem solving and group work as measured by observers of a group doing a simulated aPBL task.[54, 55] In the McMaster Oncology program, one of the first activities is a workshop on problem solving before aPBL. In the McMaster Chemical Engineering program students have a minimum of 12 hours of workshops on problem solving (4 h), stress management (2h), change management (2h), self-assessment (2h), and group work (2h) before they work in the aPBL format.[20, 57] For each workshop, students submit a self-assessment journal.[20] To facilitate the students teaching each other, it helps if each knows the learning style/preferences of others in their group.[39] Each student receives feedback from the following inventories: Jungian typology (Myers Briggs Type Inventory),[57-59] Kirton Adaptive Innovative,[57, 60] Lancaster Approaches to Studying,[57, 61, 62] and Perry.[57, 63] This information is shared with other group members. Each group invests an hour to decide on the norms for that particular group.[64] In addition, a 6-hour introduction to aPBL is given.[47, 49]

In the Netherlands, students have workshops on group collaboration skills before aPBL.[56] This includes mastering the seven-step standard procedure to translate problems into learning issues for individual study, structuring the group communication process, learning how to chair meetings, and learning how to effectively be the scribe. At Maastricht University there is more structure in the first year to provide extensive training in problem discussion, chairing meetings, and reporting findings.[30]

Mantri et al.,[33] in an electrical engineering program, provided two training sessions for students on teamwork, problem solving, and an introduction to aPBL.

2-2. Scale back to the fundamentals

For well-functioning teams about 30% of the contact time is spent on questioning, checking, task problem solving activities, and morale building.[65] For poorly functioning teams, as much as 70% of the contact time might be spend on the process of making the team work, leaving only the remaining time for the actual teach/learn process.[65] It should come as no surprise, then, to realize that in aPBL the subject knowledge "learned" is about 70 to 80% of what would be "covered" in lectures. Therefore, focus your learning objectives and the problem learning issues on 80% of what you might "cover" in lectures.[14, 66] At McMaster we achieved this by removing duplication among courses, focusing on the fundamentals, and minimizing the instructor's interesting—but not essential—enrichment.

2-3. Create the resources

Study resources for the students and room facilities need to be provided. For the study resources, I have found it helpful to provide the students with the set of visuals/PowerPoints that I used when I lectured and an annotated list of resources they might find useful. Such resources were placed on reserve in the library. For one subject that I thought was challenging for the students to understand I prepared a videotape lecture. With more than 1,000 students going through the program, that videotape was viewed by only one person.

Other resources needed include rooms with flat floors, moveable chairs and tables, and white boards for each group. Throughout the sessions the groups will be brainstorming, raising issues, seeking clarification, and summarizing. Barrows suggests that a white board or summary projection of the ideas be available to help focus and speed the process along.[9]

2-4. Use reflective journals

Many[5, 7, 20, 30, 68, 69] recommend that the students benefit from writing reflective journals. As noted in Section 2-1, students wrote self-assessment journals[20, 48, 57] for each of the process skills workshops.

We continued to have them write self-assessment journals for the chairperson skills and the life-long learning skills being developed through the aPBL activities.

2-5. Anticipate problems

In general, in either tutored or tutorless groups, some stress occurs because of the change in learning environment but more directly because of the change in student expectations of the instructor. Perry's model can be used to guide instructors and students.[5, 24, 63]

Stress, even with tutored groups, can debilitate and frustrate the groups. Solomon and Finch's analysis[70] of tutored groups suggests that the major additional contributors to stress, in addition to the above-mentioned stress related to student expectations of the instructor, include:

1) *uncertainty of the breadth and depth of knowledge required,*
2) *time needed for self-directed study,*
3) *misunderstanding of aPBL and faculty role,*
4) *lack of confidence in one's ability to be successful.*

This theme is stressed in Chapter 1 of the student guidebook.[5] Options are given to help overcome the stress of change.[5]

2-6. Understand the amount and type of work required of the instructor and students. aPBL requires a lot of up-front preparation.[7,48] The teacher prepares the learning objectives, creates a list of resources and additional learning material, and locates a room with flat floors with moveable tables and chairs. The problems are created, tested with sample readers, and revised. Students are assigned to groups, chairperson duties are assigned throughout the semester to give each a chance to chair at least three different meetings, and policy details are published about attendance, failure to hand in reports, and inadequate participation.[48,49,57,71] For the training workshops, described in Section 2-1, teachers learn how to facilitate the workshops[57]; this takes about 3 hours per workshop. Teachers run the workshops and mark the self-assessment journals submitted by each student for each workshop. Marking takes about 30 min/journal. For the inventories (Jungian, KAI, Perry, and LASQ) students can self-score these and explore the implications by viewing the PowerPoint presentation for the MPS Unit 11, the Unique You.[57]

Just before the students start aPBL as groups, the teacher introduces aPBL, as mentioned in Section 2-1, with resources and details of how to do this described elsewhere.[47,49] Part of this 6-hour briefing includes a videotape of students experiencing the three aPBL sessions: the goals meeting, the teach meeting, and the exam/feedback meeting.[72]

The students receive training through the workshops. For each of Goals, Teach, and Feedback aPBL sessions that result from each problem, the designated chair prepares and circulates the agenda. At the Goals meeting, the students identify what they know already and create five to six learning objectives for what they need to know. These are validated by the teacher.[48] Each contracts to teach one of objectives.

Each, armed with the learning preferences of his/her team members, researches, learns, and prepares teach notes to be handed out at the Teach meeting. At the Teach meeting, each receives feedback about the quality of the teach.[48] For the Feedback meeting, each student prepares a good 10-minute "exam" question (and answer) on a topic that he/she didn't teach. At the Feedback meeting, the group selects the best question to pose to another group. Each group writes an answer to the posed question they receive. After 30 minutes, their response to the posed question is marked by a student marker from the other group that posed the question. Each group then debriefs about their performance on the test and their understanding of the new knowledge. The teacher collects and marks all the evidence (the posed question and poser's answer, the other group's written response and the marking of that response). At the end of each cycle of three meetings, the students submit a self-assessment journal.[48,57]

The teacher monitors the Goals and Feedback meetings to ensure that all people are participating. If some are missing, the group is asked if they want the teacher to enforce their guidelines for dealing with delinquent, non-participating members. Usually the result is that the delinquent person is sent "the letter."[71] In our experience, about 10% of the students receive the letter once. They then negotiate to be readmitted to the group. Of the 150 who received the letter (over 25 years of using aPBL) only one decided not to seek readmission and preferred to learn on his own.

2-7. Create problems

From the problem, students will identify learning issues that equal your learning objectives for a lecture course. The general guidelines for creating any problem are:

1. *The learning goals are achievable: allow about 3 to 5 hours of study/prepare teach notes for each individual student. Each problem would have about 5 to 6 learning*

TABLE 1
How the role of the tutor and the desired outcomes affect the form of the problem.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Outcomes: knowledge plus listening, critical thinking, questioning, assessing validity of information</td></tr>
<tr><td>aPBL I, subject knowledge</td><td>aPBL II, knowledge plus clinical/trouble shooting/detective skills</td></tr>
<tr><td colspan="2">tutorless group</td><td rowspan="2">student given "question checklist" for critical thinking, questioning, assessing validity of information</td><td>difficult to do; develop skill after knowledge gained from aPBL via separate triad workshop[53]</td></tr>
<tr><td rowspan="2">tutor</td><td>facilitating several groups</td><td>tutor guides the group through the clinical/troubleshooting/detective process. Challenge, groups progress at different rates and force group to follow template process. Perhaps overcome this via astute problem sequence.</td></tr>
<tr><td>with each group</td><td>tutor asks prompting questions for critical thinking, questioning, assessing validity of information</td><td>tutor guides group through the clinical/troubleshooting/detective process.</td></tr>
<tr><td colspan="2">form of problem</td><td>short, single scenario problem</td><td>series of problems: learn knowledge and tests to perform; test results and subsequent decision about action; action and follow-up.</td></tr>
<tr><td colspan="2">usual discipline</td><td>any</td><td>health sciences, engineering, police.</td></tr>
</table>

objectives for a group of six students so that each will research/teach a major topic.

2. *The learning outcomes are consistent with the stage of development of students and builds on and activates prior knowledge.*
3. *Goals might integrate knowledge, skills, and attitudes across subjects and disciplines.*
4. *The problem contains "cues" such that the students create learning objectives that are identical or close to those of the faculty.*
5. *The problem is at an appropriate level of complexity.*
6. *The problem statement is not too restrictive. This challenges the student's thinking and expects the student to integrate the new knowledge with the old.*
7. *The problem is motivational and relevant.*
8. *The problem is similar to professional practice.*
9. *The problem promotes student activity.*
10. *The problem includes raw data, like are encountered in practice.*
11. *The problem identifies the context.*

In addition, the ***form*** of the problem you create depends on the expected outcomes in terms of the subject knowledge **and** the skills you want to develop. Table 1 lists the impact of the outcomes for aPBL on the form of the problem.

aPBL Type I, when the outcomes are subject knowledge plus critical thinking. For these outcomes my experience is that you can work with tutorless groups, and the problem is usually a single problem statement. A student can handle the role of the missing tutor (to ask questions and check understanding and link to past knowledge) via a checklist of "facilitator question prompts." The skill in problem-solving is developed through workshops ahead of time or applicants are not admitted into the program unless they have demonstrated skill in problem solving. An example of aPBL I problem in Chemical Engineering is given below.

Example problem for aPBL I: Process safety

Context: Chemical process analysis. For the past three weeks we have been analyzing the process to make maleic anhydride from butane. The students have the detailed Process & Information Flow Diagram.

Target learning objectives:

Given the name of a chemical, you will be able to identify whether the chemical is on the EPA Hazardous Organic NESHAP (HON) list, the HON Section F list.

Given various sources and data for the hazardous nature of chemicals, you will be able to define the terms and interpret the degree of hazard and the implications.

Given a process, you will be able to use HAZOP (or equivalent procedures) to identify the conditions for unsafe operation and recommend corrective actions.

Ideal but not critical learning objectives:

You will be able to describe the Natural Step approach and apply it to this process.

Problem statement:

Upcoming visit from Occupational Health & Safety

> You are the process engineer for the maleic anhydride process. Recently, a process in the United States, similar to ours, exploded. Fortunately no one was injured but the ensuing fire caused 1/2 million dollars U.S. damage. Furthermore, new environmental legislation is being proposed that really clamps down on emissions and water discharge. We also are having a visit, in four months, from the occupational health and safety branch of the government. Your supervisor requests that you systematically look over your process.

Comment: This problem description seems to satisfy the criteria of 2) builds on previous knowledge, 3) multidisciplinary, 6) not restrictive, 7) motivational, 8) authentic professional practice, and 10) only raw data are given that are typical of professional practice. Therefore this case satisfies most of the criteria. Trials with students, however, showed that the students failed to generate all the target learning objectives. Insufficient cues had been given. The case was rewritten to include cues such as chemical process, exploded, emissions, water discharge, environmental legislation, government, health and safety, HON, systematically identify potential hazards for a process, HAZOP, and sustainability.

New Problem Statement: ***Upcoming visit from Occupational Health & Safety***

> You are the process engineer for the maleic anhydride process in a Canadian company. Recently, a process in the United States, similar to ours, exploded. Fortunately no one was injured but the ensuing fire caused 1/2 million dollars U.S. damage. Furthermore, new environment legislation is being proposed that really clamps down on emissions and water discharge. We also are having a visit, in four months, from the occupational health and safety branch of the government. Your supervisor requests that you systematically look over your process.
>
> As you are thinking about this assignment, Kim walks by and suggests that the HON list would be helpful; Kim suggests that the HAZOP approach is a good systematic way to solve the problem.
>
> "Is sustainability something I should also consider?" Kim thought for a moment and then suggested that this was not a direct concern for this problem, but the visitors would be impressed if we had at least thought about sustainability.

Checklists, suggestions, and examples of creating problems are available from Barrows and Wee.[3]

aPBL Type II. When the outcomes are subject knowledge, critical thinking and skill in clinical practice or troubleshooting. Usually this option requires a tutor to be present in the group. The key feature is that clinical or troubleshooting skill is also an expected outcome. The problem is posed as a series of scenarios and the students work sequentially through the cases over a several-week period. Examples are available in the medical and nursing disciplines.[48] In chemical engineering transport courses, fundamentals can be learned through troubleshooting problems. For example, the initial problem could be a faulty pump that requires students to learn the Bernoulli equation, system analysis, and pump characteristics. After the students have learned those fundamentals, the second problem would provide answers to questions that might be asked to try to locate the fault. Such questions might be "When was maintenance done?" or "Look at the flare, to see if there are upsets on site." Once the students have seen the benefits of asking this type of question and have further enriched their knowledge of pumps and systems, the third problem would list tests and the results of tests. These might include a comparison of the pressure when the outlet is shut with the head from the pump curve at zero flow or the results of the ampere measurement to estimate the power drawn by the drive motor. So the problems continue until the fault is detected and corrected, the students reflect on the troubleshooting process used and on the knowledge gained. I am unaware, however, of any problems in chemical engineering that have been prepared in this way for aPBL Type II.

SUMMARY

In this paper the focus is on what Barrows called authentic or original PBL where no lectures are given, students learn new knowledge, and all students in the group must learn the new knowledge.

Institutions using this form of aPBL have found that, compared to traditional lectures, marks in subject knowledge are the same; clinical or troubleshooting skills are better; deep learning is promoted instead of surface learning; surveys of graduates and alumni are positive; student motivation is higher; student retention of the knowledge is higher, graduates have improved skill in gathering data, and there is improved efficiency in the graduation rates with fewer dropouts. In addition, the following career skills are developed: problem solving, teamwork, confidence, life-long learning, information gathering, interpersonal relations, and communication.

To implement an aPBL learning environment, we need to decide whether tutored or tutorless groups will be used. For tutored groups, one tutor is needed for each group of five to eight students. For tutorless groups, the students have to be trained with the skills needed to function effectively without a tutor. Seven concerns include preparing students for aPBL, scaling back to the fundamentals, providing the literature and room facilities needed, using reflective journals, anticipating problems, investing the up-front work to set up aPBL, and creating the problems that will drive the learning.

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REFERENCES

1. Barrows, H.S., *Problem-Based Learning Applied to Medical Education*, Southern Illinois University School of Medicine Press, Springfield, IL (2000)
2. Barrows, H.S., "Response to 'the problem with problem-based medical education; Promises not kept,' by R.H. Glew" *Biochemistry and Molecular Biology Education*, Nov. 3 (2006)
3. Barrows, H.S., and K.N.L. Wee, *Principles and practice of aPBL*, Singapore: Pearson/Prentice Hall (2007)
4. Barrows, H.S., "A taxonomy of problem-based learning methods," *Med. Educ.*, **20**, 481 (1986)
5. Woods, D.R., *Problem-based Learning: how to gain the most from PBL*, Woods, Waterdown, Ontario (1996); available from McMaster University Bookstore and <http://www.chemeng.mcmaster.ca/innov1.htm> for PBL and the book "Preparing for PBL"
6. Dochy, F., et al., "Effects of problem-based learning: a meta-analysis," *Learning and Instruction*, **13**, 533 (2003)
7. Schmidt, H.G., et al.,"Constructivist, Problem-based Learning Does Work: A meta-analysis of Curricular Comparisons Involving a Single Medical School," *Educational Psychologist*, **44**(4) 227 (2009)
8. Barrows, H.S., and G.C. Pickell, *Developing Clinical Problem-solving skills: a guide to more effective diagnosis and treatment*, Norton, New York (1991)
9. Barrows, H.S., *Practice-based learning: Problem-based learning applied to medical education*, Southern Illinois University School of Medicine, Springfield, Chapter 5 (1994)
10. Murray, J., and A. Summerlee,"The Impact of Problem-based Learning in an Interdisciplinary First-year Program on Student Learning Behaviour," *Canadian J. Higher Education*, **37**(3) 87 (2007)
11. Kolmos, A., E. de Graaff, and X.Y. Du,"Diversity of PBL- PBL Learning principles and Models," Chapter 2 in *Research on PBL Practice in Engineering Education*, X.Y. Du et al., eds, Sense Publishers, 9-21 (2009)
12. The IEE <http://www.ee.ucl.ac.uk/~lmflanaga/PBL_IEE.pdf>, accessed April (2011)
13. Mills, J.E., and D.F. Treagust, "Engineering Education—is problem-based or project-based learning the answer?" *Australasian Journal of Engineering Education*, (2003) <http://www.aaee.com.au/journal/2003/mills_treagust03.pdf> accessed August (2011)
14. Albanese, M.A., and S. Mitchell,"Problem-based learning: a review of literature on its outcomes and implementation issues," *Acad. Med.*, **68**, 52 (1993)
15. Vernon, D.T.A., and R.L. Blake, "Does problem-based learning work: a meta analysis of evaluative research," *Acad. Med.*, **68**, 550 (1993)
16. Mehta, S., "Quantitative and Qualitative Assessment of Using PBL in Mechanical Measurements Class," 2002 ASEE conference proceedings (2002)
17. Mantri et al., "Using PBL to deliver course in digital electronics" *Advances In Eng. Ed.*, Spring, 1- 17 (2009)
18. Coles, C.R., "Differences between Conventional and Problem-based Curricula in student's approaches to studying," *Medical Education*, **19**, 308 (1985)
19. Regan-Smith, M.G., et al.,"Rote learning in Medical School," PULSE, JAMMA, 272, 17, 1380-1381 (1994)

20. Woods, D.R., et al.,"Developing Problem-solving skills: the McMaster Problem Solving Program," *J. of Eng. Ed.*, **86**(2) 75 (1997)
21. Woods, D.R., A.H. Hrymak, and H.M. Wright, "Approaches to Learning and Learning Environments in Problem-based versus lecture-based learning," refereed conference paper published in the conference proceedings, American Society for Engineering Education, Conference, St Louis MO, June 2000 (2000)
22. Ramsden, P.,"The Lancaster Approaches to Studying and the Course Perceptions Questionnaire: Lecturer's Handbook," *Educational Methods Unit*, Oxford Polytechnic, Oxford, England (1983)
23. Ramsden, P., and N.J. Entwistle,"Effects of Academic Departments on Student's Approaches to Studying," *British J. of Educational Psychology*, **51**, 368 (1981)
24. Woods, D.R., *Motivating and Rewarding University Teachers to Improve Student Learning: a guide for faculty and administrators*, City University of Hong Kong Press, Hong Kong (2011)
25. Scott, G., "Accessing the student voice," Report to Structural Reform Fund, Department of Education, Science and Training, Australia, (2005) <www.dest.gov.au/NR/rdonlyres/919>
26. Scott, G. "What are CeQ, SETU and AUSSE and why are they important? The Course Experience Questionnaire," Institute of Teaching and Learning, Deakin University, Australia. <http://www.deakin.edu.au/itl/pd/tl-modules/scholarly/setu-ceq> downloaded April (2011)
27. Shin, J.H., R.B. Haynes, and M.E. Johnson, "Effects of problem-based, self-directed undergraduate education on life-long learning," *Can. Med. Assoc. J.*, **148**, 969 (1993)
28. Schmidt, H.G., L. Vermeulen, and H.T Van Der Molen, "Longterm effects of problem-based learning: a comparison of competencies acquired by graduates of a problem-based and a conventional medical school," *Med. Educ.*, **40**(6) 562 (2006)
29. Martenson, D., et al., "Medical chemistry: evaluation of active and problem-oriented teaching methods," *Med. Educ.*, **19**, 34 (1998)
30. Schmidt, H., and J. Moust, "Factors affecting small group tutorial learning: a review of research," in Evenson, D.H. and Hmelo, C.E., Eds., *Problem-Based Learning: A Research Perspective on Learning Interactions*, Mahwah, NJ: Lawrence Erlbaum Associates (2000)
31. Norman, G.R., and H.G. Schmidt, "The Psychological basis of problem-based learning: a review of the evidence," *Acad. Med.*, **67**(9) 557 (1992)
32. Hung, W., D.H. Jonassen, and R. Liu,"Problem-based Learning," Chapter 38 in *Handbook of Research for Educational Communications and Technology*, 3rd ed. V.M Spector et al., ed., Routledge/ Taylor and Francis Group (2007)
33. Mantri, A. et al.,"Integrating PBL into traditional Frame Work: turning challenges into opportunities," ASEE conference "Global Colloquium of Engineering Education," Oct 12 -15, Budapest, Hungary (2009)
34. Chemical Engineering Department, "Survey of Alumni," McMaster University, Hamilton, Ontario (1998)
35. Queen's Exit Survey (annual) "Undergraduate Learning Experiences at Queen's: results from the exit poll," Office of the Registrar, Queen's University, Kingston, Ontario. Details of the survey are given in Appendix F of ref. 24
36. Schmidt, H.G., "Foundations of problem-based learning: some explanatory notes," *Med. Educ.*, **27**, 422 (1993)
37. Schmidt, H.G., "Problem-base Learning: rationale and description," *Med. Educ.*, **17**, 11 (1983)
38. Larkin, J.H., "Cognitive structures and problem solving ability," Paper JL 060176, Group in Science and Mathematics Education, University of California, Berkeley (1976) (and cited in ref. 5, p 3-19)
39. Chickering, A.W., and Z.F. Gamson, "The Seven Principles for Good Practice in Undergraduate Education," *AAHE Bulletin*, March, 3-7 (1987)
40. ABET accreditation, see <http://www.abet.org/accreditation/>
41. Felder, R.M., and R. Brent, "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria," *J. of Eng. Ed.*, **92**(1), 7 (2003)
42. Woods, D.R., "Problem Based Learning," Chapter 2 in Monograph *Problem Based Learning in Education for the Professions*, D. Boud, ed., HERDSA, Sydney, p. 19 to 42 (1985)
43. Woods, D.R., "Problem-based Learning for Large Classes in Chemical Engineering," Chapter 10 in *Bringing Problem-based Learning to Higher Education: Theory and Practice*, Lu Ann Wilkerson and Wim H. Gijselaers, ed, No. 68, Jossey-Bass, San Francisco (1996)
44. Woods, D.R., F.L. Hall, C.H. Eyles, A.N. Hrymak, and W.C. Wendy-Hewitt, "Tutored versus Tutorless Groups in Problem-based Learning,"*American J. Pharmaceutical Education*, **60**, 231 (1996)
45. Woods, D.R."Issues in Implementation in an Otherwise Conventional Program," in *The Challenge of Problem-based Learning*, D. Boud and G. Feletti, eds, Kogan Page, London, p 122 to 129 (1991) and Chapter 17 in 2nd edition, Kogan Page, London, 173-180 (1998)
46. Woods, D.R., "They Just Don't Pull Their Weight!," chapter in *Problem-based Learning: Case Studies, Experience and Practice*, P. Schwartz, S. Mennin, and G. Webb, ed., Kogan Page, London 163 - 170 (2001)
47. Woods, D.R.,"Helping Students Gain the Most from Their PBL Experience," chapter in *Management of Change: implementation of problem-based and project-based learning in engineering*, E. deGraaf and A. Kolmos, ed., Sense Publishers, Rotterdam, 181-195 (2007)
48. Woods. D.R., "Preparing for PBL," (2006); download from <http://www.chemeng.mcmaster.ca/innov1.htm>. For self-assessment journals see the Appendices, and from McMaster Problem Solving at the same site, see the "Self-assessment journals"
49. Woods, D.R., "Problem-based Learning: Resources to gain the most from PBL" 2nd ed., Woods, available from McMaster University Bookstore, (1997) or download it free from <http://www.chemeng.mcmaster.ca/innov1.htm> and click on PBL and then download Chapters B, C, and D from Problem based Learning: Resources to gain the most from PBL
50. Wales. C.E., and R.A. Stager, *Guided Design*, West Virginia University, Morgantown (1977)
51. Tarmizi, R.A., and S. Bayat, "Effects of Problem-based Learning Approach in Learning of Statistics among University Students," *Procedia Social and Behavioural Sciences*, **8**, 384 (2010)
52. Hmelo-Silver, C.E., and H.S. Barrows, "Goals and Strategies for a Problem-based Learning Facilitator," *Int. Journal PBL*, **1**(1) 21 (2006)
53. Woods, D.R., "Successful Troubleshooting for Process Engineers," Wiley (2007) and MPS 34, at <http://www.chemeng.mcmaster.ca/innov1.htm>
54. Hamilton, J.D., "The selection of medical students at McMaster University," *J. R. Coll. Physicians*, London, Jul; **6**(4) 348 (1972)
55. Marrin, M.L., et al., "Use of the paired-comparison technique to determine the most valued qualities of the McMaster Medical Programme Admissions Process,"*Adv Health Sci Educ Theory Pract.*," **9**(2) 129 (2004)
56. Schmidt, H.G., S.M.M. Loyens, T. van Gog, F. Paas," Problem-based Learning is Compatible with Human Cognitive Architecture: Commentary on Kirschner, Sweller and Clark (2006)," *Educational Psychologist*, **42**(2), 91 (2007)
57. Workshops are described in ref. 48, 49 and <http://www.chemeng.mcmaster.ca/innov1.htm> and click on McMaster Problem Solving Program and move down to find the appropriate unit materials. Details include learning objectives, timing, powerpoints, workshop activities, target skills and usually a self-assessment journal.
58. Keirsey, D., and M. Bates, *Please Understand Me*, Prometheus Nemesis Book Co.: Del Mar, CA (1984)
59. Myers, I.B., and P.B. Myers, *Gifts Differing*, Stanford University Press, Palo Alto, CA, (1980)
60. Kirton, M.J., "Adapters and innovators: a description and measure," *J. Appl. Psychol.*," **61**, 622 (1980)
61. LASQ or ASQ Appendix B of ref. 24.
62. Newble, D.I., and R.M. Clarke, "The approaches to learning of students in a traditional and in an innovative problem-based medical school," *Med. Educ.*, **20**, 267 (1986)

63. Perry inventory and interpretation, see ref. 5 and Appendix C of ref. 24
64. For the norms meeting, the 17 decisions are made: 1. need for chairperson, 2. terminology for problem solving, 3. type of brainstorming approach, 4. decision making procedure, 5. role of chairperson in decision making, 6. resources needed, 7. record and distribute minutes of meeting?, 8. roles, 9. meeting agenda, 10. Sandler's rules, 11. how to handle conflict, 12. how to combat group think, 13. willingness to share personal information about "styles" with all group members, 14. level of intervention desired, 15. how to handle emergencies, 16. how to handle emotional issues brought to the group, and 17. how to ask a member to leave the group. Details are given in the Resources book, ref. 49
65. Reddy, W.B., *Intervention Skills*, Pfeiffer and Co. (1994)
66. Dolmans, D.H.J.M. et al., "Problem Effectiveness in a Course Using Problem-based Learning," *Academic Medicine*, ***68***, 207 (1993)
67. Appendices A, B and C in reference 48
68. Solomon, P., et al.,"An interprofessional problem-based learning course on rehabilitation issues in HIV," *Medical Teacher,* **25**(4) 408 (2003)
69. Van Loggerenberg, A.M., "Implementing PBL in training teachers for Outcome Based Technology curriculum," Ph.D. thesis, University of Pretoria (2000)
70. Solomon, P., and E. Finch, "A qualitative Study Identifying Stressors Associated with Adapting to Problem-based Learning," *Teaching and Learning in Medicine*, **10**(2), 58 (1998)
71. The Letter related to poor participation is given on page D-24 of the Resources book and can be downloaded from <http://www.chemeng.mcmaster.ca/innov1.htm> ref. 49
72. Videotape of students experiencing PBL in tutorless groups. This is found at <http://www.chemeng.mcmaster.ca/pbl/PBL.HTM> and look partway down through the file ❐

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- If appropriate, a **Data Analysis** section should be included that concisely describes the method of data analysis. Recognizing that the audience is primarily faculty, the description of the underlying theory should be referenced or brief. The purpose of this section is to communicate to the reader specific student-learning opportunities (*e.g.*, treatment of reaction-rate data in a temperature range that includes two mechanisms).
- The purpose of the **Summary of Experiences** section is to convey the results of laboratory or classroom testing. The section can enumerate, for example, best practices, pitfalls, student survey results, or anecdotal material.
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