Phase 1 Report

Creating a Culture for Scholarly and Systematic Innovation in Engineering Education

Ensuring U.S. engineering has the right people
with the right talent for a global society

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American Society for Engineering Education
1818 N Street, N.W., Suite 600
Washington, D.C. 20036

June 1, 2009

Dear Colleague:

In June 2006, the American Society for Engineering Education launched an initiative, "Advancing the Scholarship of Engineering Education: A Year of Dialogue," involving discussions within the society on the role and importance of educational scholarship to ensure the long-term excellence of U.S. engineering education. Those discussions led to this project, which began in October 2007 with support from ASEE and the National Science Foundation. The project represents an important step by ASEE to catalyze even broader conversations across the American engineering enterprise on creating a vibrant engineering academic culture for scholarly and systematic innovation in engineering education to ensure that the U.S. engineering profession has the right people with the right talent for a global society. We invite you to join us in this important project.

This document is the first of two reports. It reflects the efforts of sixty-eight volunteers who worked for more than six months to distill their thoughts and recent articles and reports into recommendations and associated actions to advance U.S. engineering education innovation. These were shared and discussed in a progress report with another thirty-seven volunteers at a meeting on November 4-5, 2008, in Atlanta, Georgia. The advice and ideas from that meeting were subsequently incorporated into this report to complete Phase 1 of the project.

Beginning with a plenary session on Tuesday, June 16, 2009, at the 2009 ASEE Annual Conference and Exposition in Austin, Texas, the project enters Phase 2. During the coming year, the project team will seek additional advice and ideas from the broader engineering community on the recommendations and suggested actions in the report. We are gathering this input in two ways: feedback from a sample of engineering programs and engineering education-related organizations selected by the project team, and feedback from the community-at-large via a project Web page located on the ASEE homepage at www.asee.org. The project Web page will be open for comments until March 1, 2010. We will issue a second (final) report by June 2010 incorporating the results of the feedback from the community.

On behalf of the project team, please join us in a conversation on creating a more vibrant U.S. engineering academic culture for scholarly and systematic innovation in engineering education. We have a timely opportunity to make our already world-class engineering programs even better.

Sincerely,

Leah H Jamieson

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Executive Summary

This is the first of two reports from an initiative by the American Society for Engineering Education to advance U.S. engineering educational innovation. We know that how we teach is as important as what we teach. High-quality educational environments are the result of attention to both content and learning. This report is neither about the skills, abilities, or attitudes needed to be the next generation engineer nor about how people learn *per se*. Many thoughtful reports already focus on these issues. This report connects these two bodies of knowledge by addressing a fundamental question: How do we create an environment in which many exciting, engaging, and empowering engineering educational innovations can flourish and make a significant difference in educating future engineers? *The purpose of this report, therefore, is to catalyze a conversation within the U.S. engineering community on creating and sustaining a vibrant engineering academic culture for scholarly and systematic educational innovation—just as we have for technological innovation—to ensure that the U.S. engineering profession has the right people with the right talent for a global society.*

Most reports on engineering education emphasize "what" needs to be changed. "How" the change should be driven and "who" should drive the change—both of which largely determine how quickly and how well change occurs and how it is sustained—have not been as fully addressed. This report addresses *who*, *what*, and *how* and their interrelationships. It also spotlights several illustrative examples.

We focus first on *how*. We hypothesize that, as in our traditional engineering disciplines, innovation in engineering education depends on a vibrant community of practitioners and researchers *working in collaboration* to advance the frontiers of knowledge and practice. We propose a model for scholarly and systematic engineering educational innovation based on a continual cycle of educational practice and research. Adopting such a model is the most pressing need in American engineering education. This model would *both* continually advance the body of knowledge on engineering learning *and* result in the implementation of more effective and replicable educational innovations, with the end result being better-educated students.

Next, we address *who*. While a quality higher education experience involves many stakeholders, we assert that the responsibility for the quality of the engineering educational experience rests with the engineering faculty and administrators. To ensure that engineering faculty and administrators are well prepared to design and facilitate effective learning environments, we must strengthen career-long professional development in teaching and learning, starting with the doctoral programs that produce most engineering faculty. We need to ensure that faculty recruitment, hiring criteria and standards, and reward structures explicitly take into account achievements in educational innovation. And we need to re-energize and expand our web of partners, especially with engineering practice and the learning sciences communities.

Finally, we discuss *what*. Three elements, and their alignment, are central to an effective educational environment: curriculum, instruction, and assessment. In engineering today, most approaches to curriculum, instruction, and assessment are based on implicit and limited conceptions of learning and used in fragmented educational practices. A more effective engineering education enterprise could be achieved if all three were derived from a scientifically credible and shared knowledge base on engineering learning and employed in more contemporary approaches to education, such as inquiry-based learning and experiential curricula. We need to integrate what we know about engineering with what we know about learning.

We conclude the report by offering some specific actions for those individuals (i.e, engineering faculty, chairs, and deans) and organizations (e.g., ASEE, ABET, NAE, professional engineering societies, funding agencies, industry) who are ready to begin creating a culture for scholarly and systematic innovation in engineering education.

This report concludes Phase 1 of the project. In Phase 2 we invite the U.S. engineering community and other national and international stakeholders in engineering education to offer their comments on the recommendations and suggested actions in the report. We are gathering input in two ways: feedback from a sample of engineering programs and engineering education-related organizations selected by the project team, and feedback from the community-at-large via a project Web page located on the ASEE homepage at www.asee.org. The project Web page will be open until March 1, 2010. A second (final) report will be issued by June 2010 incorporating the results of the feedback from the community.

1 A Focus on Scholarly and Systematic Educational Innovation

Who, What, and How

Why this report?

The purpose of this report is to catalyze a conversation within the U.S. engineering community on creating and sustaining a vibrant engineering academic culture for scholarly and systematic innovation in engineering education to ensure that the U.S. engineering profession has the right people with the right talent for a global society.

The recent global economic meltdown is a stark reminder that we live in a world that is rapidly transforming from one of nationally differentiated organizations and cultural identities to one of internationally integrated institutions and communities (Continental, 2006). Accelerated by dramatic technological advancements, especially in powerful and ubiquitous computing and communications technologies, this transformation is profoundly affecting national and international systems of commerce, governance, *and* education (National Intelligence Council, 2008). This new world requires a highly sophisticated workforce to address a growing list of complex and interdependent global challenges, such as health, security, and sustainability. Engineers play a critical role in addressing these and other challenges (National Academy of Engineering, 2008a; National Research Council, 2007).

On the one hand, these challenges raise concerns from many quarters about the capacity of U.S. engineering education to produce excellent engineers who are prepared for the twenty-first century (National Academy of Engineering, 2005). Some concerns are long-standing: an ambitious, tightly sequenced, and highly technical curriculum; an imbalance in emphasis and integration of theory, practice, and how people learn; and a faculty reward system weighted heavily toward technical research and technology transfer (National Science Board, 2007). More recent concerns involve the need for more multicultural experiences and cross-disciplinary education, and better utilization of information technologies (National Academy of Engineering, 2005). There is also evidence of diminishing interest in engineering careers by American youths, which is confounded by an inability to attract a broad pool of talent from America's diverse society (Chubin, May, and Babco, 2005). These concerns suggest to some in the engineering community that it is time for a fundamental change in how we educate engineers (e.g., Duderstadt, 2008; National Research Council, 2007).

On the other hand, enrollments in engineering education programs are generally robust and, indeed, are rising again (Gibbons, 2009). Global graduate and faculty talent continues to populate our programs (Kaufman Foundation, 2009). And even though industry advisory boards, employers, alumni, and students express some concerns about U.S. engineering education, they also express high degrees of overall satisfaction (Lattuca, Terenzini, and Volkwein, 2006). Further, despite curricula and department structures that have remained fairly stable for nearly a century (Imbrie, 2009), U.S. engineering graduates continue to design and deliver innovative world-class products and processes. These observations indicate to some that U.S. engineering education is doing well and that the changes needed are more a matter of fine tuning.

Whether one believes in fundamental change, fine tuning, or perhaps a bit of both depending on the issue, we know engineers are called upon to solve important and complex challenges. We know engineering curricula strain to keep pace with an expanding knowledge base. We know a more diverse engineering workforce benefits our profession and our multifaceted American society. And we know, as engineers and educators, we need to continually improve our educational programs. There is no lack of awareness, absence of thought, or proposed solutions on these and other issues, as evidenced by numerous recent presentations, conferences, articles, reports, and books, both inside and outside the engineering community. Indeed, U.S. engineering has a long history of advancements in engineering education (see inset on page 3).

However, for much of its recent history, engineering education seems driven more by external "threats" than by internal reflection and visions of how best to design a better future. For example, the 1960s were characterized by a Soviet threat precipitated by the launch of Sputnik, the '70s by an economic threat from Japan's low-cost and high-quality manufacturing prowess, the '80s by a demographic threat as post-WW II engineering retirements accelerated and engineering enrollments sagged, the '90s by the global threat as U.S. competitiveness declined in the face of rapidly rising Third World economies and ubiquitous information technologies, and the beginning of the new millennium by an environmental threat as the imperative of global sustainability became a reality (Fortenberry, 2009). In response to each, U.S. engineering education sought to graduate, respectively, the scientific engineer, transactional engineer, managerial engineer, global engineer, and now the holistic engineer.

Ideally, the need for change is anticipated, and the planning and implementation of initiatives in response to change are continuous so that transitions are smooth. Engineering programs are very successful at anticipating, planning, and implementing technological innovation but much less so in educational innovation, where the "appearance every decade of a definitive report on the future of engineering education is as predictable as a sighting of the first crocuses in spring" (Schowalter, 2003).

So why this report? What is missing from the national discussions is a conversation about the context within which change must be addressed—the engineering academic culture—the union of shared values, aspirations, and practices that influence individual and organizational attitudes, beliefs, and behaviors that largely determine engineering faculty actions[1] (Ramaley, 2002). Widespread improvements in U.S. engineering education will occur only with widespread engineering faculty engagement. Gaining their support requires, at the least, a reasonable consensus of the need for and nature of the changes desired and how to achieve them. Charles Vest (2008), president of the U.S. National Academy of Engineering, recently and eloquently stated the need and nature:

> As we think of the challenges ahead, it is important to remember that students are driven by passion, curiosity, engagement, and dreams. Although we cannot know exactly what they should be taught, we can focus on the environment in which they learn and the forces, ideas, inspirations, and empowering situations to which they are exposed. …In the long run, making universities and engineering schools exciting, creative, adventurous, rigorous, demanding, and empowering milieus is more important than specifying curricular details (p. 236).

Vest's remarks reaffirm what we already know: *How* we teach is as important as *what* we teach.[2] While pedagogy cannot make up for lack of content, inattention to pedagogy can seriously compromise learning. High-quality learning environments are the result of attention to

Over A Century of Advancements in American Engineering Education

The American engineering community has a rich history of major initiatives to improve the quality of the U.S. engineering education enterprise. It created the Society for the Promotion of Engineering Education at the 1893 World's Engineering Congress (Wood, Baker, and Johnson, 1894). This society grew to become the American Society for Engineering Education, a large, influential, and globally recognized society that is advancing engineering education worldwide. The society in turn founded in 1910 the *Journal of Engineering Education*, which is now the world's oldest, most widely read, and highly cited journal for scholarly research in engineering education (*PRISM*, 2008). In 1932, the engineering community created the Engineers' Council for Professional Development to promote the engineering profession and appraise the quality of U.S. engineering programs. The organization grew to become ABET, Inc., an internationally recognized leader in worldwide engineering accreditation (ABET, 2009). The American engineering community also helped establish, in 1950, the National Science Foundation, whose mission is to promote research and education in science and engineering (National Science Foundation Act, 1950). The engineering community also assisted in founding the National Academy of Engineering in 1964 to recognize engineers with outstanding achievements and to advise the nation and the profession on important issues involving engineering in society and a well-prepared U.S. technical workforce (National Academy of Engineering, 2009a). Finally, through a diverse set of advisory, educational, industrial, governmental, and professional organizations and societies, the engineering community issued a number of timely major reports assessing the state of engineering education and recommending directions for its future. Six of the most influential reports have been the "Mann Report" (1918), "Wickenden Report" (issued in two volumes, 1930, 1934), "Grinter Report" (1955), "Action Agenda" (1987), "Green Report" (1995), and most recently, *The Engineer of 2020* (National Academy of Engineering, 2004). These and other contributions have been driven by a professional conviction within the American engineering community that as the world changes, so, too, must engineering education.

[1] We use the term "engineering faculty" to mean those faculty who have the principal responsibility for and control of engineering programs. For most campuses, these are the tenured or tenure-track engineering faculty, including those holding administrative positions, such as dean, associate dean, chair, associate chair. Occasionally, we reference engineering administrators specifically.

[2] We use the term "teach" and "teaching" to include the many forms of instruction that occur in classrooms, laboratories, project guidance, academic advising, etc.

content and how people learn. This report is neither about the skills, abilities, or attitudes needed to be a "holistic engineer" nor about how people learn *per se*. Many thoughtful reports already focus on these issues (American Society of Civil Engineers, 2008; National Academy of Engineering, 2004; National Research Council, 2000; National Center on Education and the Economy, 2007). This report connects these two bodies of knowledge by addressing a fundamental question: How do we create an environment in which many exciting, engaging, and empowering engineering educational innovations can flourish and make a significant difference in educating future engineers?[3] *The purpose of this report, therefore, is to catalyze a conversation within the U.S. engineering community on creating and sustaining a vibrant engineering academic culture for scholarly and systematic educational innovation—just as we have for technological innovation—to ensure that the U.S. engineering profession has the right people with the right talent for a global society.*

Engineering faculty must lead in creating and sustaining a culture of scholarly and systematic educational innovation. However, they must also be empowered, supported, and rewarded.

Who, What, and How

This is the first of two reports from an initiative by the American Society for Engineering Education to advance U.S. engineering educational innovation (Huband and Melsa, 2007; Mohsen, et al., 2008). Most reports on engineering education emphasize "what" needs to be changed. "Who" should drive the change and "how" the change should be driven—both of which largely determine how quickly and how well change occurs and how it is sustained—have not been as fully addressed. This report addresses *who*, *what*, and *how* and their interrelationships. It also spotlights several illustrative examples.

Who: A quality higher education experience involves many stakeholders: faculty; students (and often their parents); staff, department, college, and university administrators; alumni; governing and advisory boards; professional societies; employers; accreditation bodies; government agencies; foundations; and taxpayers, among others. They are all important. However, the leadership of engineering faculty and administrators is critical. They determine the content of the engineering program, how it is delivered, and the environment in which it is offered.[4] They are responsible for the quality of the engineering educational experience. If the American engineering education enterprise is to create and sustain a culture for scholarly and systematic innovation in engineering education, it is the nation's engineering faculty and administrators who must lead in creating and sustaining it. However, empowering them to create and sustain such a culture requires that they be well prepared to design and facilitate effective learning environments and be supported and rewarded when they do.

How: The dominant approach to engineering educational innovation today is based largely on faculty reflection and intuition drawn from their teaching experiences. Seldom are engineering educational innovations grounded in confirmed learning theories and pedagogical practices (National Academy of Engineering, 2005; Pellegrino, 2006), and many innovations, once implemented, are not assessed for their effectiveness in achieving their stated objectives. The trial-and-error nature and focus on technical content and technological tools neither systematically ensure that our graduates have the kind of educational experiences needed for the future nor assure the innovations created are replicable in other learning environments. Interestingly, this approach is at odds with the scholarly and systematic approach used by engineering faculty in their technological innovations. We need to adopt our time-tested model for scholarly and systematic technological innovation and adapt it to our educational innovations. We need to merge the long-standing entrepreneurial spirit of engineering faculty to introduce educational innovations into their engineering programs with the confirmed theories and practices on how people learn. Such a model would *both* continually advance the body of knowledge on engineering learning *and* implement more effective and transferable educational innovations, with the end result being better educated students.

What: America's leadership in the world is possible partly because of its highly skilled and educated technical workforce. However, many reports acknowledge that America will not have this workforce in the future unless our engineering programs are perceived by students to be personally rewarding, socially relevant, and designed to help them succeed (Chubin, et al., 2008; National Academy of Engineering, 2008b; Ohland, et al., 2008). Fortunately, many engineering faculty are working to make their programs more engaging, relevant, and welcoming. However,

[3] We use the term "educational innovation" broadly to include the introduction of ideas, methods, technologies, etc. into new or existing learning environments and their continued improvement, as well as the invention of new educational ideas, methods, technologies, etc.

[4] By "engineering program" we generally mean the curriculum or degree program; occasionally we mean an administrative unit such as a department and college.

three elements are central to an effective educational environment: curriculum, instruction, and assessment. In engineering today, most approaches to these elements are based on implicit and limited conceptions of learning and used in fragmented educational practices. A more effective educational enterprise could be achieved if curriculum, instruction, and assessment, and their alignment, were derived from a scientifically credible and shared knowledge base on engineering learning and employed in more contemporary approaches to education, such as inquiry-based learning and experiential curricula. We need to integrate what we know about engineering with what we know about learning.

In the following sections we address the roles and relationships among *who*, *what*, and *how* in creating and sustaining a culture of scholarly and systematic innovation in engineering education. While it may seem logical to address them in that order, we instead begin in Section 2 by focusing on *how* and describe a proposed model for scholarly and systematic engineering educational innovation. We do so partly because it is the most pressing change needed in American engineering education to ensure the long-term excellence of its engineering programs. We also do so because it clearly identifies the roles and contributions that various stakeholders can and should play in educational innovation and which innovations hold the most promise to improve engineering learning. In Section 3, we address *who*, the engineering faculty and administrators. We outline two key components to create and sustain a culture of educational innovation—career-long professional development and a supportive environment and infrastructure for educational innovation. In Section 4, we then discuss *what.* We highlight some aspects of how people learn that can be immediately put to use to make our engineering programs more engaging, relevant, and welcoming. In Section 5, we briefly present the next phase of the project, which involves seeking additional input from the broader engineering community to help refine and shape the thoughts expressed in this report. Feedback will be gathered from both individuals and organizations. A second report synthesizing the results of the feedback will be issued by June 2010. We conclude Section 5 by offering some specific actions for those individuals and organizations who are ready to create a culture for more scholarly and systematic innovation in engineering education.

2 A Proposed Model for Scholarly and Systematic Educational Innovation (How)

The Innovation Cycle of Educational Practice and Research

The Proposed Model

The dominant approach today for engineering educational innovation is based on faculty reflection and intuition drawn from their teaching experiences. The report *Educating the Engineer of 2020* (National Academy of Engineering, 2005) describes the current situation well:

> Past attempts toward reforming engineering education—whether in individual courses or programs or on individual campuses—have been informed primarily by the opinions and experiences of those leading these efforts. What "works" has been intuitively felt, rather than based on a body of carefully gathered data that provide evidence of which approaches work for which students in which learning environments. Without such data, engineers, and their colleagues in the scientific community, have found it difficult to evaluate claims, for example, about the effectiveness of emerging pedagogies or the impact of information technologies on strengthening student learning. Unlike the technical community, wherein data-driven results from one lab have widespread impact on the work of peers, many educational reformers have not incorporated research on learning into their work (p. 26).

Higher levels of performance in any field—whether engineering, science, architecture, business, education, etc.—are achieved by continual cycles of innovation that are motivated by the desire to solve important problems and that are addressed systematically based on solid research and proven practices. *Thus, innovation depends on a vibrant community of practitioners and researchers working in collaboration to advance the frontiers of knowledge and practice.* Unfortunately, this time-tested model widely practiced by engineering faculty in their disciplines is largely untapped in engineering education. It is as applicable to the systematic advancement of knowledge and practice of engineering education as it is to engineering. As Shavelson and Towne remark in their report, *Scientific Research in Education* (National Research Council, 2002), "scientific research in education accumulates just as it does in the physical, life, and social sciences" (p. 50).

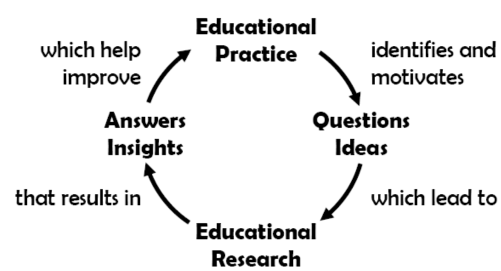
The intuition-based model has produced many capable engineers, as evidenced by the advanced society in which we live. However, the pace, scale, and complexity of the global challenges ahead should cause us to question whether it has the requisite efficiency and effectiveness to lead to the educational experiences needed to prepare excellent graduates in the future. For example, in addition to the traditional foundation in mathematics and science, knowledge of engineering science, discipline-specific knowledge, and engineering design, ABET's EC 2000 efforts drew attention to the need for communication and multidisciplinary teamwork skills, life-long learning, and a "new awareness of economic, social, and environmental concerns" (ABET, 1995, Foreword). Boeing's *Desired Attributes of an Engineer* added a systems perspective and the ability to think both "critically and creatively" (Boeing, 2009). The National Academy of Engineering's *Engineer of 2020* added ingenuity, creativity, business leadership, and flexibility (National Academy of Engineering, 2004). Thus, engineering education is being called upon to be more global, more interdisciplinary, and more connected to broader contexts, while engineering knowledge—and potential course content—is growing at an unprecedented rate. The "grand challenge" for engineering education is: How will we teach—and how will our students learn—all that is needed for the challenges of today and tomorrow? The growing list of attributes will likely require that we adopt and adapt a model for engineering educational innovation that is based on one that has already proven effective for the advancement of technological innovation (see inset).

Engaging the Proposed Model

The model outlines a continual flow between practice and research and between research and practice. Most of today's engineering education landscape is in the top half of the illustration; some is in the bottom and neither has strong connections with the other. While a wealth of innovation is being put into practice, much of it is neither being informed by a scholarly understanding of learning nor being systematically assessed to determine if the intended learning objectives are being met. By the same token, the body of knowledge on engineering learning is growing, but there is little evidence that it is making its way into widespread educational practice. The clear message is that all the arcs in the model need attention.

The model, showing a system in which educational practice and research are connected in a continual cycle, is conceptually simple and certainly valid. Some engineering faculty may develop the necessary knowledge and experience in the relevant bodies of knowledge, methods, and practices of educational inquiry to participate fully in all aspects of the cycle of engineering educational practice and research. Others will focus on educational research and will face the challenge of translating their research into practice beyond their own classes. The majority of engineering faculty members will need to approach their engineering educational innovations by forming appropriate collaborations with scholars and practitioners knowledgeable of the theories and principles of how people learn (Borrego, 2007; Cox, 2009; Cox and Cordray, 2008; McKenna, Yalvac, and Light, 2009).

The Innovation Cycle of Educational Practice and Research



Adapted from Booth, Colomb, and Williams, 2008

Engineering education innovation is about designing effective learning environments. It requires, at the least, engineering and education expertise working in continual cycles of educational practice and research.

In an instantiation of the model, scholars and practitioners, potentially from multiple fields and organizations, collaborate from the outset in framing, designing, implementing, evaluating, and disseminating an educational innovation. An application of the cycle might begin with an engineering faculty member encountering a challenging educational problem or being inspired to develop a new educational approach based on some observation in educational practice (e.g., a need to improve low rates of retention, an idea to employ computer-aided instruction). Collaborating with learning scholars and other stakeholders as relevant, the team members first identify and clarify the questions to be investigated or the ideas to be pursued. They consult the state of knowledge and application in the area so as to build on prior work and better inform their design of an experiment or pilot program to study, evaluate, and assess the questions/ideas as directly and empirically as possible. Tuning their work through iterations of the experiment or a pilot program leads to compelling answers and insights to the questions/ideas. The results are then used to improve the "mainstream" educational program and are communicated to the engineering education community through standard forums for dissemination (i.e., conferences, publications). Throughout the process, engineering faculty, learning scholars, and other stakeholders collaborate according to their experience and expertise to assure strong mutually reinforcing linkages between educational practice and research.[5]

An example of this type of collaboration is briefly described in the inset on page 8 titled "Challenge-based Instruction in an Introductory Biomedical Engineering Course." This example, with its careful advance planning, tight integration of expertise from the outset, and its execution of the full cycle, models an ideal application.

A more common application, and one still representing an advance over instances where practice and research are never connected, involves the arcs that complete the right or left half of the cycle. For example, starting with the educational practitioner at the top of the cycle, faculty member A, in response to a perceived need, is inspired to experiment with a new course structure, instructional technology, or delivery method. He or she subsequently seeks out colleague B, who helps relate the development to the literature and designs and assesses the innovation against outcomes with respect to the initial perceived need. This step, done by hand-off or, more effectively, collaboration, forms the basis for research by which B can both guide the future development of A's invention and contribute to the wider body of knowledge. A second example starts at the bottom, with educational researcher C embarking on scholarly work to study a hypothesis in the context of a wide range of educational literature. The research and subsequent experiments lead to findings that demonstrably enhance some aspects of the learning environment. In addition to publishing the results, C works with the department chair to engage colleagues D1, D2, …, D*n* to adapt the proven practice at C's home institution and, in partnership with the D*i*'s, creates tools to facilitate adaptation and adoption at other institutions.

Additional real examples are provided in Section 4. They involve developing and assessing an inquiry-based community of practice to improve student communication skills, assessing and evaluating a program to promote students' multi-cultural capabilities, and confirming general learning theories on student success applied to engineering learning.

These hypothetical and real examples illustrate that scholars and practitioners of all types may contribute to the educational innovation anywhere along the cycle as their experience and expertise allows. In all cases, though, strengthening the links in the model is critical to realizing its potential power. Through connections and collaboration, engineering education will have the opportunity to advance through continual cycles of innovation where practice builds on research and research builds on practice.

In large measure, ABET's outcomes-focused and evidence-based cycle of observation, evaluation, and improvement characterizes many aspects of this approach to educational innovation. Thus, many engineering faculty and engineering programs are already moving toward a more scholarly and systematic approach to educational innovation, and (not surprisingly) there is evidence that this approach works (Lattuca, Terenzini, and Volkwein, 2006; Kelly, 2008; Spurlin, Rajala, and Lavelle, 2008).

Supporting the Proposed Model

Creating and sustaining communities of scholars and practitioners who are advancing engineering education through more scholarly and systematic educational innovations requires support. Not surprisingly, it requires the same kind of infrastructure that supports the communities that are advancing our well-established engineering disciplines and their technological innovations: adequate fiscal resources (both operational funds and competitive grants), appropriate facilities (especially those equipped to capitalize on today's information and communications technologies), creative educational research and development centers, reputable journals, highly-regarded national and international conferences, prestigious national and international recognitions, and more.

Unfortunately, the infrastructure for engineering education innovation is incomplete and unbalanced. The infrastructure to support engineering curriculum development and teaching (educational development) is much more mature than the infrastructure to support engineering education research. A large number of teaching and learning centers, many journals, numerous conferences, and plenty of awards are devoted to curriculum development and teaching; however, far less support exists for engineering education research. Thus, there is a critical need to accelerate the development of the U.S. capacity for engineering education research and its *integration* with the existing infrastructure for curriculum development and teaching. Fortunately, we have a head start in building a better infrastructure for engineering education innovation as a result of nearly two decades of increasing

[5] A pilot version of this cyclic model was conducted with about 150 engineering faculty working with learning science and other social science researchers between 2004 and 2006 (Streveler, Borrego, and Smith, 2007). Follow up assessment and research community building continues.

Challenge-based Instruction in an Introductory Biomedical Engineering Course

Problem and Team

Studies were conducted to convert an introductory biomedical engineering course from its traditional lecture-based instruction to challenge-based instruction (CBI). CBI is similar to problem-based learning (PBL) but with several important differences. PBL eliminates lectures; discussion occurs mostly within the problem group; and learning is largely self-directed. CBI involves both inductive and deductive learning strategies revolving around a "challenge," an authentic problem. Students work in small groups but share information across the groups, guided by the instructor as an expert. Short lectures are provided by the instructor or others when students realize they need more information or understanding. This may take several iterations until the students solve the challenge.

To allow exposure to the same amount of material, some lectures were moved to the Web in the form of audio-enabled PowerPoint presentations and on-line diagnostic and formative assessment homework tutorials were created. A principal concern was whether the in-class trade-off of less time for lectures using the CBI mode diminished student performance and their attitudes toward learning or whether the trade-off would favor the CBI mode, particularly in regard to some of the more difficult concepts where more class time might be spent discussing the topics.

The team was composed of individuals with experience and expertise in assessment, biomedical engineering, learning science, and learning technology.

Study and Results

A baseline study was conducted two years prior to the study to document the traditional lecture-based mode and identify opportunities for enhancing the course with CBI. The three-year study then compared the course organized around CBI and a traditional lecture-based course (control group). Students were randomly assigned and issues of student capability, instructor variability, course content, and other factors were measured and monitored to minimize bias. Students in the CBI course outperformed the students in the lecture-based course on 26 percent of the questions on a knowledge-based exam, while the reverse was true on 8 percent of the questions. Further, students in the CBI course outperformed students in the control course on the more difficult questions (35 percent versus 4 percent). A comparison of end-of-year student surveys indicated a slight preference for CBI.

Implications for Practice

The trade-off of less time for lectures neither degraded student performance nor diminished their attitudes toward learning. The results clearly suggest that engineering students in challenge-based courses can perform just as well as students in lecture-based courses, and they can actually perform better on more difficult concepts. If more such experiences were integrated into the engineering curriculum to give students more opportunities to practice challenge-based learning, larger gains in student preferences for CBI could result.

The introductory course continues to be taught via CBI and by faculty who were not part of the course development. Additional CBI modules were developed by the investigators in bioheat transfer and biotransport, and all modules have been adopted at other institutions. A series of workshops have resulted in CBI modules in calculus, biology, chemistry, physics, and several engineering disciplines. Although the initial development costs were high, published guidelines now provide enough support to enable interested faculty to develop their own CBI modules.

References

Barr, et al., 2007; Linsenmeier and Babensee, 2008; Roselli, 2007; Roselli and Brophy, 2003, 2006a, 2006b.

attention to the scholarship of teaching (see inset on page 9). We are also not alone in our efforts to design better discipline-oriented learning environments. Extensive bodies of knowledge and vibrant communities of scholars and practitioners are advancing the frontiers of knowledge in other disciplines, such as computer science, law, medicine, and the sciences (Fincher and Petre, 2004; Fincher and Tenenberg, 2006; Sheppard, et al., 2009), not to mention the fields of education, educational psychology, cognition, etc. (American Educational Research Association, 2009; DePass and Chubin, 2009; International Society of the Learning Sciences, 2009). Engineering programs would benefit considerably by empowering some engineering faculty to dedicate part or all of their research to advancing the body of knowledge on engineering learning and for the remainder of the faculty to offer their courses, laboratories, etc., as research opportunities and/or to seek out what is known about learning and systematically apply it in their teaching. However, this requires that we capitalize on and "endorse research in engineering education as a valued and rewarded activity for engineering faculty as a means to enhance and personalize the connection to undergraduate students, to understand how they learn, and to appreciate the pedagogical approaches that excite them" (National Academy of Engineering, 2005, p. 54).

Growing the body of knowledge on engineering learning and incorporating it into engineering educational practices will require a *conscious effort* from all stakeholders—faculty and administrators, scholars and practitioners—*to reach out and work with one another,* a difficult task, but one that will lead to significantly improved learning environments (Henderson and Dancy, 2007, 2008; Henderson, Dancy, and Beach, 2007; Shershneva, Carnes, and Bakken, 2006).

Benefits of the Proposed Model

Educational innovation based on a cycle of educational practice and research will enable the engineering education enterprise to more easily and methodically incorporate research on how people learn into its educational practices. It will help to systematically build upon prior educational innovations and simultaneously advance the body of knowledge on engineering learning. It will facilitate the transfer of educational innovations among engineering programs because they will be based on practices that work and, more importantly, on the knowledge of *why* they work, i.e., it will facilitate their replication in other learning environments. Finally, it will improve the ability of the enterprise to anticipate and respond to evolving professional and societal trends with more efficient and effective use of increasingly limited resources. Thus, engineering education should be more able to prepare the engineer of 2020—and beyond (National Academy of Engineering, 2004):

> If the United States is to maintain its economic leadership and be able to sustain its share of high-technology jobs, it must prepare for a new wave of change. While there is no consensus at this stage, it is agreed that innovation is the key and engineering is essential to this task; but engineering will only contribute to success if it is able to continue to adapt to new trends and educate the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today (p. 5).

The Emergence of Engineering Education Research

Discipline-based education research seeks to marry deep knowledge of the discipline with similarly deep knowledge of learning and pedagogy. Thus, engineering education research differs from general education research in that the emphasis is on student understanding of engineering rather than on educational theory or methodology in general. It requires an in-depth understanding of engineering, learning theory, and pedagogical practice as well as access to engineering students and their learning environments. Research results provide insights on how students learn engineering, what makes certain topics or concepts difficult or easy, what conceptions or misconceptions students bring to learning, etc. so as to improve engineering educational practice (Fortenberry, et al., 2007).

The importance of engineering education research began to surface in the United States in the mid-1980s, when the National Science Board issued its report *Undergraduate Science, Mathematics, and Engineering Education* (National Science Board, 1986), in which it stated: "The recommendations of this report make renewed demands on the academic community—especially that its best *scholarship* [emphasis added] be applied to the manifold activities needed to strengthen undergraduate science, engineering, and mathematics education in the United States" (p. 1). The report helped revive the National Science Foundation's role to initiate and support science and engineering education programs. The report was also among those efforts that sparked a vigorous national dialogue on the role of scholarship in improving the quality of U.S. higher education (Boyer, 1990; National Science Foundation, 1992). The introduction in the 1990s of EC 2000 was also a major driver to improve the quality of U.S. engineering education (ABET, 1995). Its outcomes-focused, evidenced-based approach characterizes many aspects of systematic educational innovation.

These and other efforts paved the way for the assembly of a small community of scholars in engineering education by the beginning of this century. The growth of this community has been accelerated by several recent events, including the inauguration of the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education in 2001 and the creation of the Center for the Advancement of Scholarship on Engineering Education in 2002 (National Academy of Engineering, 2009b); the repositioning of the *Journal of Engineering Education* in 2003 to publish only engineering education research (Lohmann, 2005, 2008); the appearance of campus and national centers with a focus on engineering education (Atman, 2009); the creation of the degree-granting School of Engineering Education at Purdue in 2004 (Purdue, 2009), followed by departments at Virginia Tech, Utah State University, and Clemson; the launch of the international Research Symposium on Engineering Education (REES) in 2007 (Borrego, Froyd, and Knight, 2007; REES, 2009); and funding for engineering education research at the National Science Foundation (e.g., CAREER, EEC, DUE).

3 Empowering Engineering Faculty and Administrators (Who)

Career-long Professional Development and Supportive Environments

Why Focus on Engineering Faculty and Administrators?

This report is principally for engineering faculty and administrators. While other stakeholders are important, the teaching-learning experience is where the "rubber meets the road" and engineering faculty and administrators largely determine the quality of the experience. *Educating the Engineer of 2020* (National Academy of Engineering, 2005) states this well:

> Engineering faculty, of course, will be on the front line of any change, and encouraging and enlisting their support for engineering education innovations is essential. Providing incentives for their support is challenged by the present faculty reward system, which bases decisions for tenure primarily on excellence in research. The nation has benefited enormously from the efforts of research universities, through their research faculty and Ph.D. programs, but this has not necessarily translated into excellence in undergraduate education.[6] …Increased attention to teaching, to how students learn, and to student mentoring is important for enriching the undergraduate experience. To effect such changes, one must engage engineering faculty leaders, including deans, department chairs, and individual faculty in consideration of how to reward attention to and excellence in such activities (p. 23).

Sustained excellence seldom happens serendipitously. It is generally the result of a compelling vision, clear goals, careful planning, and a commitment to follow through. It often requires a willingness to embrace ambiguity, persist in the face of disappointments, adapt as necessary, and collaborate with diverse stakeholders. These are significant challenges and navigating them successfully requires both knowledge and experience. Engineering faculty, as professionals, should have the talents to be world-class leaders in their technical fields derived from scholarly research and experience in engineering, and they should be highly-effective educators, employing knowledge and techniques on learning that have been proven by research. Highly-qualified faculty members are the foundation of the excellent educational experiences our students and profession deserve.

The situation today, however, is far different than this ideal. As Ambrose and Norman (2006) describe it:

> When engineering faculty members enter the academy, many—through no fault of their own—are not fully prepared for their role as educators. Although graduate schools have begun to focus more attention on developing teaching skills, the main focus continues to be on creating researchers. As a result, when most faculty members enter the academy, they are, as Kuh and associates note (2005), "well intentioned gifted amateurs" when it comes to teaching.
>
> Furthermore, it has become increasingly clear that teaching and learning involve complex, interrelated intellectual, social, and emotional processes. Thanks to research in social psychology, the cognitive sciences, and education, we now know much more than we did 20 years ago about how cognition, motivation, and intellectual development affect learning and teaching. Unfortunately, universities have not successfully transmitted this information to faculty (p. 25-26).

Empowering engineering faculty and administrators to create and sustain a culture for scholarly and systematic educational innovation requires that they be well prepared to design and facilitate effective learning environments and that they be supported and rewarded when they do. The first issue speaks to career-long professional development in teaching, learning, and educational innovation and the second to supportive environments within and outside engineering programs. Both would also be greatly enhanced by more collaborative relationships with a broader set of partners.

[6] See Prince, Felder, and Brent (2007) for an analysis of research on this issue.

Strengthening Professional Development

The educational role of faculty members is not to impart knowledge; it is to design learning environments that support the process of knowledge acquisition (Adams and Felder, 2008; National Research Council, 2000). Competency in educational design requires domain-specific (content) knowledge, knowledge in teaching and learning, and reflective educational practice. If the current conversations continue to emphasize topics to be covered and experiences to be offered, it is logical to envision engineering education "teaching more and more about less and less, until it teaches everything about nothing" (National Academy of Engineering, 2004, p. 23). If we want informed, reflective conversations about learning outcomes and how to develop and assess students with respect to those outcomes, then programs for facilitating career-long development in teaching, learning, and educational innovation for faculty are critical to changing the conversations. Professional development programs and activities in teaching and learning are not remedial, although they are sometimes viewed as such on campuses that have them. Nor are they programs to learn new tricks in the classroom. Career-long professional development programs are characteristic of a mature profession that seeks to become better at what it already does well. They also provide a means to effectively link educational practice and research.

Career-long programs in teaching and learning are critical to promote informed and reflective conversations about student learning and educational innovation.

It is reasonable to expect students aspiring to faculty positions to know something about pedagogy and how people learn when they begin their academic careers (Ambrose and Norman, 2006; Boice, 1991; Bomotti, 1994; Golde and Dore, 2001; White, 1993). Although not all graduate students wish to become faculty, they can benefit from the knowledge and skills gained through integrating pedagogy and how people learn into their research and programs of study. Knowing how to explain difficult concepts; what misconceptions, preconceived notions, and biases people bring to learning; how to work with diverse groups; how to use learning and collaboration technologies; and so forth, are also valuable skills in industry, government, and non-profit organizations. We should assure that all students entering the professoriate are prepared to teach in informed and reflective ways and can apply an integrated content, pedagogy, and assessment design approach (Bransford, Vye, and Bateman, 2002; Fink, 2003; Pellegrino, 2006).

It is also reasonable for faculty members to expect support and encouragement for their continual development as educators and educational innovators just as they do for their growth as researchers and technological innovators (American Association of Physics Teachers, 2008; King, 2004; Science Education Resource Center, 2008). This is especially important during the pre-tenure years and is helpful if continued into their mid-careers. Faculty should be encouraged to take advantage of local, regional, national, and international opportunities to advance both their knowledge about education and their discipline throughout their faculty careers, and they should be recognized and rewarded for doing so. Professional development programs need to acknowledge the different stages of faculty careers, prior education, experiences, and departmental, college, and university settings, among other factors. A considerable body of knowledge exists on designing and offering effective professional development programs (Fink, Ambrose, and Wheeler, 2005; Gillispie, 2002; Seldin, et al., 1990; Sorcinelli, et al., 2005; Weimer, 1990).

Nonetheless, a few points should be considered in designing effective professional development programs, initiatives, or activities. First, a core purpose of programs to advance teaching and learning expertise is to extend the participants' pedagogical content knowledge. Shulman (1986, p. 9) describes such knowledge as

> the most useful forms of representation of [topics], the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others. … Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult, the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons.

In essence, helping faculty learn to effectively merge deep knowledge of their subjects (content) with effective knowledge on how people learn lies at the heart of their becoming better educators and educational innovators. Second, just as faculty members should design learning environments for their students that are grounded in research on teaching and learning, designers of professional development programs should similarly incorporate research results related to the processes of adult learning, instructional change, and effective program design with engineering faculty in mind. For example, Wlodkowski (1999) suggests five factors that motivate adult learners: expertise of the presenters, relevance of the content, choices in application of the content, opportunities for action and reflection, and group work. Third, professional, accreditation, and other education-related organizations should help expand professional development opportunities and provide forums for inter-institutional networking and sharing of "best practices."

Among the most well-known programs for improving engineering faculty teaching is the National Effective Teaching Institute. This program has been offered annually at the society meeting of ASEE since 1991, as well as at other national and international locations (see inset). Faculty wishing to expand their understanding of educational research should consider one of the workshops recently developed by the National Science Foundation project "Rigorous Research in Engineering Education" (RREE, 2009; Smith, 2006; Streveler and Smith, 2006). The workshops are also being disseminated internationally by the *Annals of Research in Engineering Education* and the *Journal of Engineering Education* (Lohmann, Smith, and Streveler, 2008, 2009).

Even well-designed, numerous, and easily accessible career-long professional development programs will not achieve their purpose if engineering programs do not seriously address issues of incentives and recognition, both individually and organizationally; without encouragement, significant numbers of faculty are not likely to take full advantage of the opportunities provided.

Impact of the National Effective Teaching Institute

The National Effective Teaching Institute (NETI, 2009) is a three-day teaching workshop conducted at the ASEE annual conference. Topics include learning and teaching styles, learning outcomes and objectives, assessing learning, student-centered instructional methods, and dealing with some common problems in the lives of engineering educators. Deans of engineering and engineering technology in North America are invited to nominate up to two of their faculty members, and applications are accepted on a first-come-first-served basis up to a maximum of 55 participants. Since 1991, the workshop has been attended by 935 professors from 209 different colleges.

In spring 2008, NETI participants whose contact information could be found were surveyed regarding their teaching practices, student ratings, and involvement in instructional development and educational scholarship (Felder and Brent, 2009). Six hundred seven surveys generated 319 usable responses. The ideal assessment of the workshop would have been to measure its impact on student learning. Conducting such measurements retrospectively was not possible; however, studies have shown that aggregated self-assessments of teaching effectiveness compare well with external evaluations by trained observers (D'Eon, et al., 2008), and when the participants' self-assessments were combined with their aggregated student ratings, the impact of the workshop on learning could be reasonably inferred. Highlights of the survey findings include the following.

Teaching Practices: The strategies most heavily emphasized in the workshop are designing instruction to address a broad spectrum of learning styles; using learning objectives as the basis of design, delivery, and assessment of instruction; and active learning. Substantial percentages of the respondents reported using those strategies following the workshop and credited NETI with motivating them to do so.

Student Ratings: Sixty-seven percent of the respondents reported increased student ratings following the NETI, 29 percent saw no change (some of them had close to the maximum rating before they came), and 6 percent experienced decreased ratings, with only one of the decreases being substantial.

Instructional Development: Fifty-two percent felt that the workshop motivated them to become involved in instructional development, with 44 percent already having done so.

Educational Scholarship: Many respondents reported engaging in practices that characterize scholarly teaching: 89 percent read education-related journal articles, 73 percent participated in education conferences, and 69 percent belonged to ASEE, with between a third and one-half of each group having been motivated by NETI. Three-quarters of the respondents had done educational research, half of whom were induced to do so by NETI.

The survey results strongly suggest that the workshop successfully motivated many participants to increase their use of effective teaching strategies; made their teaching practice more student-centered and scholarly; increased the student ratings for most of them; and induced a number of them to engage in instructional development.

Creating a Supportive Environment

Schein and his colleagues (2003) argue that "culture is a complex force field that influences all of an organization's processes. We try to manage culture but, in fact, culture manages us far more than we ever manage it, and it happens largely outside our awareness" (p. 11). If we wish to encourage a more scholarly and systematic approach to engineering educational innovation, we must *consciously* work to create it. This requires that educational innovation become a visible, valued, and strategic priority of engineering departments and colleges with the associated planning, programs, and processes to sustain it.

Within the engineering academic environment, three principal actions can rapidly increase support for engineering educational innovation. First, increase access to knowledgeable individuals in credible and sustainable units or activities that foster scholarly and systematic engineering educational innovation (Finelli, et al., 2008). Whatever forms these "units" may take (such as stand-alone department or college centers, department/college-based arms of university units, degree-granting departments, etc.), engineering education R&D units should promote a mix of knowledge creation, dissemination, and application to increasing scholarship and teaching practice in engineering education. The type, scope, and balance of activities should reflect the history, mission, and aspirations of the engineering program, and they should be integral to the academic fabric of the department or college.

"Culture manages us far more than we ever manage it, and it happens largely outside our awareness" (Schein, et al., 2003, p. 11). We must *consciously* work to create and sustain a culture of scholarly and systematic educational innovation.

Second, provide adequate department and college resources to initiate, experiment, and implement educational innovations. While extramural support, especially peer-reviewed support, is an important element to identify and validate highly-competitive and meritorious educational innovations, department and college support is critically important to encourage faculty initiative and to sustain successful innovations. Allocation of resources to support these activities is also an important and symbolic statement of a program's commitment to engineering educational innovation.

Third, ensure that faculty recruitment, hiring criteria and standards, and reward structures explicitly consider achievements in educational innovation (beyond teaching excellence), including promotion and tenure criteria, processes, and practices, as well as the merit evaluation of chairs, departments, deans, and colleges. Addressing the reward structure "may involve reconsideration of the basic structure of engineering departments and the infrastructure for evaluating the performance of professors…" (National Academy of Engineering, 2004, p. 23). While it may be tempting to point to engineering administrators for leadership on this issue, leadership must also come from engineering faculty members themselves. Rare would be the department chair or college dean who does not know that his or her authority to lead is determined by the degree to which it is granted by the faculty and the degree to which he or she leads by example. On the one hand, chairs, deans, and faculty committees often claim that they recognize scholarly educational innovations when they can be documented and measured, and that these contributions are rewarded in the same manner as technological innovations. On the other hand, the validity of those claims remains a persistent concern among faculty rising through the professorial ranks. Regardless of whether the claims and concerns are real or perceived, the dissonance clearly remains a problem. We encourage chairs, deans, and faculty committees to continue to examine the merits and transparency of their faculty reward and recognition processes. As we build the culture and infrastructure for scholarly and systematic educational innovation, which has many similarities to scholarly and systematic technological innovation, we hope the polarizing discussion of the rewards and recognitions for "teaching vs. research" will diminish.

Engaging in New Relationships

A quality engineering educational experience requires the support of many stakeholders and others beyond engineering faculty and administrators. The list is long, the players well known, and their roles historically framed in supplier-customer relationships:

- mathematics, humanities, and natural and social sciences faculties supply scientific, mathematical, and liberal arts instruction to engineering student customers;
- funding agencies supply resources, ABET "supplies" credentials, K-12 and community colleges supply students to engineering program customers; and
- engineering programs supply engineers and continuing education to employer customers, students to graduate education customers, engineering learning modules to pre-college customers, etc.

Industry knows well that the customer-supplier model, with its strict demarcation of roles, no longer works. It has moved to a collaborative-distributed model where creating value is shared. Engineering education needs to move to a new approach built more on inter-organizational collaborations focused on the formation of engineers rather than one based on suppliers and customers delivering instruction to engineering students. The approach must embrace students long before they matriculate and continue to support them throughout their careers.

Developing this alternate approach requires that we develop new relationships with both old partners and new partners. For example, while many engineering faculty are developing very innovative simulations, virtual models, and other technology-based learning approaches, they have much to gain from collaborations with learning scientists, information technology specialists, and other experts in this area. We can "curse the spread of cell phones, Facebook pages, and text messaging, or we can recognize the new ways in which students communicate and process information, and embrace these to improve education" (Cohn, 2009). Flowers (2009) argues that well-designed on-line systems could take care of the "training" aspects of engineering education while allowing faculty more time to spend helping students learn (as was done in the CBI example presented on page 8).

Further, engineering programs would benefit considerably from including students in the educational design process. We can learn an enormous amount from students about how they learn best and what motivates them to learn. These two issues lie at the heart of deep learning as well as recruitment and retention of engineering students (Chubin, et al., 2008; Li, et al., 2008; Lichtenstein, et al., 2009; Pomales-Garcia and Liu, 2007; Sheppard, Pellegrino, and Olds, 2008a).

Finally, one must remember that engineering programs are education programs, yet we seldom draw upon the abundant bodies of knowledge on how people learn. Some of the new knowledge informing engineering education innovations will be unique to engineering and will be created by the engineering community, while other knowledge will come from collaborations outside engineering, such as the extensive educational scholarship in the sciences, social sciences, humanities, and education generally. Many disciplines, notably the natural sciences and mathematics, have long invested in research in education, and their fields have grown richer in understanding issues of cognitive, social, and behavioral development. Developing collaborative partnerships with these and other learning science communities is important to engineering education innovation, to the future of engineering education, and to the quality of America's engineering workforce in both the short and long term.

Engineering education must move from its customer-supplier model of delivering engineering instruction to a collaborative-distributed model of shared investment in the formation of engineers.

4 Integrating Engineering and Learning (What)

Invigorating Engineering Education with What We Know about Learning

Grounding Our Efforts in How People Learn

In a recent paper commissioned by the National Center on Education and the Economy for the New Commission on the Skills of the American Workforce, Pellegrino (2006) speaks to several critical issues facing American education generally. The issues are particularly applicable to American engineering education.

> Whether we recognize it or not, three things are central and operative in the American educational enterprise—curriculum, instruction, and assessment. The three elements of this triad are linked, although the nature of their linkages and reciprocal influence is often far less explicit than it should be. Furthermore, the separate pairs of connections are often inconsistent which leads to overall incoherence in the educational enterprise. …A precept of educational practice is the need for alignment among curriculum, instruction, and assessment. ...
>
> Most current approaches to curriculum, instruction, and assessment are based on theories and models that have not kept pace with modern knowledge of how people learn. They have been designed on the basis of implicit and highly limited conceptions of learning. Those conceptions tend to be fragmented, outdated, and poorly delineated for domains of subject-matter knowledge. Alignment among curriculum, instruction, and assessment could be better achieved if all three are derived from a scientifically credible and shared knowledge base about cognition and learning in the subject matter domains (p. 2-3).

While there are many important findings about learning and understanding that bear on the design of curriculum, instruction, and assessment, Pellegrino offers three important principles, each based on solid research, that have strong implications for how we teach and design effective learning environments.

- Students come with preconceived notions about how the world works, which include beliefs and prior knowledge acquired through various experiences.
- Developing competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize facts and ideas in ways that facilitate retrieval and application.
- A "megacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

Pellegrino concludes:

> While the above three principles, and others, are now well understood and have been shown to be operative in multiple areas of the curriculum, it is an unfortunate reality that little of this knowledge has found its way into contemporary curricular materials and instructional practices. Included among the latter are problem-based and project-based approaches to instruction of the type seen in other countries and in certain areas of advanced education, including medicine, law, and engineering (p. 5-6).

Recent literature, program announcements, and themes in engineering education conferences and meetings confirm that many of the current efforts to improve engineering education use more contemporary approaches. This is good news. However, these efforts would be well served if they took greater advantage of the theories and practices of how people learn (Felder, Sheppard, and Smith, 2005; Sheppard, Pellegrino, and Olds, 2008b). Doing so would assure more effective program development, facilitate dissemination, and encourage broader adoption. Therefore, in this section we illustrate how confirmed learning theories and pedagogical practices can be employed in the design, development, implementation, and dissemination of effective engineering education innovations. We focus on three areas in which engineering education is (justifiably) directing a considerable amount of attention: making engineering programs more engaging, relevant, and welcoming. In the next three subsections, we review some concepts and approaches on how people learn as they relate to these three areas, share examples of engineering education innovations that employ these concepts, and illustrate the application of the innovation cycle of educational practice and research.

Engaging Learning Environments

Engineering teaching often begins with theories and abstractions and then progresses to applications of those theories. Indeed, the engineering curriculum itself is similarly structured, beginning with the foundational topics (e.g., science, mathematics, humanities) and progressing to the senior capstone design experience. Few engineering students learn well this way. As Sheppard, et al. (2009) state:

> First, it is important to grasp that students are on a trajectory from novice to competent performance as practitioners. That is, students must learn to move from solving highly structured problems involving formal concepts, as in their theoretical courses, toward building ability to both formulate and solve less structured, more uncertain kinds of problems. In one sense, this describes a linear progression.
>
> The surprising insight from learning theory, however, is that the most efficient way to facilitate this transition is not a simple one-way movement, starting from "theory" courses and ending with unstructured design. In a professional practice like engineering, competence is manifested in the ability to read complex and ambiguous contexts and to carve out from them the important and productive problems that can then be addressed with precision through structured problem-solving techniques. Developing this capacity requires not a once-and-for-all movement from theory to application, but a continuing back-and-forth between general theoretical principles and the particularities of the problem situation as the student builds more sophisticated skills through experience (p. 24).

Instructional approaches, such as inquiry learning, problem-based learning, project-based learning, case-based learning, guided discovery learning, just-in-time teaching, and other pedagogies of engagement blend inductive and deductive processes by introducing topics through observations, case studies, or problems and by teaching theory when the need to know it has been established. While evidence varies from one method to another, these approaches are at least equal to, and in general more effective than, strictly deductive methods for achieving a broad range of learning outcomes (Leung, et al., 2008; Prince and Felder, 2006). Further, these more engaging pedagogies "redefine the purpose of colleges and universities to learning and in so doing dramatically alter the roles of teachers and learners…students teach and learn from one another as well as from faculty, and instructors are learning guides and facilitators rather than knowledge dispensers" (Pascarella and Terenzini, 2005, p. 645). A large-scale correlational study by Astin (1993) found that two environmental factors—interaction among students and interaction between faculty and students—were the most predictive measures of positive change in college students' academic and personal development and satisfaction. When coupled with other studies (Kuh, 2008; Light, 2001; Pascarella and Terenzini, 1991, 2005; Vogt, 2008), we know that how students approach their education and how faculty approach the curriculum and interact with students have profound effects on student performance well beyond the content, collection, and sequence of courses.

Moving students from novice to competent practitioners is not a one-way movement. It requires continuing back-and-forth movements from general principles to problem particularities as students build sophisticated skills through various experiences.

However, implementing engaged learning approaches has challenges, including overcoming a significant educational socialization of faculty and students accustomed to more traditional instructional methods.

> Employees enrolled in industry courses often show resistance to being asked to begin instruction by trying to solve problems. Most want the efficiency of being told the answers to problems rather than first trying to generate answers and discuss them with peers. Deep within their educational experience, this dependency has emerged in the form of distorted neural plasticity; they have been conditioned to respond to a single "correct" solution (Richey, 2009).[7]

Engaged learning, or cooperative learning, has been part of the landscape of engineering education for at least thirty years (Smith, Johnson, and Johnson, 1981a, 1981b) and has been continually refined for higher education faculty in general (Johnson, Johnson, and Smith, 1991, 1998, 2007; MacGregor, et al., 2000; Millis and Cottell, 1997; Smith, Cox, and Douglas, 2009) and engineering educators in particular (Felder, 1995; Prince, 2004; Smith, et al., 2005, Terenzini, et al., 2001). For example, the influence of foundational work on cooperative learning is evident in the University of Delaware Problem-based Learning model (Allen, Duch, and Groh, 1996; Duch, Groh, and Allen, 2001), the SCALE-UP model at North Carolina State University (Beichner, et al., 2000), the Technology Enhanced Active Learning model at MIT (Dori and Belcher, 2005; Dori, et al., 2003), and the Legacy Cycle model from the VaNTH Center (Rayne, et al., 2006).

However, simply engaging students in discussions or collaborative activities is not enough. One must understand that the foundation of such learning is the theory of social interdependence, which argues that highly engaging and productive learning environments require the simultaneous presence of a need to work together (interdependence, such as a challenging problem, a complex project, difficult concepts, multiple perspectives) and a high level of individual and mutual accountability (support, i.e., members can count on one another) (Deutsch, 1949; Johnson and Johnson, 1974, 1989). More importantly, the simultaneous presence of these two factors has also been shown to be critical to creative performance (Edmondson, 2008; Pelz, 1976; Pelz and Andrews, 1966; Sanford, 1967). Efforts such as Women in Engineering and Minority Engineering Programs, and the professional societies associated with them (e.g., Society for Women Engineers, Women in Engineering ProActive Network, National Association of Multicultural Engineering Program Advocates Network), are exemplars of the power of social interdependence.

The example in the inset on page 17 titled "A Research Communications Studio to Promote an Inquiry-based Community of Practice," is an example of an engaged instructional approach.[8]

Indeed, the importance of the theory of social interdependence, cooperative learning, and balancing challenge and support for creative performance may extend well beyond the classroom and university (Smith, 2008). For instance, the United States has been guided recently by calls to increase its global competitive advantage. However, counter arguments call for increasing its global *collaborative* advantage and developing the knowledge, skills, and habits of mind that support developing collaborative approaches to challenges and opportunities. Lynn and Salzman (2006) argue:

> The United States should move away from an almost certainly futile attempt to maintain dominance and toward an approach in which leadership comes from developing and brokering

[7] The slight preference for CBI vs. lecture-based instruction exhibited by students in the example on page 8 may be due in part to this conditioning.

[8] The example on page 8 as well as the forthcoming example on page 19 also include engaged instructional approaches.

A Research Communications Studio to Promote an Inquiry-based Community of Practice

Problem and Team

Three engineering programs, chemical, electrical, and mechanical engineering, created and assessed the Research Communications Studio (RCS), which was designed to help undergraduate students do authentic written, oral, and graphical communications tasks while also learning to do research. In the RCS, small groups of undergraduate researchers meet weekly with an experienced communications faculty member, an engineering graduate mentor, and a communications graduate mentor. The RCS is built upon the theory that learning is constructed by students by interacting with other students and teachers (social constructivist theory). In the RCS, learning occurs during facilitated communication and reflective activities. RCS also utilizes distributed cognition, i.e., each group member's expertise is available to other group members. In communicating their research to others, students discover gaps in their own knowledge, a necessary stage to knowledge construction. Students practiced oral and poster presentations as well as wrote progress reports and pieces for publication.

Study and Results

The analysis triangulates across various data sets, including surveys from engineering faculty members, undergraduate researchers, graduate mentors, participants' reflective writings, and digitized video recordings of weekly RCS sessions. The results showed increased satisfaction and performance in the students' ability to organize and communicate their research more effectively. In terms of metacognition (explicitly thinking about their learning processes), participants clearly moved from novice toward expert in research ability, becoming more knowledgeable about communication, and in using other group members' feedback effectively. Discourse analysis revealed seven important speech acts that educators can recognize and promote to facilitate active learning in more traditional pedagogical settings: elicitation of critique, critique, internalization, (direct and indirect) instruction, contextualization, explanation, and negotiation and consensus-building.

Implications for Practice

A social constructivist environment for learning can be created among undergraduate researchers and experienced mentors. Metacognitive strategies can be explicitly taught and practiced (through habitual verbal reference and reflective writing assignments) so that students can more readily track the path of their learning. Such strategies facilitate self-directed learning and life-long learning. As noted in *How People Learn* (National Research Council, 2000), "Teaching approaches congruent with a metacognitive approach to learning…have been shown to increase the degree to which students transfer their learning to new settings and events" (p. 12). The results from the project have been integrated into other degree programs, both at the host institution and elsewhere.

References

Craig, Thompson, and Donath, 2005; Donath, et al., 2004, 2005; Long, et al., 2004; Long, Matthews, and Thompson, 2007; Thompson, et al., 2005.

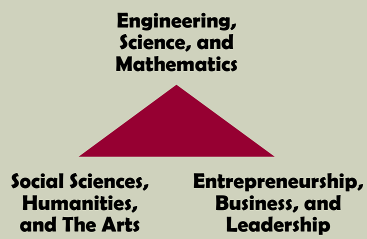
> mutual gains among equal partners. Such "collaborative advantage," as we call it, comes not from self-sufficiency or maintaining a monopoly on advanced technology, but from being a valued collaborator at various levels in the international system of technology development (p. 76).

They further state that "the United States needs to develop a S&T [science and technology] education system that teaches collaborative competencies rather than just technical knowledge and skills" (p. 81). Their research indicates that working across disciplinary, organizational, cultural, and time/distance boundaries is important.

Achieving collaborative and creative performance in engineering learning environments requires that we balance academic challenge, that is, an academic demand that may be beyond the individual student's capacity to achieve, with social support, that is, classmates and faculty who provide assistance and who care about and are personally committed to helping students succeed (Vygotsky, 1978). The greater the social support, the greater the academic challenges can be. Further, despite faculty concerns that more engaging curricula may increase student workloads and thereby decrease instructor evaluations, evidence suggests this is not the case (Dee, 2007). In light of the ever expanding bodies of engineering knowledge and the increasing scale and complexity of engineering challenges, engaged approaches to teaching are more amenable and sustainable for preparing future engineers than our continued reliance on direct instruction and skill-and-drill.

Relevant Learning Environments

While including more engaging learning experiences is important, so too are experiences that prepare graduates for practice (Parsons, Caylor, and Simmons, 2005; Schuurman, Pangborn, and McClintic, 2008). As Nobel laureate Herbert Simon (1996, p. 1) states, "The meaning of 'knowing' has shifted from being able to remember and repeat information to being able to find and use it." The trend in engineering education has been to provide more science and to focus more narrowly, with reduced emphasis on hands-on engineering. However, engineering today involves team-based cross-disciplinary projects that require engineers who are "technically adept, culturally aware, and broadly knowledgeable, as well as innovative, entrepreneurial, flexible, and mobile" (Continental, 2006, p. 33). It is imperative, therefore, that engineering students experience this type of real-world engineering as part of their professional formation as engineers (Trevelyan, 2007). It is equally important that students have design-related experiences early in their academic careers and not wait for the senior design capstone experience to do "real engineering." By the same token, engineering faculty should reflect on their individual as well as collective talents and traits to assure that they are well prepared to design educational experiences that provide students with repeated opportunities over time, both formal and informal and inside and outside the classroom, to gain a real-world professionally relevant education (Lattuca, Terenzini, and Volkwein, 2006).



Opportunities for more relevant experiential learning can integrate the fundamental components of an engineering education.

The importance and impact of more relevant experiential learning in engineering education has been confirmed in a number of reports. For example, Chubin, et al. (2008) recently reported that when freshmen and sophomores were asked what experiences had a positive impact on their desire to become an engineer, other than interaction with professors and teaching assistants, they most frequently mentioned team projects, internships, and extracurricular activities. A special issue of the *Journal of Engineering Education* adds to this important point from the perspective of a societal good (Sheppard, Pellegrino, and Olds, 2008b):

> U.S. engineering education must not only prepare graduates to work in this rapidly changing world, but also engage students in disciplines beyond engineering to make them better engineers and more informed human beings and citizens (Bok, 2005). Educated professionals, such as engineers, with a highly developed understanding of technical matters and a well grounded sense of social responsibility, are arguably among the best equipped to struggle with the complexity of consequences of technological innovation and intervention. This should challenge each of us in engineering education to reflect deeply on the significance of integrating ethical reasoning into the learning agenda in a more intentional and holistic manner (p. 231).

The recent expansion of experiential learning in many engineering programs is capturing our students' desires for an education that will enable them to contribute to the solution of problems of societal significance (Coyle, Jamieson, and Oakes, 2006; Lamancusa, et al., 2008). For example, a larger percentage of women students articulate the need to make a positive societal impact in the practice of engineering compared to their male counterparts (Adelman, 1988). Thus, engineering education today must go beyond technical fundamentals, not just in response to the growing complexity of engineering problems, but also to attract and retain excellent students.

The inclusion of more relevant learning experiences in U.S. engineering curricula should be guided by three common principles. First, content: students should gain a basic understanding of the sciences and mathematics; an appreciation of the social sciences, humanities, and the arts; an emphasis on creativity, design, and leadership; and comprehensive training in one or more of the engineering disciplines. Second, faculty: engineering faculty, as a collective body of professionals, should possess significant talent in cutting-edge technical research and development, educational research and teaching, and contemporary engineering practice. Third, practice: engineering programs should reflect upon the experiential aspects of the education they seek to provide to their students, decide what they will emphasize, and clearly align their curricula based on these choices.

An example of the innovation cycle presented in Section 2 as applied to assessing an experiential learning curriculum is briefly described in the inset on page 19 titled "Promoting Self-directed, Life-long Learning through an Experiential Global Studies Program."

Providing more relevant learning experiences requires reaching beyond the resources within engineering, science, and mathematics to embrace the practice of engineering in a global context and applying leadership and systems thinking in teams involving international and multicultural perspectives. Given these trends, both faculty and students need increased exposure to the contemporary practice of engineering, disciplines beyond engineering science, and principles of leadership in a global context. This can be accomplished without lengthening the four-year curriculum—provided engineering faculty and administrators allow more flexible engineering curricula.

Promoting Self-directed, Life-long Learning through an Experiential Global Studies Program

Problem and Team

Self-directed learning (SDL) and life-long learning (LLL) are among the skills strongly advocated for today's engineers by many national reports and ABET. Studies were conducted to assess the extent to which an ongoing experiential program, called the Global Studies Program, increased student readiness for SDL and LLL. The team was composed of experience and expertise in assessment, chemical engineering, and interdisciplinary and global studies.

Study and Results

The study used three assessment methods: the nationally recognized Individual Development and Educational Assessment system (IDEA) and the Self-directed Learning Readiness Scale (SDLRS), and an internal student project quality assessment protocol involving trained and calibrated faculty evaluators. Comparisons were made involving four cohorts of Global Studies students and comparable cohorts of non-participating students both locally and from a national data set. The Global Studies Program involves completion of an interdisciplinary project during the course of one semester. Students complete site and project-specific preparation work and then spend two months off-site at an international location completing their project in teams of three to four students. The total preparation and sojourn experience is 4.5 courses (13.5 credit hours).

The IDEA system results showed that the project preparation experience strongly improves student acquisition of SDL and LLL capacities in research capabilities, critical thinking skills, and oral and written expression, both deeply (individual student gains) and broadly (most students benefited). Faculty review of the final reports further confirmed improved SDL and LLL abilities with better reviews of the literature, understanding, and synthesis; and better choices and applications of methodology. Critical thinking was apparent in the rigor of the analyses, with conclusions grounded in sound interpretation and better written and visual communication. However, only modest improvements were observed in student readiness for self-directed learning, and some reported declines in the SDRLS.

Implications for Practice

Assessing SDL, and especially LLL, is difficult since it involves judging future behavior. Nonetheless, the Global Studies Program clearly improved important SDL and LLL skills more so than for the non-participating students. Two interesting observations of concern were that students with higher self-perceived SDL readiness and those sojourning to non-English speaking locations may be disproportionately at greater risk for having negative SDL experiences. Extensions of this work include investigations into faculty preparedness to help students develop cross-cultural competence. Further, the work has underscored that understanding complex dynamic cognitive issues requires nuanced and triangulated approaches from multiple perspectives. A single disciplinary lens will not likely see the complexities at the heart of student learning.

References

Jiusto and DiBiasio, 2006; DiBiasio and Jiusto, 2005; DiBiasio and Mello, 2004.

Welcoming Learning Environments

While engineering programs may take pride in higher persistence rates than other undergraduate majors (for example, 57 percent of engineering matriculates remain in engineering compared to 55 percent in business, 44 percent in science and mathematics, and 38 percent in computer science), the attrition rate is still too high, especially in light of the "pre-screening" that typically characterizes entry into engineering programs (Fortenberry, et al., 2007; Ohland, et al., 2008; Seymour and Hewitt, 1997). Further, once lost, these students are seldom replaced; engineering has the lowest percentage of students "migrating into" the field (7 percent of enrolled engineering students were not engineering matriculates compared to 35 to 59 percent for all other majors) (Ohland, et al., 2008). In addition, although women and underrepresented minority students generally persist in engineering at the same rates as majority students, their overall absence from the engineering student body relative to their presence in other professions (e.g., medicine, law) and in the American population remains a problem. Studies have shown that a primary culprit in the attrition of students from engineering is their perception of a learning environment that is often unmotivating and unwelcoming; it is neither the students' capabilities nor their potential for performing well as engineers that determines their persistence. These perceptions are even more problematic for women and underrepresented ethnic and racial minorities (Bergval, Sorby, and Worthen, 1994; Busch-Vishniac and Jarosz, 2004; Harris, et al., 2004; Salter and Persaud, 2003; Sax, 1994; Vogt, Hocevar, and Hagedorn, 2007).

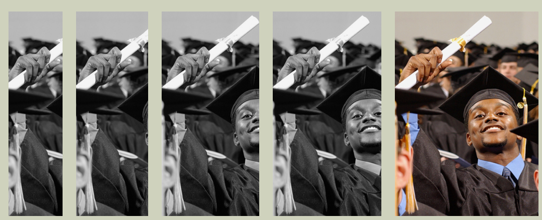
Without question, engineering faculty want students to succeed; however, they (and their students) often do not realize that a lack of knowledge about how people learn is a root cause of the mismatch between faculty and student perceptions of the learning environment. The result is often a learning environment that is unmotivating or unwelcoming (or even disrespectful) to students (Chubin and Malcom, 2008; Russell, Hancock, and McCullough, 2007). Seymour and Hewitt (1997), in their often-cited study *Talking About Leaving*, conclude that "…the most effective way to improve retention among women and students of color, and to build their numbers over the longer-term, is to improve the quality of the learning experiences for all students…" (p. 394).

For example, students have an evolved sense of when they have put in enough effort on a learning task. This sense is affected by the motivational belief of the student for the task at hand. The task could range from completing a course to completing an engineering degree. Research has shown that self-efficacy is a powerful motivational construct relating to choices to engage in class activities and to persistence in engineering (Hackett, et al., 1992; Lent, et al., 2003).[9] Self-efficacy beliefs are an individual's beliefs about his or her ability to succeed at a particular task (Bandura, 1997). These beliefs are formed over time through four primary sources, including mastery experiences, attempting the task; vicarious experiences, observing the experiences of others who attempt the task; social persuasions, feedback from others about ability to complete the task and psychological states; and feelings that arise while doing the task, such as anxiety, etc. Mastery experiences are believed to be the most influential. Thus, to treat all engineering students as if they come with the same evolved sense of the value of effort and motivation is destined to result in many students failing to see that effort "pays." These students soon believe that learning engineering is too dependent on luck or innate aptitude and leave for other majors in which they believe they have more personal control and a better fit (Chubin and Malcom, 2008).

Another example includes "stereotype threats." Steele and Aronson (1995) observed that they could lower the scholastic performance of students by presenting negative group stereotypes prior to students performing academic tasks. This detrimental effect was labeled "stereotype threat." Other studies show that academic performance of virtually any identity group can be influenced by stereotype threat (Bell, et al., 2003; Steele, 1997, 1998; Steele and Ross, 2004), such as Hispanics (Gonzales, Blanton, and Williams, 2002; Schmader and Johns, 2003), students from low socioeconomic backgrounds (Croizet and Claire, 1998), females in mathematics (Good, Aronson, and Harder, 2008; Inzlicht and Ben-Zeev, 2000), and even white males when faced with the specter of Asian superiority in math (Aronson, et al., 1999). Recent research shows that the behavior of our own engineering students toward their fellow students contributes to an unwelcome learning environment (Hutchinson-Green, Follman, and Bodner, 2008; Wolfe and Powell, 2008).

An example of the relevance of these kinds of studies to engineering learning, and an application of the innovation cycle that begins with educational research, is briefly described in the inset on page 21 titled "Faculty Influence on Engineering Student Learning."

Understanding our students is crucial to designing a welcoming learning environment. An educational environment bereft of diverse ideas and diverse people is unlikely to be maximally effective.



Studies show it is neither the students' capabilities nor their potential for performing as an engineer that determines persistence. The most effective way to improve persistence is to improve the quality of the engineering learning experience.

[9] There are other motivational constructs that are also important to learning and persistence (Wigfield and Eccles, 2002; Pintrich, 2003; Svinicki, 2004).

Faculty Influence on Engineering Student Learning

Problem and Expertise

Significant numbers of students depart from engineering programs before graduation, and faculty approachability appears to be critical. This study investigated the degree to which faculty approachability influenced engineering students' academic integration into engineering programs. Prior studies confirm that high degrees of self-efficacy and academic confidence result in improved student retention and performance. The expertise in the study was composed of computer science, educational psychology, and statistics.

Study and Results

A survey was administered to engineering students at four large research universities. It covered all class levels, both genders, and several ethnic/racial groups. The instrument measured student feelings, attitudes, and perceptions in eight areas: (1) interactions with teaching assistants and faculty; (2) faculty approachability or accessibility; (3) self-confidence in academic ability relative to their fellow students; (4) motivation and ability to learn; (5) beliefs about effort relative to academic challenge; (6) cognitive strategies to gain additional subject knowledge; (7) the degree and manner in which they sought help; and (8) the degree and manner in which they sought peer support. Structural equation modeling was used to analyze the data, and potential confounding effects of gender and class with GPA were monitored. The primary result buttressed the call for engineering faculty to extend themselves more to all students. Perceptions of faculty distance lowered student self-efficacy, negatively impacted self-regulated learning behaviors, and resulted in lower GPAs. Further, the gains for women's self-efficacy exceeded those of men and led to equal profiles for men and women in terms of self-efficacy, critical thinking, and academic confidence.

Implications for Practice

The work confirmed the results of prior studies that show the environment created by faculty affects students' performance and persistence. When learners are engaged, active, and using strategies such as help-seeking, effort, and critical thinking, they have higher levels of academic self-confidence and self-efficacy, which raises their academic performance. Thus, faculty should take advantage of opportunities to be accessible to students in ways that generate positive and welcoming interactions, including in-class discussions, collaborative learning environments, advisement on student projects, etc. Indeed, in examining the subscale items for academic integration, even small changes can make a difference, such as sharing personal information, showing an interest in students, and being warm and open.

References

Vogt, 2003, 2008; Vogt, Hocevar, and Hagedorn, 2007.

5 Engaging U.S. Engineering Education

Phase 2 and Suggested Actions

What should we do?

Today, many local, regional, national, and international institutions, organizations, and agencies are engaged in far-reaching discussions about their future with potentially profound and long-lasting changes. This is a time when we, in engineering education, must be adaptive, innovative, entrepreneurial, and opportunistic. This is easier said than done. Bransford (2007), co-editor of the highly influential book *How People Learn* (National Research Council, 2000), describes this aptly: "The hard part of being adaptive and innovative is that often it forces us to change ourselves, our environments, or both. These changes can evoke strong emotions and take us away from our momentary efficiencies and comfort zones by forcing us to unlearn old skills, [and] tolerate momentary chaos and ambiguity in order to move forward..." (p. 2).

This report completes the first phase of our project. We now begin the task of engaging the broader community of engineering education stakeholders. Your thoughts, comments, and proposed actions are welcome, and we encourage you and your organization to share them with us.

They may be shared via a project Web page located on the ASEE homepage at www.asee.org until March 1, 2010. We will also gather feedback from a sample of engineering programs and engineering education-related organizations. A second (final) report will be issued by June 2010 incorporating the results of the feedback received.

During the course of this project, numerous examples and ideas were generated as potentially fruitful actions to help create a vibrant culture of scholarly and systematic innovation in engineering education. Some suggested actions were based on current practices, others on emerging innovations with potential for success, and still others on interesting ideas. Some actions were aimed at addressing specific issues raised in the report, while others were more general and applicable to many issues. We have chosen to provide a list of suggested actions categorized by the principal stakeholders. In most cases, the issue the suggested action seeks to address should be apparent.

While it is easy to speak of American engineering programs as if they are all alike, they are as different as their histories, their faculty, the universities in which they reside, the feeder schools upon which they depend, and the constituencies they serve. Thus, we leave to our colleagues' ingenuity and entrepreneurial spirit how best to pursue the suggested actions within the context of their own engineering programs. We believe the following suggested actions will point them in productive directions.

Engineering Faculty, Chairs, and Deans

Link Engineering Education Practice and Research

- Develop local communities of expertise in educational innovation via cross-unit appointments (e.g., joint/adjunct appointments between engineering and education, educational psychology, anthropology, ethnic studies, women's studies) and cross-disciplinary research collaborations with education and related learning science fields.

- Develop "educational incubators" where engineering faculty may experiment with new pedagogies with professional support and minimal risk.

- Include members of the K-12 community, education and learning science community, and industry on department and college curriculum committees.

- Create, or facilitate easy access to, units with expertise in educational innovation, such as stand-alone teaching/learning/educational innovation centers, centers affiliated with university units, or degree-granting departments.

- Create administrative support to facilitate "technology transfer" and "commercialization" of educational innovation in a fashion similar to technology innovation.

"The hard part of being adaptive and innovative is that often it forces us to change ourselves, our environments, or both. These changes can evoke strong emotions and take us away from our momentary efficiencies and comfort zones by forcing us to unlearn old skills, [and] tolerate momentary chaos and ambiguity in order to move forward..." (Bransford, 2007, p. 2)

- Publish educational innovations alongside technological innovations in department, college, and university magazines or through professional society newsletters, e-forums, etc.

- Review and modify, as appropriate, end-of-course/faculty evaluations of course/teaching effectiveness to ask questions focused on student learning.

Support and Recognize Educational Innovation

- Review hiring, tenure, and promotion guidelines, policies, and practices to ensure that educational innovation and pedagogical preparation beyond teaching excellence are recognized, rewarded, and transparent. Include support for educational innovation and faculty development in hiring packages. Include scholarly achievements in educational innovation as part of a candidate's *research* dossier. Include educational scholars and innovators on tenure and promotion committees as external references.

- Discuss individual and department faculty development plans in educational innovation during merit evaluations, post-tenure reviews, and unit reviews.

- Create endowed chairs or professorships on engineering education innovation.

- Support junior to mid-career faculty to participate in engineering education conferences and those who are more deeply involved in educational innovation to participate in general educational conferences (e.g., American Educational Research Association, International Society for Learning Sciences).

- Consider the suggestions in the National Academy of Engineering report (2009c), *Developing Metrics for Assessing Engineering Instruction: What Gets Measured is What Gets Improved.*

Prepare Future Faculty

- Integrate pedagogy into doctoral programs through coursework in education, educational psychology, etc., and/or mentored teaching programs to gain knowledge and experience in teaching. Include teaching apprenticeships and mentoring, as well as familiarity and proficiency with educational courseware and tools. Award a minor, certificate, or similar credential in engineering education. Include a chapter in doctoral dissertations on the pedagogical, curriculum, or broader educational merits of the research.

- Provide opportunities for some students to pursue studies in engineering education through educationally-focused engineering doctoral programs leveraging local education expertise, dual/joint, or major/minor programs in engineering education (e.g., programs where students holding engineering B.S. or M.S. degrees complete doctoral programs in psychology, educational psychology, higher education, anthropology, sociology, public policy analysis, or related fields), and doctoral degrees in engineering education.

Your thoughts, comments, and suggested actions are welcome. We encourage you and your organization to share them with us by March 1, 2010, at the project's Web page at www.asee.org.

Integrate the Curriculum

- Integrate the design experience vertically by including K-12, freshmen, sophomores, juniors, and graduate students in engineering design projects, e.g., the EPICS program first introduced at Purdue (Coyle, Jamieson, and Oakes, 2006) or competitive teams such as those that enter the Concrete Canoe, Future Car, Future Truck Challenge, North American Solar Car Challenge, and Future City.

- Horizontally integrate the design experience with elements that impact the translation of an engineering design solution to a real-world solution. These include business aspects (fund raising, communication, marketing, cost-effectiveness), societal impact (impact on people and the environment), and policy and governmental issues.

- Include partnership(s) of faculty across engineering, as well as with faculty in business, policy, and social science programs.

Promote Learning through Entrepreneurship

- Encourage more entrepreneurship programs or competitions to expose engineering students to business formation, intellectual property, business finance, and marketing (Bilén, et al., 2005). Develop the programs jointly with faculty in the business school. These experiences sometimes also connect students to alumni who may contribute both time and resources to the activity and to subsequent company formation.

- Increase the knowledge base on learning through entrepreneurship and how to facilitate such learning, including (i) determining desired entrepreneurship capabilities, (ii) assessing these capabilities, (iii) helping students self-assess their learning with respect to entrepreneurship, and (iv) evaluating and improving entrepreneurship programs with respect to desired capabilities. (The same suggested action also applies to educating the global engineer, developing leaders, and service learning.)

Educate the Global Engineer

- Offer a minor in international engineering. A minor might consist of 15 credits, with courses and a practicum abroad focusing on the language, culture, history, geography, society, or institutions of a particular country or region of the world. These programs can be developed from scratch within engineering or sometimes coupled to international programs in the humanities that exist at major universities. A student might take courses overseas, hold a summer internship in industry, conduct research overseas, engage in a service project, or any combination of these (e.g., Global Studies program at Worcester Polytechnic Institute, Humanitarian Engineering program at Colorado School of Mines).

- Integrate global competence into the fabric of the engineering curriculum through an integrated program of coursework and international study and/or engineering research or practice (e.g., the International Plan at Georgia Tech, 2005).

- The second bullet of Promote Learning through Entrepreneurship is also applicable to educating the global engineer.

Develop Leaders

- Support leadership development programs such as a structured program (e.g., Catalyst program) or through a retreat away from campus with a self-selected set of students (e.g., Leadershape). Encourage student leadership through student groups and societies, many of which undertake community service, and also through cross-disciplinary design projects and entrepreneurial teams.

- The second bullet of Promote Learning through Entrepreneurship is also applicable to programs to develop leaders.

Promote Learning through Service

- Encourage service-learning experiences in which students work with community members to address pressing needs. Beyond co-curricular programs, such as Engineers without Borders, develop curricula in which students go into the field for sustained engagement in community-focused design. These programs help students integrate their learning by providing learning opportunities that ask them to use their knowledge and skills to work with clients in the community (e.g., the American Indian Housing Initiative at Penn State).

- The second bullet of Promote Learning through Entrepreneurship is also applicable to programs to learning through service.

Enhance Faculty Experience

- Ensure more faculty have contemporary engineering experience, either before or during their academic career, such as “spin-in/spin-out” semester/summer programs, “bridge programs” for longer sabbatical-style immersion, and specific academic positions for professionals (i.e., professor of engineering practice).

ASEE

Develop National Resources

- Lead the development of a national network of seminars, workshops, and continuing education courses on education theory, research findings, and proven practices for engineering learning. Ideally, these would also be offered in collaboration with other professional engineering societies. Offerings should address graduate students, new faculty, mid-career faculty, and senior faculty and should possibly be accredited, perhaps by ABET. Create a certificate to recognize faculty who have become distinguished teaching scholars through faculty development programs.

- Form learning communities to develop and share faculty development efforts, including developing college and department leadership, perhaps led by the Engineering Deans Council and department heads groups.

- Encourage doctoral consortiums on engineering education innovations to provide visibility and enable communities of future faculty to showcase their work, be mentored by experts in the community, and receive feedback on their work in progress.

- Offer complimentary memberships in ASEE to graduate students from schools that are institutional members and have active campus representatives. Provide complimentary ASEE membership to active campus representatives, i.e., provide an incentive for active leadership (type and level of activity to merit such membership would need to be determined).

Disseminate and Promote Innovations

- Facilitate the dissemination of educational innovations, such as a Web site of funding opportunities (perhaps in partnership with others, e.g., National Academy of Engineering’s Center for the Advancement of Scholarship in Engineering Education) or creating a visiting innovator or innovator-in-residence program.

- Establish credible venues for disseminating scholarship of teaching/learning, integration, and application so that they match the impact of the *Journal of Engineering Education* in the scholarship of discovery. Increase the access and flexibility of search engines for ASEE conference papers.

- Revise the mission of the Engineering Research Council to include research in engineering education.

- Revise/utilize the annual campus report system to generate reports on nationwide educational innovation. Increase the effectiveness of section meetings to disseminate engineering educational innovations.

- Create a leadership group from the various professional engineering societies to develop a long-term inter-society strategy to facilitate engineering education innovation.

National Academy of Engineering

- Create an engineering education section.

- Create a prestigious symposium on engineering education similar to the current Frontiers of Engineering symposium.

- Expand the current Grand Challenge to "advance personalized learning" to a broader list of Grand Challenges in Engineering Education.

Professional Engineering Societies

Promote Educational Innovation

- Sponsor major honors for educational innovation.

- Carefully review national design competitions to ensure that timelines coincide with academic calendars and include deliverables that align with common course deliverables.

- Encourage student chapters on engineering education innovations as professional development for future faculty and engineering leaders.

Expand Collaborations

- Create education-focused interest groups, publications, and meetings. For example, encourage senior society sections to adopt student society sections in their regions. In many cases, student sections and their advisors, who are often energetic educational innovators, may invigorate senior sections.

- Encourage joint student organizations/meetings rather than propagate small, subcritical student sections.

- Integrate graduate student activities/conferences with undergraduate student conferences promoting broader communities of practitioners.

ABET

Enhance the Process

- Modify criterion 4 so that programs must show evidence of scholarly and systematic innovations as well as other actions to improve the program. These actions should be based on available information, such as results from Criteria 2 and 3 processes or scholarly and systematic study of student learning in engineering classrooms and related contexts.

- Modify criterion 6 to include continuing development in education and contributions to educational scholarship as part of faculty qualifications.

- Embrace qualitative research methods associated with learning outcomes and encourage meaningful action research that addresses local issues.

- Strengthen training of evaluators to match the level of on-campus educational innovators and ultimately reduce compliance behavior and increase the level of collaboration during accreditation visits.

Focus More on Learning

- Increase the emphasis on learning outcomes based on learning theories, assessment incorporating more scholarly education research practices, and utilization of results for improved student learning. That is, promote a mindset of assessment (focused on identifying strengths and areas for improvement) over a mindset of evaluation (judgment against a standard).

- Help promulgate exemplary teaching and learning tools and techniques.

Industry

Increase Access to Experience

- Increase the number of experiences for students, especially international co-op experiences and internships.

- Establish more opportunities for faculty to gain contemporary engineering experiences, especially those that engender exposure to global engineering practices, e.g., Boeing summer program. Establish formal partnership programs of rotational positions with engineering programs. Invite faculty to participate in events facilitated by corporate trainers and consultants.

Increase Connections to Education

- Encourage engineering line personnel to participate in benchmark surveys, serve as adjunct faculty, and other activities that connect line personnel with engineering programs.

- Increase participation in educational innovations to better understand the educational process by which skills, abilities, and attitudes are developed in students. Enunciate the value of scholarly and systematic engineering educational innovation within the corporation, such as employee training and development, customer support, marketing and sales, etc.

- Encourage educational scholarship in the industry environment. This allows access to (and research involving) practicing engineers and provides another link between theory and practice, e.g., the Boeing-LIFE Center partnership (LIFE Center, 2009).

Funding Agencies

- Substantially increase funding for individuals, groups of researchers, and departments and colleges that propose significant educational innovations. Also increase the diversity of scholarly areas of inquiry to accelerate the maturation of the field of scholarly inquiry in engineering education.
- Establish competitive long-term programs for faculty-practitioner "trading places" programs. Such programs help establish legitimacy, e.g., National Science Foundation GOALI program.
- Support assessment research to better develop descriptions, tools, instruments, processes, rubrics, etc. to evaluate educational innovations. Consider the suggestions in the NSF-funded initiative Engineering Education Research Colloquies (Special Report, 2006a, 2006b).
- Support programs for faculty preparation and development, especially programs that help faculty learn about the many facets of educational scholarship (e.g., framing a project, choosing methods of investigation, writing proposals and papers).

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Leah H. Jamieson
Jack R. Lohmann

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A Appendix
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Atlanta Meeting Participants

The following additional individuals contributed their thoughts and recommendations at a progress report meeting held November 4-5, 2008, in Atlanta, Georgia.

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Delores Etter, Southern Methodist University

Dennis Fallon, The Citadel

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Comments and suggestions on the recommendations and suggested actions contained in this report may be contributed on-line at the project Web page located at www.asee.org. Contributions will be accepted until March 1, 2010.