INNOVATION WITH IMPACT

Creating a Culture for Scholarly and Systematic Innovation in Engineering Education

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Dear Colleague:

This report represents the culmination of a series of evolving conversations that began in the summer of 2004 within the American Society for Engineering Education and that progressively broadened to include hundreds of engineering faculty, chairs, and deans across the United States. The initial conversations focused on how the Society could and should contribute to the national dialogue on preparing U.S. engineers for the 21st century. As a consequence of those conversations, ASEE launched in June 2006 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. A report based on those discussions led to this project, which began in October 2007 with support from ASEE and the National Science Foundation. The project sought to catalyze even broader conversations across the American engineering enterprise on creating a vibrant engineering academic culture for scholarly and systematic innovation to ensure that the U.S. engineering education enterprise keeps pace with changes in the engineering profession and in the world.

The project was conducted in two phases. Phase 1 involved the efforts of 68 volunteers who worked for more than six months to distill their thoughts and recent articles and reports into a set of critical issues and actions to advance U.S. engineering education. These were shared and discussed with another 37 volunteers at a meeting in November 2008 in Atlanta, Georgia. The advice and ideas from that meeting were incorporated into the report, "Creating a Culture for Scholarly and Systematic Innovation in Engineering Education," which was presented at the main plenary at the ASEE annual conference in June 2009 and posted on the ASEE website *(www.asee.org)*.

Immediately following that conference, Phase 2 was launched to seek additional advice and ideas from the broader U.S. engineering community on the critical issues and suggested actions in the Phase 1 report. The project's research team prepared and conducted a survey of a large sample of U.S. engineering programs to gather feedback and to establish a baseline on current practices in engineering education. This was supplemented by written feedback collected following the presentation of the report at a number of conferences and meetings over a two-year period. The feedback was analyzed, combined with the highlights of the Phase 1 report, distilled into seven recommendations and over 70 potential actions generated during the course of the project, and this final report prepared.

As reflected in the report title, we believe that there is an opportunity to foster a culture of innovation with impact. On behalf of all of those who contributed their time and energy to this project, we hope this report provides new ideas and timely inspirations to help make our world-class engineering programs even better—and to continue to evolve engineering education as a vibrant, high-performing, effective, efficient, collaborative, rigorous, and valued endeavor that is responsive to the changing needs of the profession and the world.

Sincerely,

Leah H. Jamieson, the John A. Edwardson Dean, College of Engineering, and
Ransburg Distinguished Professor of Electrical and Computer Engineering
Purdue University

Jack R. Lohmann, P.E.
Vice Provost for Faculty and Academic Development, and
Professor of Industrial and Systems Engineering
Georgia Institute of Technology

01 | EXECUTIVE SUMMARY

As engineering careers have become increasingly collaborative, multidisciplinary, entrepreneurial, and global, and as the pace of change of technology has accelerated, the expectations for engineering education have expanded. To the foundations of mathematics, science, engineering fundamentals, disciplinary depth, and professional and ethical standards have been added interdisciplinary breadth; communication; teamwork; global economic, environmental, and societal contexts; critical thinking; ingenuity; creativity; leadership; flexibility (ABET, 2011; NAE, 2004; McMasters and Komerath, 2005) … and the list continues to grow. Although the American engineering community has a rich history of commitment to continually improve the U.S. engineering education enterprise (ASEE, 2009), there are major gaps between our reports and our curricula, our desire to graduate diverse talent and our ability to deliver, and our encouragement for educational innovation and our follow-through to support it. At a time when local, state, and national resources for education are becoming increasingly scarce, expectations for institutional accountability and student performance are becoming more demanding. It is clear that "business as usual" will not ensure success in meeting the growing demands, much less a place at the forefront of the global engineering education community.

"...the issue is *not* simply a need for more educational innovations. The issue is a need for more educational innovations that have a *significant impact* on student learning and performance, whether it is through widespread and efficient implementation of proven practices or scholarly advancements in ideas, methods, or technologies."

If a "grand challenge" for engineering education is *"How will we teach and how will our students learn all that is needed to tackle the challenges of today and tomorrow?"* then the issue is *not* simply a need for more educational innovations. The issue is a need for more educational innovations that have a *significant impact* on student learning and performance, whether it is through widespread and efficient implementation of proven practices or scholarly advancements in ideas, methods, or technologies.

Several factors combine to limit the broad impact of our innovations. The dominant approach to engineering education innovation today is based largely on faculty intuition drawn from personal experiences as students and teachers. Seldom are engineering education innovations grounded in confirmed learning theories and pedagogical practices, and many innovations once implemented are not assessed for their effectiveness in achieving their stated objectives. Transfer of education innovations into practice falls prey to the same "valley of death" that challenges technological innovations. And neither educational innovation nor transfer or adoption of educational innovations has a firm place in the academic reward system.

Against this backdrop, the American Society for Engineering Education launched a two-phase project in October 2007, with support from the National Science Foundation. The Phase 1 report, *Creating a Culture for Scholarly and Systematic Innovation in Engineer-*

ing Education, was presented at the main plenary at the ASEE annual conference in June 2009 and posted on the ASEE website. The report, which drew on the understanding and insight of over 100 volunteers, developed a framework for tackling the issue of culture change in engineering education: that although there are many thoughtful reports on improving engineering education, most reports emphasize "what" needs to be changed, i.e., topics to cover, skills to obtain, or experiences to offer. "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—are often not fully addressed. The Phase 1 report zeroed in on three key messages:

Who—While a quality higher education experience involves many stakeholders, the responsibility for the quality of the engineering educational experience rests with the engineering faculty and administration.

What—A more efficient and effective educational enterprise could be achieved if the engineering curriculum and its instruction and assessment were deployed in programs perceived by students to be personally rewarding, socially relevant, and designed to help them succeed.

How—Higher levels of performance in any field are achieved by continual innovation that is motivated by the desire to solve important problems and that is addressed systematically in tight interplay with research and proven practices. This time-tested model, widely practiced by engineering faculty in their disciplines but largely untapped in engineering education, lies at the heart of transforming the culture in engineering education.

Building on this "who/what/how" framework, Phase 2 of the project set out to understand the current "state of the culture" by conducting a survey of faculty committees, chairs, and deans. Narrative and quantitative responses from 110 departments representing 72 colleges provide insight into current views and practice in teaching and learning, faculty preparation and engagement, and infrastructure and support for engineering education innovation. In a nutshell:

- While faculty committees report that active and engaging pedagogies such as cooperative learning are being used more than may be fully realized by the engineering community as a whole, most of those pedagogies, as well as their educational innovations, are largely directed to long-standing learning environments such as laboratories and research experiences. Newer learning environments, such as international, entrepreneurship, or service-learning experiences, are not as warmly embraced.

- While there is increased interest in making engineering programs more engaging and relevant, there is much less emphasis or attention to making them more welcoming, especially to groups traditionally underrepresented in engineering.

- Engineering programs are quite comfortable and routinely interface with industry and employers, but they are much less engaged with just about everyone else on campus or across the full spectrum of the American educational system.

- There is substantial support for career-long faculty development in teaching and learning, beginning with doctoral students aspiring to faculty careers. However, more specific development opportunities, such industry experiences or graduate study in educational scholarship, are of much less interest.

- Not too surprising, there is a strong desire for more supportive policies, practices, and physical and fiscal resources for educational innovation. Indeed, there is agreement among faculty, chairs, and deans that the top three challenges for improving educational innovation are: resources, workload, and the reward system.

- Engineering education innovation remains largely focused on departmental curricula viewed through the lens of "teaching," and much of the current infrastructure for educational innovation (e.g., conferences, journals, funding), inside and outside engineering, appears largely unknown.

- The gap between what is valued and what is practiced across several areas of pedagogy, learning environments, and faculty preparation speaks to the divide that exists between innovation and impact.

Besides providing a baseline on the current "state of the culture," the survey also provided a basis for developing seven recommendations to address the question of how we can build a stronger foundation for our engineering education enterprise, taking advantage of the creativity and innovation that exists throughout our enterprise, but looking especially to those elements that will ensure impact. In the report appendix, these broad recommendations are accompanied by specific actions that faculty, chairs, and deans; ASEE, the National Academy of Engineering, and professional engineering societies; funding agencies; ABET; and industry can take to get started on a transformation of engineering education.

WHO

Recommendation 1—Value and expect career-long professional development programs in teaching, learning, and education innovation for engineering faculty and administrators, beginning with pre-career preparation for future faculty.

Recommendation 2—Expand collaborations and partnerships between engineering programs and (a) other disciplinary programs germane to the education of engineers as well as (b) other parts of the educational system that support the pre-professional, professional, and continuing education of engineers.

WHAT

Recommendation 3—Continue current efforts to make engineering programs more engaging and relevant and especially expand efforts to make them more welcoming.

HOW

Recommendation 4—Increase, leverage, and diversify resources in support of engineering teaching, learning, and educational innovation.

Recommendation 5—Raise awareness of the proven principles and effective practices of teaching, learning, and educational innovation, and raise awareness of the scholarship of engineering education.

CREATING A BETTER CULTURE

Recommendation 6—Conduct periodic self-assessments within our individual institutions to measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation—innovation with impact—in engineering education.

Recommendation 7—Conduct periodic engineering community-wide self-assessments to measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation—innovation with impact—in engineering education.

While we can be proud of the international stature of our engineering programs, we also should not be complacent and assume that what has worked in the past will continue to work in the future. The rich history of U.S. technological innovation and its entrepreneurial collaboration between scholars and practitioners across many fields has served us well. We need to adopt and adapt this time-tested model for U.S. engineering education innovation.

"Innovation with impact" and "creating a culture for scholarly and systematic innovation in engineering education" are mutually reinforcing: practices grounded in scholarship are more likely to be effective in achieving their desired objectives, and scholarship driven by important problems is more likely to produce results with potential for meaningful impact.

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Addressing the challenges we face will not be easy but tackling them provides targets of opportunity in which engineering programs, industry, government, and engineering-affiliated organizations can work collaboratively to significantly advance U.S. engineering education. While the engineering profession has become a critical component in our national capacity for innovation, the same cannot be said for engineering education. A key to maintaining our technological preeminence is to ensure that we educate many more young people with imagination and passion as engineers. Just as the engineering sciences transformed the curricula content in engineering education in

"We hope this report and its recommendations will ultimately earn U.S. engineering education a "seat at the table" as a complementary peer companion with engineering research in advancing the nation's capacity for innovation with impact in all domains of engineering and technology."

the 1950s and 1960s, so the "Sputnik moment" for the current generation pivots on a transformation in the processes used to educate engineers to meet the challenges of our time. This demands innovation in educational approaches that boost the effectiveness and the efficiency of engineering education for both undergraduate and graduate students. Thus, we hope this report and its recommendations will ultimately earn U.S. engineering education a "seat at the table" as a complementary peer companion with engineering research in advancing the nation's capacity for innovation with impact in all domains of engineering and technology. ■

TABLE OF CONTENTS

02 | KEEPING PACE WITH THE CHANGING WORLD

WHY THIS REPORT?

We know we live in increasingly globally integrated institutions and communities. We know we face a growing list of complex societal and environmental problems. We know we need a more sophisticated engineering workforce to address these and other challenges. We know that expectations for the knowledge and skills that engineering students will learn as a part of their college education continue to grow. We know that American youths continue to show diminishing interest in engineering careers at a time when increasing the number of students graduating with engineering degrees is becoming a national imperative (NAE, 2005, 2008, 2009). And we know that this is further compounded by our inability to attract a broad pool of talent to engineering from America's diverse society. Educational

ADVANCEMENTS IN ENGINEERING EDUCATION

External "threats" have driven several decades of advancements in U.S. engineering education. 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 enrollment sagged; the 90s by the global threat as U.S. competitiveness declined in the face of rapidly rising economies in developing nations 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 sought to graduate, respectively, the scientific engineer, transactional engineer, managerial engineer, global engineer, and now the holistic engineer.

institutions in the United States are being challenged to secure their place at the forefront of engineering education at a time when local, state, and national resources for education are becoming increasingly scarce and expectations for institutional accountability and student performance are becoming more demanding.

There is no lack of awareness, absence of thought, or paucity of proposed solutions to produce the engineering workforce of the 21st century (McMasters and Komerath, 2005; NRC, 2010; Smith, 2011). Yet our engineering programs remain overly ambitious, tightly sequenced, and highly technical curricula rooted in a paradigm from the 1960s, at a time when the attributes demanded of our graduates have expanded significantly beyond raw technical knowledge. Although the American engineering community has a rich history of commitment to continually improve the U.S. engineering education enterprise (ASEE, 2009), it is clear there are major gaps between our reports and our curricula, our desire to graduate diverse talent and our ability to deliver, and our encouragement for educational innovation and our follow-through to support it.

Why do these gaps persist? One need only listen to the frequent faculty conversations in the hallways, attend any of numerous regional, national, and international conferences, or read some of the many papers and reports published regularly on engineering education to know that the U.S. engineering education community is involved in many exciting, engaging, and empowering educational innovations. However, the dominant approach is based largely on faculty intuition drawn from personal experiences as students and teachers. Seldom are engineering education innovations sufficiently grounded in relevant learning theories and pedagogical practices, and many innovations, once implemented, are not adequately assessed for their effectiveness in achieving their stated objectives (NAE, 2005; Pellegrino, 2006). This approach does not ensure that our graduates will develop the qualifications needed for the future; that the innovations will have long-term impact and are replicable in other learning environments; and that our efforts will be an efficient and effective use of increasingly limited resources.

Interestingly, this approach is at odds with the scholarly and systematic approach used by engineering faculty in their technological innovations. If a "grand challenge" for engineering education is *"How will we teach and how will our graduates learn all that is needed to tackle the challenges of today and tomorrow?"* then the issue is *not* simply a need for more educational innovations. The issue is a need for more educational innovations that have a *significant impact* on student learning and performance, whether through widespread and efficient implementation of proven practices or scholarly advancements in ideas, methods, or technologies. We need to adapt our time-tested model for scholarly and systematic technological innovation to our educational innovations. Such an approach would ensure more effective, efficient, and transferable educational innovations *and* continually advance engineering programs with the end result being better educated students (NRC, 2011).

This report, therefore, offers recommendations to the U.S. engineering community on creating and sustaining a more vibrant engineering academic culture for scholarly and systematic educational innovations that can have significant impact in educating future engineers to ensure that the U.S. engineering profession has the workforce and talent to meet the needs of a global society. The connection between "innovation with impact" and "creating a culture for scholarly and systematic innovation in engineering education" is straightforward: Engineering practices that are grounded in scholarship—whether it be scholarship on how people learn, on creativity, on measuring efficiency and effectiveness, on what attracts students to engineering (or drives them away)—are more likely to be effective in achieving their desired objectives. Further, engineering practices that can, through assessment, be proven to be effective are more likely to be disseminated, thereby extending the reach of their impact. Connecting scholarship and practice in a systematic way—via a new culture—has the potential to create a virtuous cycle that leads to systemic change. By building this culture, it is our hope that engineering education earns a "seat at the table" as a peer companion with engineering research in advancing the nation's capacity for innovation in all domains of engineering and technology.

In discussions about change in organizations and communities such as, for example, in engineering education, the term *culture* is often not defined. Rather, it is assumed that we all know what it means. In this report we adopt the definition developed by Schein (1992) and used by Godfrey and Parker (2010) in their ethnographic study of an engineering college:

> "… a pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid, and therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems."

It is clear from this working definition that fostering a culture change, a shift from one valid set of shared, basis assumptions to another set, is a significant undertaking. Results do not appear overnight, nor do they come easily or without resistance. Yet the magnitude of the challenge—creating an engineering education enterprise where innovation with impact continually propels us forward to keep pace with changes in the engineering profession and in the world—demands nothing less.

This is the second of two reports in a seven-year project sponsored by the American Society for Engineering Education with additional support from the National Science Foundation (Huband and Melsa, 2007). The first phase of the project focused on catalyzing a conversation within the Society and a segment of the U.S. engineering community on creating a culture for more scholarly and systematic innovation in engineering education. It resulted in a Phase 1 report published in June 2009 (ASEE, 2009) that outlined several critical issues and actions to create such a culture. The second phase of the project sought broader national input through a survey of U.S. engineering faculty, department chairs, and deans on the current state of engineering education. This report is the culmination of the project.

We first summarize the key points from the Phase 1 report. In Part 2, we present the results of the national survey of engineering faculty, department chairs, and deans. Part 3 presents seven recommendations for creating and sustaining an engineering academic

HISTORY OF THE PROJECT

2004-05 – Project design and planning by the ASEE leadership and a committee of members.

2006-07 – ASEE launches the "Year of Dialogue," beginning with a Socratic session at its 2006 annual conference. Structured discussions within the Society on the role and importance of educational innovation are held during the following year (ASEE, 2006).

2007-08 – Results of the "Year of Dialogue" are published (Mohsen, et al., 2008). They lead to a two-phase project in collaboration with the National Science Foundation (Huband and Melsa, 2007) involving a project team of 68 engineering education stakeholders.

2008-09 – Phase 1 report, *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education,* is published in June 2009 (ASEE, 2009) and presented at the 2009 annual conference. Phase 2 is launched seeking feedback on the current state of engineering education practice from a large national sample of engineering faculty, department chairs, and deans. In parallel, the Phase 1 report is presented at many national and international meetings and feedback gathered.

2009-12 – Results of the national survey are analyzed and a draft final report prepared. The draft report is peer-reviewed by an independent committee of thought-leaders in engineering and education. The final report, *Innovation with Impact,* is published on June 1, 2012.

culture that encourages and supports educational innovations with impact, with specific actions detailed in the Appendix C. Part 4 concludes the report by revisiting the challenge of ensuring that engineering education is, indeed, a national treasure and a cornerstone of broader national success.

PHASE 1 REVISITED: WHO, WHAT, AND HOW?

There are many thoughtful and respected reports on improving engineering education. However, most reports emphasize "what" needs to be changed, i.e., topics to cover, skills to obtain, or experiences to offer. What is often not as fully addressed is "who" should drive the change and "how" the change should be driven—both of which largely determine how quickly, how efficiently and how well change occurs, and how it is sustained. The Phase 1 report addressed who, what, and how to create and foster an engineering academic culture for scholarly and systematic innovation in engineering education and it also spotlighted a number of examples of innovation with impact (ASEE, 2009). Here we summarize the key points from the Phase 1 report. We will revisit the key points in our discussions of the results of the national survey and again in our conclusions and recommendations.[1]

"If the American engineering education enterprise is to foster a culture focused on educational innovations with impact, it is the nation's engineering faculty and administrators who must lead in creating and sustaining it."

WHO

Providing a quality engineering education experience depends upon many stakeholders: faculty, students (and often their parents), staff and administrators, alumni, governing and advisory boards, professional societies, employers, accreditation bodies, government agencies, foundations, K-12 schools, and taxpayers, among others. All these stakeholders are important. However, among them, engineering faculty and administrators are key: We determine the content of our programs, how they are delivered, and the environment in which they are offered. While we must be mindful of and accountable for meeting the needs of those who employ our graduates, we are ultimately responsible for the quality of

[1] Additional discussions and feedback since the release of the Phase 1 report in June 2009 have allowed us to refine some of its points. Thus, while the summary is largely reflective of the Phase 1 report, a few points have been further developed or sharpened.

PRINCIPAL POINTS FROM PHASE 1

We need to create and sustain a vibrant engineering academic culture for scholarly and systematic innovation in engineering education, just as we have for technological innovation, to ensure the U.S. engineering profession has the workforce and talent for a global society. Who should drive the change? What change is needed? How should the change be driven? We point the reader to the Phase 1 report for an in-depth discussion and for examples of innovation with impact drawn from the literature; key points are:

WHO

Engineering faculty and administrators are the key to quality engineering programs. They determine the content, decide how it is delivered, and shape the environment in which it is offered. We need to: strengthen career-long development for faculty and students aspiring to faculty careers, create supportive environments for educational innovation, and form broader collaborations both on campus and off. In particular, high-quality learning environments can be achieved if curriculum, instruction, and assessment, and their alignment, are tied to scientifically credible and shared knowledge on engineering learning and employed in contemporary approaches to education. We need to form partnerships that allow us to integrate what we know about engineering with what we know about how people learn.

WHAT

A survey of recent literature suggests that we can make significant strides in improving engineering education, including recruitment and retention of students, if we make engineering programs more engaging, relevant, and welcoming.

HOW

Engineering education innovation depends on a vibrant community of scholars and practitioners working in collaboration to advance the frontiers of knowledge and practice. It also requires better infrastructure including adequate fiscal resources, appropriate facilities, respect for scholarship in the field, creative educational research and development centers, reputable journals, and highly-regarded conferences, just as we have for technological innovation.

the engineering educational experience. If the American engineering education enterprise is to foster a culture focused on educational innovations with impact, it is the nation's engineering faculty and administrators who must lead in creating and sustaining it. However, empowering faculty and administrators to create and sustain such a culture requires strengthening career-long faculty development in teaching, learning, and educational innovation; creating supportive environments within and outside engineering programs; and forming collaborative relationships with a broader set of partners.

Strengthening Career-long Faculty Development: The educational role of faculty members is not to impart knowledge; it is to design learning environments that support knowledge acquisition (Adams and Felder, 2008; Bransford, Vye, and Bateman, 2002; Duderstadt, 2008; NRC, 2000). Competency in educational design requires domain-specific (content) knowledge, knowledge in teaching and learning, and reflective educational practice (Shulman, 1986). 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 (Felder, Brent, and Prince, 2011). Further, 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 members, all graduate students 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 to different audiences; what misconceptions, preconceived notions, and biases people bring to learning; how to work with diverse groups; and how to use learning and collaboration technologies are also valuable skills in industry, government, and non-profit sectors.

Creating a Supportive Environment: Engineering education innovation must become a visible, valued, and strategic priority of engineering departments and colleges with the associated planning, programs, and processes to sustain it. Three components are important to increasing effective educational innovation: 1) access by engineering faculty to individuals and organizations knowledgeable in learning and educational innovation (Finelli, et al., 2008); 2) adequate department and college resources to initiate, experiment, and implement educational innovations; and 3) faculty recruitment, hiring criteria, and reward structures that explicitly consider and value achievements in educational innovation, including promotion and tenure criteria, processes, and practices, as well as the merit evaluation of chairs, departments, deans (Felder, Brent, and Prince, 2011). High quality educational innovation shares many similarities with high quality technological innovation and, therefore, it should be supported, valued, and evaluated similarly.

Forming Broader Collaborations: The engineering education enterprise involves many stakeholders beyond engineering faculty and administrators. The list is long, the players well known, and their roles historically framed in supplier-customer relationships. Engineering education would be better served by moving to a new approach, one built more on collaborations focused on the formation of engineers than one based on distributed responsibilities focused on delivering instruction to engineering students. Developing this alternative approach requires that we reaffirm and deepen our relationships with old partners, largely industry employers and faculty on our campuses, and reach out and establish new partnerships, including university partners from education, the learning and social-behavioral sciences, and partnerships outside the university, e.g., K-12 and community colleges.

Among the suite of partners, education, the learning sciences, and social-behavioral sciences stand out. 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 applied in fragmented educational practices. A more effective and efficient educational enterprise could be achieved if curriculum, instruction, and assessment, and their alignment, were derived from a scientifically credible knowledge base on engineering learning and employed in more cohesive approaches to education (Streveler, Smith, and Pilotte, 2011). While many engineering faculty are working to improve engineering education, their efforts would be well served if they took greater advantage of the theories and proven practices of how people learn, including an increasing body of knowledge specific to engineering learning (Felder, Sheppard, and Smith, 2005; Sheppard, Pellegrino, and Olds, 2008). Doing so would assure more effective program development, facilitate dissemination, and encourage broader adoption. 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 (NRC, 2011). Developing collaborative partnerships with these and other educational communities is important to engineering education innovation.

WHAT

The United State's technical leadership has been possible at least in part because of our highly skilled and educated technical workforce. However, many reports acknowledge that the United States 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 and Malcom, 2008; NAE, 2008; Ohland, et al., 2008). Three areas of particular concern are to make our engineering programs more engaging, relevant, and welcoming.

Engaging: 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. Instructional approaches such as inquiry-based 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 learning 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 (Deslauriers, Schelew, and Wieman, 2011; Leung, et al., 2008; Prince and Felder, 2006; Smith, Sheppard, Johnson, and Johnson, 2005). Further, despite faculty concerns that more engaging curricula may increase their workload and/or damage their instructor evaluations, evidence suggests this is not the case over the long term (Dee, 2007). Nonetheless, implementing engaged learning approaches has challenges, including significant educational socialization of faculty and students accustomed to less active, more traditional instructional methods. Coming to terms with this socialization is central to our understanding the current culture of engineering education and hence what it might take to foster changes.

Relevant: A long-standing trend in engineering programs has been to be more scientific, with an emphasis on theory, equations, and modeling and less emphasis on hands-on experience. However, current engineering practice involves team-based, cross-disciplinary projects that call on engineers to be "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). The inclusion of more relevant learning experiences in U.S. engineering curricula should be guided by three common principles:

- Content: Students should gain a fundamental understanding of the sciences and mathematics; an opportunity to learn about social sciences, humanities, and the arts and to relate them to engineering work; an emphasis on creativity, critical thinking, design, and leadership; and basic training in at least one of the engineering disciplines.
- 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 engineering practice.
- Practice: Engineering programs should reflect upon the experiential aspects of the education, decide what they will emphasize, and clearly align their curricula, instruction, and assessment based on these choices. An exploration of how learning outcomes can be met and measured through experiential education should be considered as an opportunity for engineering faculty and administrators to consider more flexible, non-traditional, and perhaps even more efficient engineering curricula.

Welcoming: While engineering programs may take pride in persistence rates higher than those in other under-graduate majors, the attrition rate is still too high, especially in light of the rigorous academic preparation typically required to gain 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 (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 professional disciplines (e.g., medicine and law) and in the American population remains a problem. Just as a homogeneous engineering workforce is unlikely to be maximally creative (Wulf, 1998), an educational environment bereft of diverse ideas and diverse people is unlikely to be maximally effective.

Studies have shown that a primary culprit in the attrition of students from engineering is their perception that the learning environment is not motivating or welcoming (Chubin and Malcom, 2008; Russell, Hancock, and McCullough, 2007). Indeed, this perception can also have long-term consequences of discouraging students to consider careers as engineering faculty. It is neither the students' capabilities nor their potential for performing well as engineers that determines their persistence. These negative perceptions are even more problematic for women and underrepresented ethnic and racial minorities (Bergvall, Sorby, and Worthen, 1994; Busch-Vishniac and Jarosz, 2004; Harris, et al., 2004; NAE, 2008; Salter and Persaud, 2003; Sax, 1994; Vogt, Hocevar, and Hagedorn, 2007).

"Innovation depends on a vibrant community of practitioners and researchers working in collaboration to advance the frontiers of knowledge and practice."

HOW

Higher levels of performance in any field—whether engineering, science, architecture, business, or education—are achieved by continual innovation motivated by the desire to solve important problems. Improvements are addressed systematically based on research and proven practices. Thus, innovation depends on a vibrant community of practitioners and researchers working in collaboration

THE RESEARCH PROCESS

The Craft of Research, W.C. Booth, J.M. Williams, G.G. Colomb,
Third Ed., University of Chicago Press, 2008.

to advance the frontiers of knowledge and practice. Unfortunately, this time-tested model, which is widely practiced by engineering faculty in their technical disciplines, is largely untapped in engineering education. The current intuitive approach of faculty based on their own prior learning and teaching experiences 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, coupled with shrinking resources and increasing calls for accountability in higher education, should give pause for thought as to whether this unsystematic approach has the requisite efficiency and effectiveness to lead to the educational experiences needed to produce well-prepared graduates in the future. The Research Process model that connects research and practice in traditional engineering fields may be aptly applied to innovation in engineering education as well. To implement this model, however, requires a deeper and broader conceptualization of engineering education innovation and the need to create infrastructure to sustain it.

Education Innovation Reconceived: Engineering education innovation is generally conceived of as better teaching, mostly in aspects of curricula within our direct control. It is much more. As noted above, engineering education innovation is a cross-disciplinary endeavor involving at least two disciplines, engineering and education, and often others. Effective educational innovation requires expertise in both content and pedagogy. Educational innovation also includes the introduction of proven ideas, methods, and technologies into learning environments where they have not been employed before, as well as the invention and introduction of new educational ideas, methods, and technologies. It spans the entire educational continuum in which we educate engineers, from K-12 through continuing professional development. Further, there are many ways for engineering faculty to contribute to educational innovation, ranging from adopting and adapting the educational innovations of others in different learning environments, to expanding the state of educational practice through curriculum reform and assessment, to advancing the body of knowledge of engineering learning through education research. In the context of the Research Process cycle, education innovation encompasses work that starts with research questions that are ultimately translated into practice, (enter the cycle on the right) as well as "light bulb" solutions to practical problems that motivate research to assess and understand if, why, and to what degree a solution is effective (enter at the top). In engineering education, as in traditional engineering fields, making the connections in the cycle is what transforms "innovation" to "innovation with impact."

To implement this model, the U.S. engineering faculty, *as a collective body*, should have the talents, or have access to the talents, to assure high-quality educational experiences derived from scholarship and experience in both technological and educational innovation. Rather than assuming that all engineering faculty will become experts in pedagogy, it is more realistic to suggest that high-impact innovation will most often be achieved through collaboration: experts in content and experts in pedagogy collaborating, either in tandem or in sequence, to conceive, develop, demonstrate, and assess innovations. 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 seek 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).

Better Infrastructure: Creating and sustaining communities of scholars and practitioners who are advancing engineering education through 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 to support engineering curriculum development and teaching (educational development) is inadequate or underutilized at many institutions. The infrastructure to translate innovations to widespread practice—i.e., to amplify the impact of innovations—is limited. Further, engineering education research and scholarship are only now emerging and gaining acceptance, and neither is widely embraced within the infrastructure for engineering research and development. For engineering education innovation to thrive and have significant impact, these deficiencies will have to be addressed. ■

03 | THE STATE OF U.S. ENGINEERING EDUCATION

ENGAGING ENGINEERING FACULTY, CHAIRS, AND DEANS

Following the release of our Phase 1 report, a research team was formed to develop and administer a survey to a large sample of U.S. engineering faculty, department chairs, and deans. The purpose of the survey was to seek their thoughts and comments on the Phase 1 report and to gather data to better understand the current state of engineering education in the U.S.

The survey had six parts. The first four parts were for engineering faculty, the fifth part was for department chairs, and the sixth for deans. The survey contained 12 Likert-type questions, some with subparts, which were directed to the engineering faculty, and five open-ended questions, two directed to the engineering faculty and one each directed to the department chairs and deans. The survey instrument is in Appendix A.

NATIONAL SURVEY OF ENGINEERING FACULTY COMMITTEES, DEPARTMENT CHAIRS, AND DEANS

RESEARCH TEAM: Drs. Barbara M. Olds, National Science Foundation, *Chair*; Maura J. Borrego, Virginia Tech; Mary Besterfield-Sacre, University of Pittsburgh; Monica F. Cox, Purdue University

SAMPLE: A random sample of 100 colleges (deans) and 200 designated departments (chairs and faculty committees) selected randomly plus a focused sample of an additional 57 colleges (deans) and approximately 114 departments (chairs and faculty committees) selected by several attributes, e.g., size, degrees awarded, diversity, ranking. The response rate was 46%, with 110 programs representing 72 colleges responding.

SAMPLE DISTRIBUTION BY HIGHEST DEGREE OFFERED: 26 bachelor's, 40 master's, and 90 doctoral programs.

A total of 157 institutions were invited to participate in the survey, as part of two sample sets: a random sample of 100 colleges of engineering and a focused sample of 57 colleges of engineering stratified by attributes of size, degrees awarded, diversity, and ranking. In both samples, responses were solicited from two departments in each college except in cases where engineering was only one department. A total of approximately 314 departments were invited and 46% provided responses. The distribution of departments responding by the highest degree offered was 9 bachelor's, 17 master's, and 46 doctoral.

The survey was sent to the dean of each college, who was asked to forward the survey to the chairs of two specified departments in the random sample. The departments were unspecified in the focused sample. Each department was asked to appoint an ad hoc committee or use a standing committee of their faculty to read the report and to respond to the Likert-type questions and two open-ended questions. The committee then passed their responses to the department chair who provided his or her comments to a third open-ended question and in turn passed the surveys to the college dean, who responded to a fourth open-ended question and returned the survey.

The survey produced a rich set of data. The responses to the Likert-type questions were analyzed first and the results were then used to frame the analysis of the open-ended questions. A paper providing a detailed analysis of the results is in preparation for publication by the research team. In this report we provide a summary of the results.

The Likert-type questions asked the faculty committees to rate the degree of importance of an educational practice and the degree to which the department practiced it. For example, one survey item was to "Create next generation of engineering educators by: Integrating instruction/pedagogy into PhD programs." The committees were to choose a response from each of two corresponding four-point scales: importance, ranging from "not important" to "highly important" and practice, ranging from "do not practice" to "we consider ourselves leaders." Figure 1(a) shows the collective responses for this particular example. To present the large body of data resulting from all the questions in a compact form, the responses were assigned into one of four categories depending on the degree of importance and degree of practice indicated for the question. The four categories are as follows and are illustrated in Figure 1(b) for this example:

- *Practice routinely*—items rated as "important" or "highly important" and practiced "routinely" or "we consider ourselves leaders."
- *Practice lagging*—items rated as "important" or "highly important" and practiced "somewhat" or "do not practice," i.e., practice lagging importance. This group represents "low hanging fruit" for improvement: the item is already valued, so change is primarily a matter of increasing/improving practice.
- *Practice occasionally*—items rated "somewhat important" or "not important" and practiced "somewhat" or "do not practice."
- *Practice reluctantly*—items rated as "not important" or "somewhat important" and practiced "routinely" or "we consider ourselves leaders." Such responses suggest the item is practiced perhaps because of requirement, mandate, or history. There were (fortunately) very few such responses.

FIGURE 1(A)

"Create next generation of engineering educators by: Integrating instruction/pedagogy into PhD programs." N = 85

	Not Important	Somewhat Important	Important	Highly Important
Leaders in this				3
Practice Routinely		3	5	7
Practice Somewhat		13	24	7
Do Not Practice	1	10	7	5

FIGURE 1(B)

Percentage of responses divided into four categories.

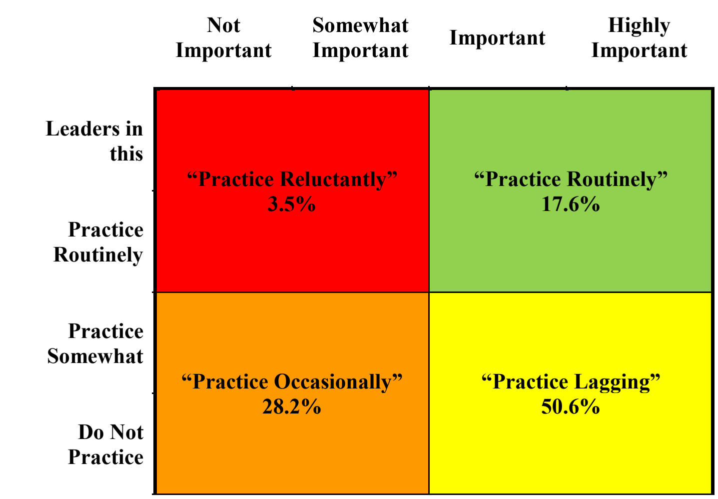


Table B1 in Appendix B displays the four-category results for all the Likert-type questions.

For the open-ended questions, members of the research team read and re-read the faculty committee, department chair, and dean transcripts and open-coded the responses into "opportunities" and "challenges" across three groups. Opportunities were then classified in more detail into a codebook containing approximately 29 codes for opportunities identified across the groups. A similar process occurred for coding challenges and a codebook was created for the 32 challenges identified across groups. After all codes had been identified, the frequency of occurrence of each "opportunity" and "challenge" code was noted for faculty committees, department chairs, and deans. The most frequently occurring opportunities and challenges codes were examined in greater detail to understand how respondents perceived their greatest opportunities and most pressing challenges.

Observations from the Likert-type questions (faculty committee responses) and the open-ended responses (faculty committees, chairs, and deans) can be summarized into three somewhat overlapping areas that align with what, who, and how: teaching and learning, faculty preparation and engagement, and infrastructure and support. While many interesting insights can be gleaned from the survey data, there are two principal observations in each area that are summarized as follows and explained more fully in the next section. Throughout this section, we note that the survey results represent self-reported rather than independently verified data.

Teaching and Learning

— Engineering programs report that they are using active pedagogies. However, they are also largely employed in long-standing and familiar learning environments.

— Engineering programs are working to make their programs more engaging and relevant, but there appears to be less effort in making them more welcoming.

Collaboration and Faculty Preparation

— Engineering programs are comfortable collaborating on their educational innovations with industry, employers, and the natural sciences and mathematics. They are much less engaged, however, with other non-STEM colleagues on their campuses and with the pre-college and community college systems.

— Engineering programs report that they value having more career-long faculty development in teaching and learning, including pre-career preparation. However, they have less enthusiasm for other aspects of career development that might improve the learning environment, e.g., faculty experience in industry.

Infrastructure and Support

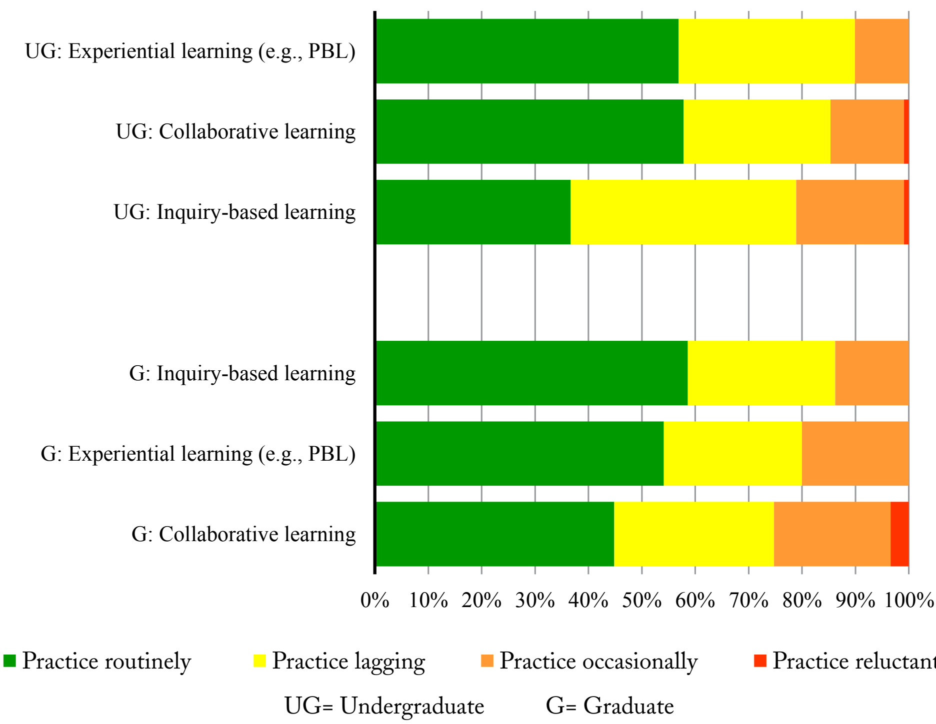
— Engineering programs strongly endorse more supportive policies and practices for educational innovation, as well as more physical and fiscal resources. However, it is also clear that engineering education innovation is largely viewed through the lens of "teaching" and focused on departmental curricula.

— Engineering programs agree uniformly that the top three challenges to advancing more educational innovation are resources, rewards, and workload. However, there is less uniformity of agreement on the opportunities to pursue should the challenges be overcome, and further, evidence suggests that the opportunities pursued would more likely be to expand familiar practices than to engage in ground-breaking innovations.

TEACHING AND LEARNING

Good news—it is apparent from Figure 2 that the largest number of faculty committees, and generally a majority, report that their departments routinely practice active and engaging pedagogies, such as collaborative, experiential, or inquiry-based learning, both for undergraduates and graduates. While the survey did not capture the sophistication or depth of the way in which the pedagogies are being used, this does suggest that we are working to transform our classrooms and labs. When coupled with those faculty committees that indicated their departmental practice lags relative to its importance, a sizeable majority of faculty committees clearly indicate that their departments value active and engaging pedagogies. An examination of the narrative responses affirms Figure 2. Faculty committees, chairs, and deans often mention specific educational innovations that naturally lend themselves to active and engaging pedagogies, such as research and laboratory experiences, cooperative education and industry internships, and first-year and senior-year design opportunities.

FIGURE 2
Pedagogies of Engagement



Encouraging more active and engaged teaching and learning has been a point of discussion within the engineering community for some time. Thus, it appears we have good reason to celebrate our progress. However, it appears that most of these pedagogies are being employed in long-standing learning environments, namely laboratories, research, or internships, as shown in Figure 3. Extracurricular activities and student mentoring programs also make a respectable showing, with "practice routinely" receiving the largest response. When coupled with those whose practice is lagging (important but not yet practiced), a significant majority sees these learning environments as important.

FIGURE 3

Learning environments

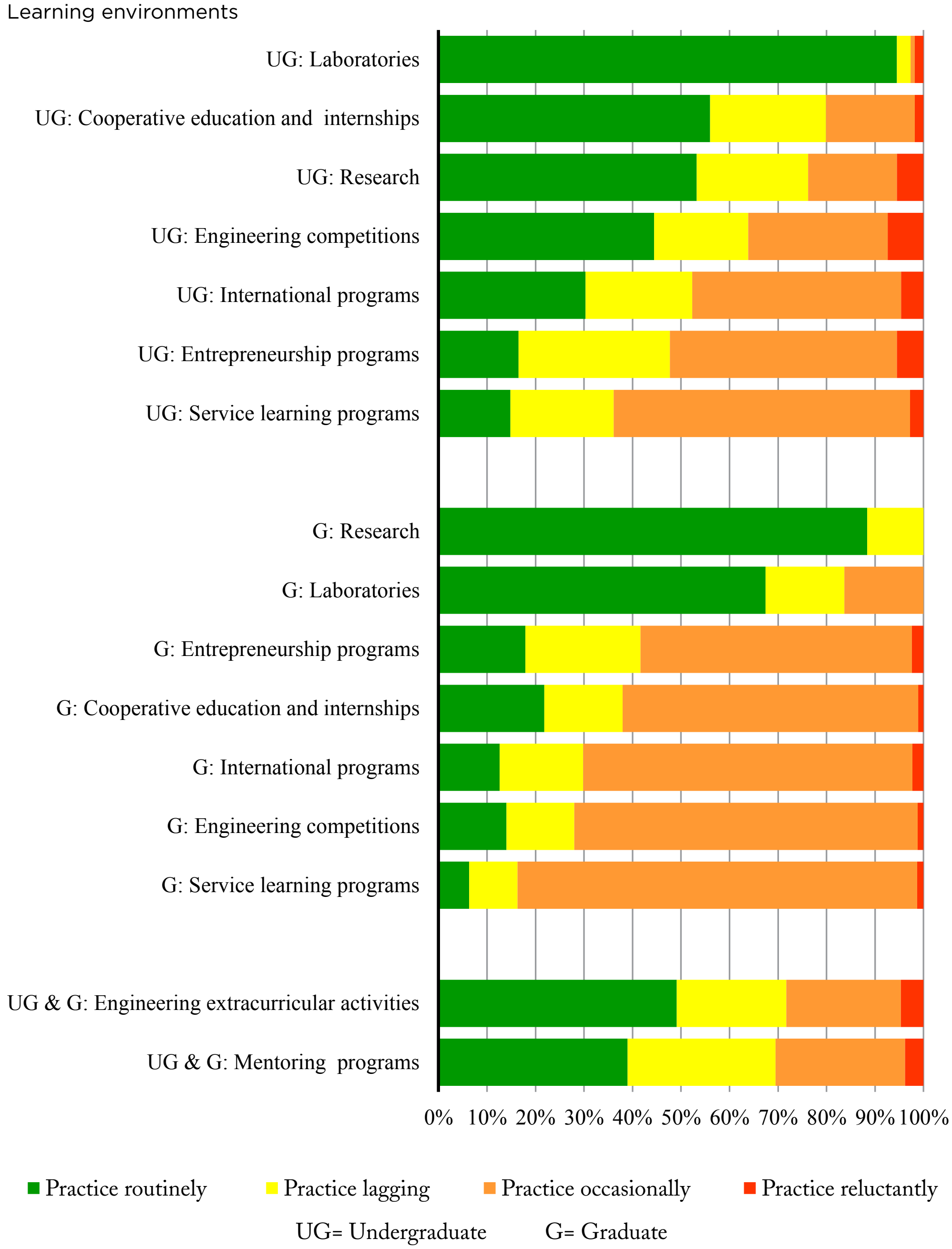
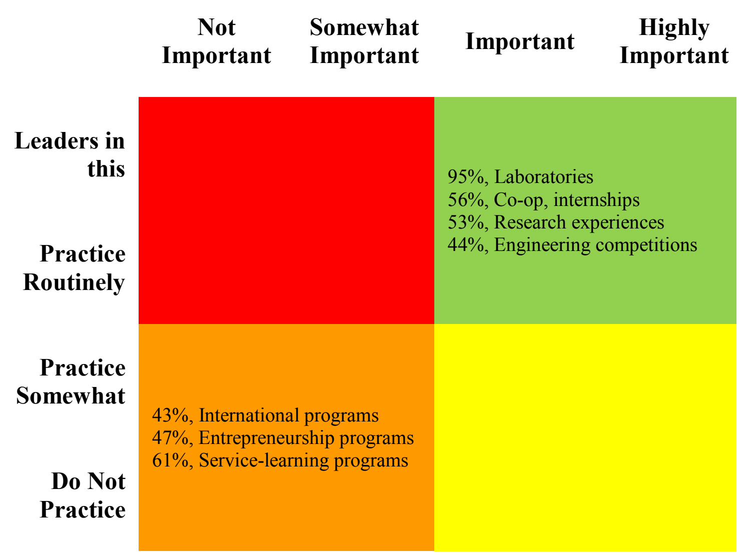


FIGURE 4
Undergraduate learning environments.



However, the faculty committees report that newer learning environments, such as international programs, entrepreneurship, or service learning are not widely used. This is highlighted in Figure 4. According to one department chair, the "overcrowded curriculum" is part of the problem:

> The amount of material engineering programs feel compelled to include in the curriculum increases every year and the number of courses needed to graduate has been reduced over the past 10 years. It is very difficult to accomplish a complete shift in teaching methodology in this type of environment.

Perhaps even more significant is that these newer learning environments are not seen as particularly important. For undergraduates, nearly half (48%) of the faculty committees rated international programs as not important or somewhat important (the sum of "Practice occasionally" and "Practice reluctantly" in Table B1, corresponding to the left-hand column in the quadrant format), and over half gave the not important or somewhat important rating to entrepreneurship programs (52%) and service-learning programs (64%) These three learning environments for graduate students were viewed even less favorably (from 70% to 84%). Not too surprising, these environments were rarely mentioned in the narratives. These perspectives are at odds with several reports which point to globalization, economic development, and community engagement as important emerging themes for engineering education (Continental, 2006; NAE, 2005, 2008).

Further, the pattern of responses on the degree of practice between long-standing environments (such as cooperative education and internships) and newer learning environments (such as international programs) is bifurcated. There is little middle ground in terms of practice (Figure 4). Most responses indicate a learning environment is both valued and practiced or it is not; relatively few responses indicate a desire to practice an environment more.

Thus, it appears that a majority of the faculty committees and administrators are comfortable with their long-standing learning environments and see less need for the newer ones. This is striking since many of the newer learning environments provide opportunities to expand the educational experiences of the students without necessarily expanding the "formal" curriculum. It is noteworthy that while the faculty committees generally indicated their departments routinely practice active and engaged pedagogies (Figure 2), they do not see much value in adopting the newer learning environments which lend themselves naturally to active and engaging pedagogies (Figure 3). This suggests the lack of adoption of the newer learning environments is not necessarily due to apprehension that they may involve learning new pedagogies but rather that they are not seen as needed.

This lack of interest in newer learning environments has broader implications. Research shows that educational experiences such as international programs, entrepreneurship, and service learning are important to attracting and retaining a more diverse pool of students (Smith, Sheppard, Johnson & Johnson, 2005)—to making engineering more welcoming. So though universities, government, and industry continue to invest heavily in a wide range of diversity programs, it appears that we are not taking advantage of the role that learning environments can play in broadening the inclusiveness of engineering programs. This is a missed opportunity.

COLLABORATION AND FACULTY PREPARATION

COLLABORATION

A substantial majority of the faculty committees (69%) indicated that their departments routinely collaborate with industry and employers on their educational innovations, as can be seen in Figure 5. However, it is noteworthy that it appears their departments do not to want to collaborate with anyone else, except perhaps with their colleagues in the natural sciences and mathematics. For example, substantial fractions (37%-61%) of the faculty com-

FIGURE 5
Faculty collaborations

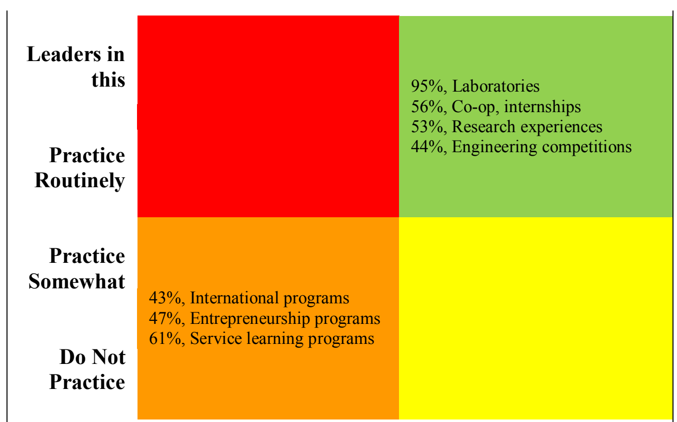


Figure 4—Undergraduate learning environments.

Further, the pattern of responses on the degree of practice between long-standing environments (such as cooper ative education and internships) and newer learning environments (such as international programs) is bifurcated. There is little middle ground in terms of practice (Figure 4). Most responses indicate these a learning environment is both valued and practiced or it is not; relatively few responses indicate a desire to practice an environment more.

Thus, it appears that a majority of the faculty committees and administrators are comfortable with their long

■ Practice routinely ■ Practice lagging ■ Practice occasionally ■ Practice reluctantly mittees viewed collaborations with pre-college and community colleges, education, learning science, and social-behavioral sciences, business, architecture, law, etc., as not important or somewhat important. Of course, it is not necessarily from a lack of trying. As one chair noted, "It is difficult enough to collaborate with the sciences that are closer to engineering but collaboration with the social sciences and humanities can be both frustrating and difficult."[2] Absent collaborations with a broader set of colleagues, it seems unlikely that most engineering education innovations will be designed, implemented, and sustained in a manner that takes advantage of the scholarship, expertise, and experiences of these other fields. This may particularly hamper our ability to address issues of diversity in its many dimensions, be it topically (e.g., humanities/social sciences, math/science, business/law) or pedagogically (e.g., education, learning sciences, psychology). We do find it encouraging that many would like to form closer linkages with their colleagues in education, learning sciences, social-behavioral sciences, etc., where current collaboration is very low but where almost half (47%) felt the practice of collaborating with these colleagues lagged relative to its importance. As one dean commented: "Over the past year, engineering has collaborated with education to write three grant proposals for education research and innovation centered around the first-year program and K-12 outreach. I am hopeful that these interactions will grow." These results reaffirm what can be observed in practice: engineering faculties' eductional innovations are focused largely on their students' technical preparation rather than also on the students' professional preparation. As one chair commented, "It is difficult to add concepts to established courses and faculty feel that students could be shorted if fundamental concepts are not adequately covered." While it is possible that engineering students may be obtaining the necessary breadth of professional preparation through their engineering-centered curriculum, the lack of collaboration outside engineering is, again, at odds with many national and international reports that note, if not advocate for, engineering as an increasingly global, cross-disciplinary, society-driven field of practice.

The particularly low rating of collaborations with pre-college and community colleges is especially concerning. If U.S. engineering education is to grow—for example, by 10,000 graduates per year as envisioned by President Obama—and broaden its appeal to prospective

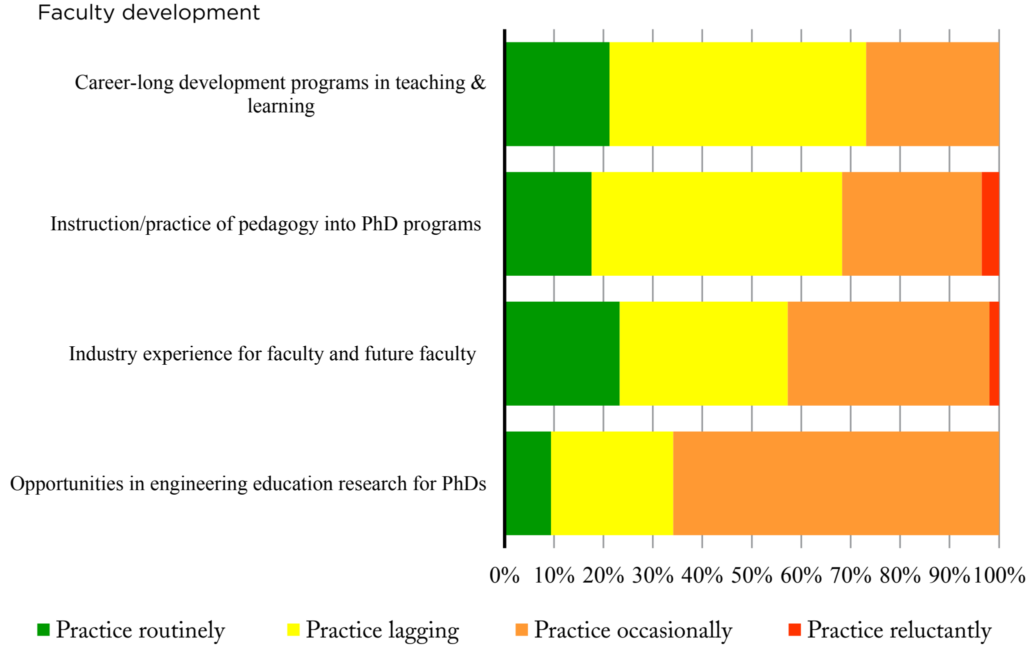
[2] It would not be surprising if they say the same thing about us!

students and better prepare its graduates for global engineering practice, then U.S. engineering faculty need to engage in a broader population of stakeholders. Otherwise, it is difficult to envision that their collective educational innovations will be designed for and reflect the kind of broad diversity of people and talents needed for the U.S. engineering profession.

FACULTY PREPARATION

As shown in Figure 6, a majority of engineering faculty committees (52%) indicated that the practice of career-long development in teaching and learning lags relative to its importance, as does the practice of integrating instruction/practice of pedagogy into Ph.D. programs (51%). While it is unfortunate that practice presently lags importance, it is very encouraging news for the future of the professoriate. This is reaffirmed by an examination of the narratives, where faculty workshops and seminars were often mentioned as the means by which

FIGURE 6
Faculty development



to improve faculty performance in teaching and learning. Indeed, Table 1 (page 42) shows the top five challenges and opportunities mentioned most frequently in the narratives. It is noteworthy that faculty development is one of only two areas mentioned as an opportunity that was in common among faculty, chairs, and deans.

While it is heartening to know significant support exists for faculty development in teaching and learning, only 23% routinely encourage industry experience for faculty, mostly because such experience is not viewed by the faculty as particularly important (43%). Further, few (9%) routinely provide graduate students with opportunities to conduct engineering education research. Two-thirds do not see such opportunities as particularly important (66%).

Consequently, while there is considerable support for improving the pedagogical abilities of current and future faculty, the development of other kinds of abilities, such as industry experience or educational research, is not well supported. It would appear that a majority of faculty committees see the need for better pedagogy for many engineering faculty but they do not see the need for faculty development experiences that might improve the overall educational environment.

The other area mentioned in common as an opportunity among faculty committees, chairs, and deans was rewards; indeed, it was also the only item among the top five items mentioned in common in both challenges and opportunities. This, of course, is not surprising. As one faculty committee commented:

> A challenge to bring about significant change in the current engineering educational paradigm is the current tenure system and reward structures that are heavily weighted toward research success. This system is so embedded in faculty that they would hesitate to collaborate on anything (educational innovation, in particular) that would take them away from their research endeavors.

INFRASTRUCTURE AND SUPPORT

It is not too surprising that a majority of faculty committees feel support for educational innovation lags its practice (Figure 7) and that resources, rewards, and workload are major challenges (Table 1). Indeed, Table 1 reveals agreement among the faculty committees, department chairs, and deans on the top three challenges, which appear in nearly the same rank order. However, they agree on only two of the top five opportunities. It is apparent that we know our principal challenges whereas our principal opportunities are less clear. This is mostly good news in that the faculty committees and administrators generally want to increase their involvement in education innovation. They just do not feel that they have the policies, practices, resources, and infrastructure they need to be more successful.

FIGURE 7
Infrastructure and support

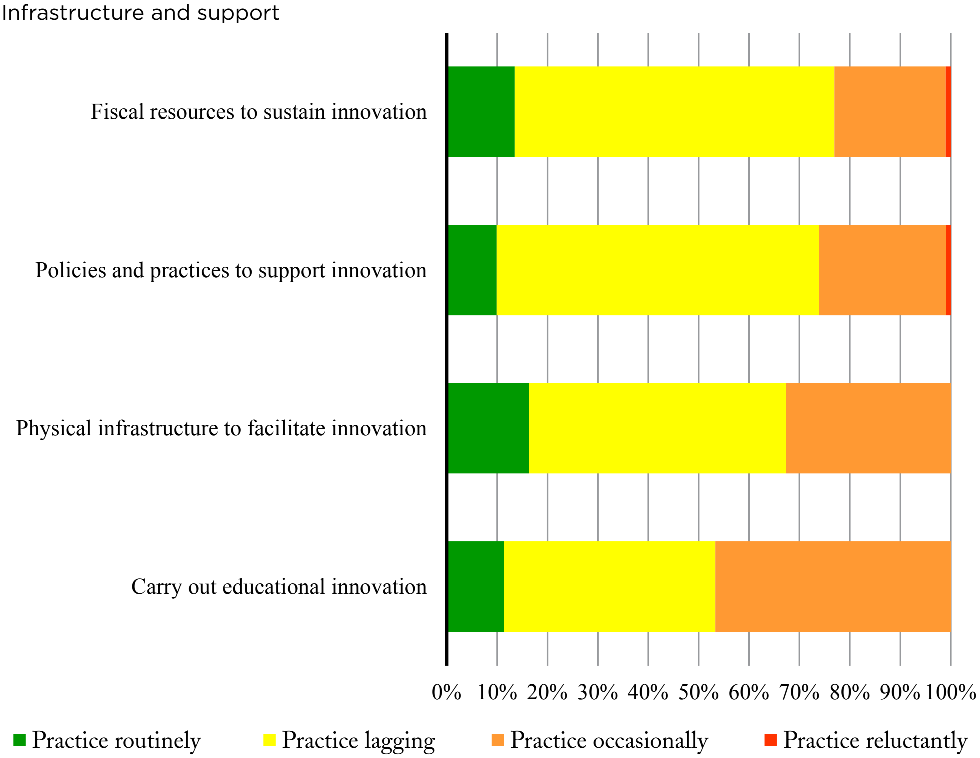


TABLE 1
Top Five Challenges and Opportunities

Challenges

Faculty	Count	Chairs	Count	Deans	Count
Resources	46	**Resources**	36	**Resources**	19
Rewards	37	**Rewards**	29	**Workload**	17
Workload	36	**Workload**	27	**Rewards**	16
Awareness of Innovations	18	Tech. Research Emphasis	13	Innovation Not Valued	12
Assessment of Innovations	18	Changing the Curriculum	12	Resistance to Change	10
		Awareness of Innovations	12		

Opportunities

Faculty	Count	Chairs	Count	Deans	Count
Faculty Development	16	Faculty Commitment	24	**Rewards**	21
Rewards	15	**Faculty Development**	18	Changing the Curriculum	18
Industry & Entrepreneurship	12	Awareness of Innovations	15	Collaborating with Others	15
STEM Centers	10	Innovative Pedagogy	15	**Faculty Development**	14
Resources	7	**Rewards**	12	Instructional Innovations	14
Changing the Curriculum	7				

Examination of the narratives, however, reveals some other issues. It is apparent that the faculty committees, chairs, and deans used the terms education innovation, teaching excellence, educational scholarship, engineering education research, and other similar terms interchangeably. Furthermore, most of the discussion surrounding engineering education innovation, as well as the examples offered, was largely within the context of improving departmental courses and curricula and occasionally teaching effectiveness. There was also a widespread absence of comments citing dissemination of engineering education innovations. For example, the *only* conference or publication mentioned by name was the ASEE annual conference and its proceedings, despite the fact there are at least two dozen journals and even more regional, national, and international engineering education conferences. Fundamentally, there is a noticeable lack of awareness of the infrastructure that already exists and modalities in which one can engage in engineering education innovation. As one faculty committee commented, "People are not aware of the science of teaching and learning, and those who are may not know how to access and interpret this literature," or in the words of a dean, "…our faculty by and large are not trained in conducting pedagogically oriented research. They would need to have professional development to help them develop in this area."

INTEGRATING THE RESPONSES

The collective survey responses show that the faculty committees and administrators feel most comfortable with their long-standing partners and learning environments and almost equally less comfortable with newer partners and learning environments. It would appear that perhaps engineering programs have become comfortable (or complacent?) with their current efforts and have little desire to expand or move forward. One dean summarized this concern well:

> One challenge is that the greater part of our faculty do not see a need to think about educational approaches beyond those with which they are already familiar—there is marginal motivation to innovate because our faculty don't see a problem with their current, implicitly considered, approach to education. Our own self-perception of success in engineering education is a barrier to investment in fully considered progress.

The survey results point to a lag between the emergence of new ideas and widespread adoption—i.e., between *innovation* and *innovation with impact.*

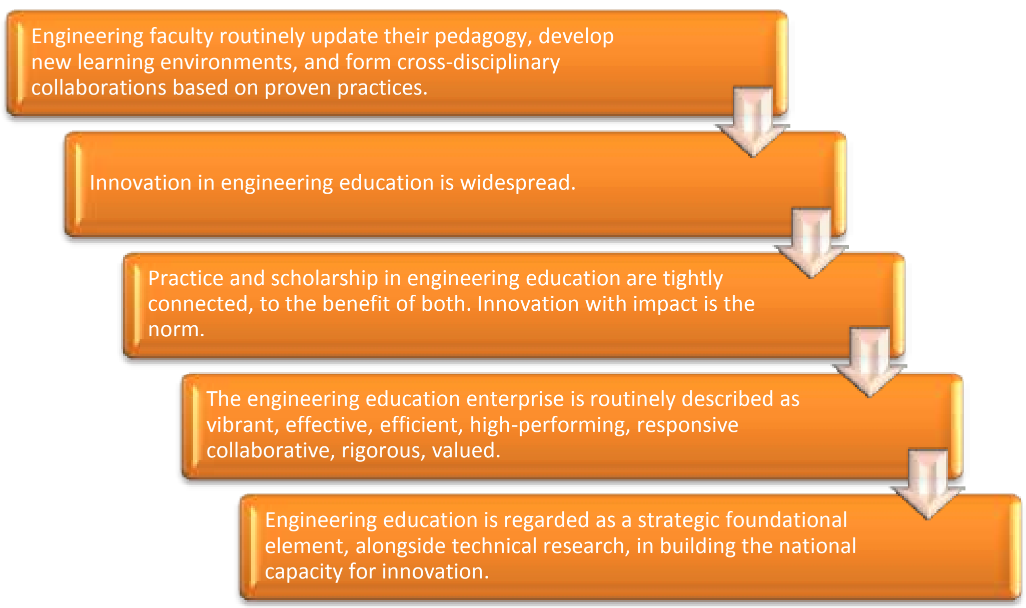
Collectively, the observations suggest that if a more supportive environment for educational innovation were to materialize today (e.g., polices, practices, resources) it is likely that most engineering program efforts would be focused on improving pedagogy within long-standing learning environments. While such a focus would be welcomed as it would continue to improve the engineering educational experience, it would be unlikely to change significantly the current educational paradigm in ways that have been advocated by many national and international reports. *Encouraging more engineering faculty members to move toward ground-breaking innovations will likely require policies, practices, and resources specifically aimed to helping them venture into new and unfamiliar territories.* ■

04 | MOVING TO INNOVATION WITH IMPACT

RECOMMENDATIONS FOR ACTION

Moving to educational innovation with impact requires deliberate steps that will challenge our current mindset and practice. We therefore must, as a community, believe that the journey is worth the effort. Figure 8 outlines a series of steps along the path to transforming engineering education. Fostering and sustaining a culture for scholarly and systematic innovation in engineering education is at the heart of this transformation. Creating such a culture, however, is only a means to an end. It is not the end itself. While the engineering profession has become an important component of the national capacity for innovation, the same cannot be said for engineering education. Thus, we hope this report and the actions recommended ultimately will result in U.S. engineering education being regarded as a critical component in the national capacity for innovation. Achieving such stature will not happen overnight; it will take years of effort and commitment to follow through. Fortunately, a number of engineering programs are currently working toward this end. They are joined in partnership with forward-thinking companies, government and engineering-affiliated agencies, professional societies, accreditation bodies, and others. To increase the national capacity for engineering education innovation, we offer the following seven recommendations. Appendix C suggests specific potential actions under each recommendation, organized by stakeholder/actor.

FIGURE 8
Evidence of progress in transforming engineering education



RECOMMENDATIONS FOR CREATING A CULTURE FOR SCHOLARLY AND SYSTEMATIC INNOVATION IN ENGINEERING EDUCATION: GOING FROM *INNOVATION* TO *INNOVATION WITH IMPACT*

1. Value and expect career-long professional development programs in teaching, learning, and education innovation for engineering faculty and administrators, beginning with pre-career preparation for future faculty.
2. Expand collaborations and partnerships between engineering programs and (a) other disciplinary programs germane to the education of engineers as well as (b) other parts of the educational system that support the pre-professional, professional, and continuing education of engineers.
3. Continue current efforts to make engineering programs more engaging and relevant, and especially expand efforts to make them more welcoming.
4. Increase, leverage, and diversify resources in support of engineering teaching, learning, and educational innovation.
5. Raise awareness of the proven principles and effective practices of teaching, learning, and educational innovation, and raise awareness of the scholarship of engineering education.
6. Conduct periodic self-assessments within our individual institutions to measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation—innovation with impact—in engineering education.
7. Conduct periodic engineering community-wide self-assessments to measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation—innovation with impact—in engineering education.

WHO

Recommendation 1 — Value and expect career-long professional development in teaching, learning, and education innovation for engineering faculty and administrators, beginning with pre-career preparation for future faculty.

It bodes well for the future that engineering faculty and administrators want more career-long development in teaching, learning, and educational innovation, including for those aspiring to faculty careers. High-quality engineering educational experiences are more likely achieved when created and implemented by individuals who collectively have informed knowledge and experience of both engineering and education. The engineering community has a robust infrastructure for the technological preparation of future faculty and their continuing technological development throughout their careers. We need a similar infrastructure to support their preparation and continuing development in teaching, learning, and educational innovation. Presently, faculty development in teaching and learning is largely ad hoc and heavily dependent on short workshops and seminars offered through campus teaching and learning centers or professional societies. While these are important elements of a faculty development infrastructure and should continue to be supported and expanded, career-long faculty development should be much more intentional. It should begin with pre-career preparation and continue throughout faculty careers; it should be planned and its fulfillment explicitly incorporated into faculty tenure, promotion, and annual merit evaluations; and it should be broad-based to allow for progressively higher levels of educational attainment that are in alignment with individual faculty aspirations for achievement in teaching, service, and research. Finally, unless some attention is specifically directed to help faculty seek out and collaborate with the broader educational community (both on and off campus) or to lower the anxiety level of venturing into new modes of educational innovation, we will likely simply see more of the same. While an increase of activity in the current approaches to educational innovation would be welcomed and may indeed be a good place to start, such activity is unlikely to produce regularly the kind of ground-breaking innovations needed for educating future engineers. Faculty and future-faculty development programs can play an especially supportive role.

Recommendation 2 — Expand collaborations and partnerships between engineering programs and (a) other disciplinary programs germane to the education of engineers as well as (b) other parts of the educational system that support the pre-professional, professional, and continuing education of engineers.

Future engineers must possess a broad set of skills, abilities, and attitudes reflective of the multi-faceted global challenges they will face. Developing and delivering similarly broad educational experiences requires a multidisciplinary approach involving knowledge experts in the applicable domains. While engineering programs collaborate well with industry and employers and to some degree with mathematicians and natural scientists, they need to broaden their interactions with many others, such as business, education, humanities, law, social sciences, etc.

Further, the formation of engineers begins long before their collegiate experience and continues long after they graduate. We need to adopt a more holistic perspective of engineering education ranging from pre-professional preparation (K-12), to professional education (community colleges and universities), and finally to continuing education (universities, employers of engineers, and professional societies). While there is a need to expand collaborations and partnerships all along the educational infrastructure, special attention is needed now on the pre-professional and professional education of engineers. In pre-professional education, we need to expand and strengthen our collaborations with the K-12 system and with community colleges. In professional education, we need to strengthen our collaborations with our colleagues in education, the learning sciences, social-behavioral sciences, etc., who could help us strengthen our pedagogical approaches and improve our learning environments.

WHAT

Recommendation 3 — Continue current efforts to make engineering programs more engaging and relevant, and especially expand efforts to make them more welcoming.

It is clear that engineering programs have made considerable progress in making their programs more engaging. However, there remains a significant dependence on traditional laboratory and research experiences as a principal means for delivering relevance. Newer learning environments, such as international experiences, entrepreneurship, and service learning, also offer opportunities for more relevant and welcoming learning. They also are natural opportunities to expand student learning experiences without expanding the curriculum, provided engineering programs are willing to replace some long-standing conceptions about what constitutes the "engineering curriculum." While there is evidence of some progress in making programs more relevant, there is little evidence of making them more welcoming. Attention to and progress in making engineering programs more welcoming has the potential to address such long-standing challenges as making engineering more inclusive while increasing interest and enrollment in engineering.

HOW

Recommendation 4 — Increase, leverage, and diversify resources for engineering teaching, learning, and educational innovation.

The need for better supportive infrastructure is widely recognized. Without doubt, the infrastructure in support of educational innovation is less complete and less valued than that which supports technological innovation. Faculty preparation in teaching, learning, and educational innovation is ad hoc and sporadic; fiscal support is inadequate relative to the importance of the educational mission of engineering programs, especially in support of faculty time to develop, implement, and share new approaches; policies and practices do not adequately motivate the faculty nor reward their efforts; and physical facilities are often dated and lagging in their technological sophistication. While engineering faculty and administrators have an interest in educational innovation, it is clear that support for innovation in education often loses out in the competition for resources and time. Investment in engineering education will foster innovation, accelerate the "technology transfer" of innovation into widespread practice, and signal that engineering education is on the path to becoming a key element in building the national capacity for innovation.

Recommendation 5 — Raise awareness of the proven principles and effective practices of teaching, learning, and educational innovation, and raise awareness of the scholarship of engineering education.

It is clear that much of the discussion about engineering education innovation remains focused on "what" should be taught, and viewed through the lens of "teaching." Engineering education innovation is largely viewed as experimenting with new teaching approaches and mostly within departmental curricula. While such efforts are an important part of the milieu of engineering educational innovation, they focus on only a small part of the broader engineering educational experience. They are less likely to produce the kind of ground-breaking impact possible from more evidence-based approaches grounded in the principles and practices of how people learn and from approaches that are rigorously assessed for their effectiveness in achieving stated objectives. *Perhaps the engineering community's most pressing "grand challenge" is to raise its awareness of the considerable educational infrastructure that already exists, both within and outside engineering, and the substantive body of knowledge of proven principles and effective practices in teaching, learning, and educational innovation.* Raising awareness of effective practices among faculty will have an immediate impact on student learning. Raising awareness of effective practices among faculty (especially senior faculty), department chairs, and deans, has the potential to increase awareness of the educational scholarship that has produced and/or validated innovative practices. This will ideally lead to increased respect for contributions to engineering education, which in turn leads to a broader conceptualization of innovation and changes in resources, rewards, organizational support, and infrastructure.

CREATING A BETTER CULTURE

Recommendation 6 — Conduct periodic self-assessments within our individual institutions to measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation—innovation with impact—in engineering education.

Sustained excellence seldom happens serendipitously. It is generally the result of a compelling vision, shared values, clear goals, careful planning, and commitment to follow through. The same can be said for creating a culture for scholarly and systematic innovation in engineering education. The engineering and engineering education communities are composed of many units, programs, and organizations with diverse aspirations, missions, and roles. Each has its own culture, so it is fully expected that each may have its own approach to innovation with impact. Each institution/college/program/unit should self-assess the means and structures by which it can evolve scholarly and systematic innovation in engineering education into its own culture. If we believe that the creation of such a culture is essential to the long-term vision of being a cornerstone of the national innovation ecosystem, then it is up to us to make it happen within each of our organizations.

Recommendation 7 — Conduct periodic engineering community-wide self-assessments to measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation—innovation with impact—in engineering education.

The engineering and engineering education community, as a whole, needs to conduct candid periodic self-assessments of its progress in creating a culture for more scholarly and systematic innovation for engineering education. We recommend that the American Society for Engineering Education and the National Academy of Engineering work in collaboration to develop and implement this system. We envision that such self-assessments would likely result in observing the following indicators of an emergent new culture:

> Within the next five years, a majority of engineering programs would be found to be routinely evaluating and updating their pedagogy, exploring and implementing new learning environments, and forming broad cross-disciplinary and cross-system collaborations based on proven educational practices (i.e., "walk before you run"). The scholarship of engineering learning would be found to be continuing to emerge, gaining broad acceptance as a legitimate field of inquiry within engineering, and being valued as such. Discourse surrounding engineering education would become more nuanced, as would different levels and activities of educational innovation.
>
> Starting now, and in the next ten years, engineering educational practice and educational scholarship would become more tightly connected to the benefit of both. This connection would be found to be stimulating additional relevant research and accelerating advances in educational practice. This connection lies at the heart of creating a culture of "scholarly and systematic innovation in engineering education." Much of the needed fiscal and physical infrastructure would be in place, and policies and practices would be more widely viewed as mutually encouraging engineering faculty to pursue educational and technological innovation.

In the decade that follows, U.S. engineering education would be increasingly described as vibrant, high-performing, effective, efficient, responsive, collaborative, rigorous, and valued. Ultimately, U.S. engineering education would be regarded as a strategic foundational element in the national capacity for innovation. It would have "a seat at the table" as a peer with engineering research in promoting and sustaining innovation in all domains of engineering and technology. ■

EPILOGUE

It was not surprising during our study that we reaffirmed some long-standing challenges that face U.S. engineering education, e.g., issues of workload and the need for more resources and recognition for educational innovation. It was also not surprising that engineering education innovation remains largely focused on departmental curricula and discussed mostly within the context of better teaching. It was surprising, however, to discover how isolated we are in the U.S. educational community, and probably as a consequence, how limited we are in our thinking and approaches to educational innovation. While we can be proud of the international stature of our engineering programs, we also should not be complacent and assume that what has worked in the past will continue to work in the future. The rich history of U.S. technological innovation and its entrepreneurial collaboration between scholars and practitioners across many fields has served us well. We need to adopt and adapt this time-tested model for U.S. engineering education 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..."

Addressing the challenges we face will not be easy. Now is the time for the engineering community to be adaptive, innovative, entrepreneurial, and opportunistic to significantly advance U.S. engineering education. Bransford (2007, p. 2), co-editor of the highly influential book *How People Learn* (NRC, 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…" ■

REFERENCES

ABET, Inc. 2011. *www.abet.org.*

Adams, R.S., and R.M. Felder. 2008. Reframing Professional Development: A Systems Approach to Preparing Engineering Educators to Educate Tomorrow's Engineers. *Journal of Engineering Education* 97 (3): 239-240.

Ambrose, S., and M. Norman. 2006. Preparing Engineering Faculty as Educators. *The Bridge* 36 (2): 25-32.

American Society for Engineering Education (ASEE). 2006. Main plenary: Advancing the Scholarship of Engineering Education: A Year of Dialogue.

American Society for Engineering Education (ASEE). 2009. Creating a Culture for Scholarly and Systematic Innovation in Engineering Education (Phase 1 Report). Washington, D.C.: American Society for Engineering Education.

Bergvall, V.L., S.A. Sorby, and J.B. Worthen. 1994. Thawing the Freezing Climate for Women: Views from Both Sides of the Desk. *Journal of Women and Minorities in Science and Engineering* 1 (4): 323-346.

Bilén, S.G., E.C. Kisenwether, S.E. Rzasa, and J.C. Wise. 2005. Developing and Assessing Students' Entrepreneurial Skills and Mind-set. *Journal of Engineering Education* 94 (2): 233-243.

Boice, R. 1991. Quick Starters: New Faculty Who Succeed. In *Effective Practices for Improving Teaching: New Directions for Teaching and Learning,* 48. M. Theall and J. Franklin, eds. San Francisco, CA: Jossey-Bass Publishers.

Bomotti, S. 1994. Teaching Assistant Attitudes Toward College Teaching. *Review of Higher Education* 17 (4): 371-393.

Booth, W.C., J.M. Williams, G.G. Colomb. 2008. *The Craft of Research.* 3rd ed. Chicago, IL: University of Chicago Press.

Bransford, J. 2007. Preparing People for Rapidly Changing Environments. *Journal of Engineering Education* 96 (1): 1-3.

Bransford, J., N. Vye, and H. Bateman. 2002. Creating High-quality Learning Environments: Guidelines from Research on How People Learn. In *The Knowledge Economy and Postsecondary Education: Report of a Workshop*. P.A. Graham and N.G. Stacy, eds. Committee on the Impact of the Changing Economy on the Education System. Center for Education, National Research Council. Washington, DC: National Academies Press.

05 REFERENCES

Busch-Vishniac, I.J., and J.P. Jarosz. 2004. Can Diversity in the Undergraduate Engineering Population be Enhanced Through Curricular Change? *Journal of Women and Minorities in Science and Engineering* 10 (3): 255-282.

Chubin, D., and S. Malcom. 2008. Making a Case for Diversity in STEM Fields. *Inside Higher Education* October 6. *www.insidehighered.com/views/2008/10/06/chubin.*

Continental, Inc. 2006. *In Search of Engineering Excellence: Educating the Next Generation of Engineers for the Global Workforce.* Hannover, Germany. *www.conti-online.com/generator/www.com/en/continential/gee/themes/download/study_order_medium_en.pdf.*

Coyle, E., L. Jamieson, and W. Oakes. 2006. Integrating Engineering Education and Community Service: Themes for the Future of Engineering Education. *Journal of Engineering Education* 95 (1): 7-11.

Dee, K.C. 2007. Student Perceptions of High Course Workloads are Not Associated with Poor Student Evaluations of Instructor Performance. *Journal of Engineering Education* 96 (1): 69-78.

Deslauriers, L., E. Schelew, and C. Wieman. 2011. Improved Learning in a Large-Enrollment Physics Class. *Science* 332 (6031): 862-864.

Duderstadt, J.J. 2008. *Engineering for a Changing World: A Roadmap for to Future of Engineering Practice, Research, and Education.* Ann Arbor, MI: The University of Michigan.

Felder, R.M., R. Brent, and M.J. Prince. 2011. Engineering Instructional Development: Programs, Best Practices, and Recommendations. *Journal of Engineering Education* 100 (1): 89-122.

Felder, R.M., S.D. Sheppard, and K.A. Smith. 2005. A New Journal for a Field in Transition. *Journal of Engineering Education* 94 (1): 7-10. (Special issue—The art and science of engineering education research.)

Finelli, C.J., M. Ott, A.C. Gottfried, C. Hershock, C. O'Neal, and M. Kaplan. 2008. Utilizing Instructional Consultations to Enhance the Teaching Performance of Engineering Faculty. *Journal of Engineering Education* 97 (4): 397-411.

Fink, L.D. 2003. *Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses.* San Francisco, CA: Jossey-Bass.

Fortenberry, N.L. 2009 (March 6). A Short Thematic History of Engineering Educational Research in the United States. Presentation at the National Symposium on Creating Engineering Education Opportunities: Why and How, Washington, DC.

Fortenberry, N.L., J.F. Sullivan, P.N. Jordan, and D.W. Knight. 2007. Engineering Education Research Aids Instruction. *Science* 317 (5842): 1175-1176.

Godfrey, E., and L. Parker. 2010. Mapping the Cultural Landscape in Engineering Education. *Journal of Engineering Education* 99 (1): 5-22.

Golde, C.M., and T.M. Dore. 2001. *At Cross Purposes: What the Experiences of Today's Doctoral Students Reveal About Doctoral Education* (www.phd-survey.org). Philadelphia, PA: Pew Charitable Trusts.

Harris, B.J., T. Reed-Rhoads, S.E. Walden, T.J. Murphy, R. Meissler, and A. Reynolds. 2004. Gender Equity in Industrial Engineering: A Pilot Study. *NWSA Journal* 16 (1): 186-193.

Henderson, C., and M. Dancy. 2007. Barriers to the Use of Research-Based Instructional Strategies: The Influence of Both Individual and Situational Characteristics. *Physical Review Special Topics: Physics Education Research* 3 (2), 020102.

Henderson, C., and M. Dancy. 2008. Physics Faculty and Educational Researchers: Divergent Expectations as Barriers to the Diffusion of Innovations. *Physics Education Research Section: American Journal of Physics* 76 (1): 79-91.

Henderson, C., M. Dancy, and A.L. Beach. 2007. Promoting Instructional Change: Beyond an Emphasis on Curriculum. *Proceedings, American Assoc. of Physics Teachers.* Winter Meeting, Seattle, WA.

Huband, F., and Melsa, J. 2007. Engineering Education for the Global Economy: Research, Innovation, and Practice. National Science Foundation, Engineering Education and Centers. Grant No. 0743223.

Leung, M-Y., X. Lu, D. Chen, and M. Lu. 2008. Impacts of Teaching Approaches on Learning Approaches of Construction Engineering Students: A Comparative Study Between Hong Kong and Mainland China. *Journal of Engineering Education* 97 (2): 17-26.

LIFE Center. The Learning in Informal and Formal Environments (LIFE) Center. 2009. *http://life-slc.org*.

McMasters, J.H and N. Komerath. 2005. Boeing-University Relations: A Review and Prospects for the Future. *Proceedings, 2005 ASEE Annual Conference and Exposition,* Portland, OR.

Mohsen, J.P., R. Barr, J. Fraser, A. Karimi, N. Macken, J. Stratton, J. Uhran, and S. Yost. 2008. The Year of Dialog: What We Have Learned. *Proceedings, 2008 ASEE Annual Conference and Exposition, Pittsburgh, PA.*

National Academy of Engineering (NAE). 2004. *The Engineer of 2020: Visions of Engineering in the New Century.* Washington, D.C.: National Academies Press.

National Academy of Engineering (NAE). 2005. *Educating the Engineer of 2020: Adapting Engineering Education in the New Century.* Washington, DC: National Academies Press.

National Academy of Engineering (NAE). 2008. *Changing the Conversation: Messages for Improving Public Understanding of Engineering.* Washington, DC: National Academies Press.

05 REFERENCES

National Academy of Engineering (NAE). 2009. *Developing Metrics for Assessing Engineering Instruction: What Gets Measured is What Gets Improved.* Washington, DC: National Academies Press.

National Research Council (NRC). 2000. *How People Learn: Brain, Mind, Experience, and School.* Expanded Edition. J.D. Bransford, A.L. Brown, R.R. Cocking, S. Donovan, and J. Pellegrino, eds. Washington, DC: National Academies Press.

National Research Council (NRC). 2010. *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5.* Washington, D.C.: National Academies Press.

National Research Council (NRC). 2011. *Promising Practices in Undergraduate Science, Technology, Engineering, and Math Education: Summary of Two Workshops*. Washington, DC: National Academies Press.

Ohland, M.W., S.D. Sheppard, G. Lichtenstein, O. Eris, D. Chachra, and R.A. Layton. 2008. Persistence, Engagement, and Migration in Engineering Programs. *Journal of Engineering Education* 98 (3): 259-278.

Pellegrino, J.W. 2006. Rethinking and Redesigning Curriculum, Instruction and Assessment: What Contemporary Research and Theory Suggests. A paper commissioned by the National Center on Education and the Economy for the New Commission on the Skills of the American Workforce.

Prince, M.J., and R.M. Felder. 2006. Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. *Journal of Engineering Education* 95 (2): 123-138.

Russell, S.H., M.P. Hancock, and J. McCullough. 2007. Benefits of Undergraduate Research Experiences. *Science* 316 (5834): 548-549.

Salter, D., and A. Persaud. 2003. Women's Views of the Factors that Encourage and Discourage Classroom Participation. *Journal of College Student Development* 44 (6): 831-844.

Sax, L. 1994. *Mathematical Self-Concept: How College Reinforces the Gender Gap.* Research in Higher Educaiton Vol. 35, No. 2: 141-166.

Schein, E.H. 1992. *Organizational Culture and Leadership,* 2nd edition. San Francisco, CA: Jossey-Bass.

Seymour, E., and N. Hewitt. 1997. *Talking About Leaving: Why Undergraduates Leave the Sciences.* Boulder, CO: Westview Press.

Sheppard, S.D., J.W. Pellegrino, and B.M. Olds. 2008. On Becoming a 21st Century Engineer. *Journal of Engineering Education* 97 (3): 231-234. (Special issue—Educating future engineers: Who, what, and how.)

Shershneva, M.B., M. Carnes, and L.L. Bakken. 2006. A Model of Teaching-Learning Transactions in Generalist-Specialist Consultations. *Journal of Continuing Education in the Health Professions* 36 (3): 222-229.

Shulman, L. 1986. Those Who Understand: Knowledge Growth in Teaching. *Educational Researcher* 15 (2): 4-14.

Smith, K. 2011.Cooperative Learning: Lessons and Insights from Thirty Years of Championing a Research-based Innovative Practice. *Proceedings, IEEE/ASEE Frontiers in Education Conference,* Rapid City, SD.

Smith, K.A., S.D. Sheppard, D.W. Johnson, and R.T. Johnson. 2005. Pedagogies of Engagement: Classroom-Based Practices. *Journal of Engineering Education,* 94 (1), 87-102.

Special Report. 2006a. The National Engineering Education Research Colloquies. *Journal of Engineering Education* 95 (4): 257-258.

Special Report. 2006b. The Research Agenda for the New Discipline of Engineering Education. *Journal of Engineering Education* 95 (4): 259-261.

Streveler, R.A., K.A. Smith, and M. Pilotte. 2011. Content, Assessment and Pedagogy (CAP): An Integrated Engineering Design Approach. In K.M. Yusof, S. Mohammad, N.A. Azli, M.N. Hassan, A. Kosnin, and S.K.S Yusof, eds. *Outcome-Based Education and Engineering Curriculum: Evaluation, Assessment and Accreditation,* Universiti Teknologi Malaysia, Malaysia.

Trevelyan, J. 2007. Technical Coordination in Engineering Practice. *Journal of Engineering Education* 96 (3): 194-201.

Vogt, C., M. Hocevar, and D.Hagedorn. 2007. A Social Cognitive Construct Validation: Determining Women's and Men's Success in Engineering Programs. *The Journal of Higher Education* 78 (3): 337-364

White, L. 1993. Future Engineering Faculty: An Assessment of Engineering TAs. In *The TA Experience: Preparing for Multiple Roles,* K. Lewis, ed. Stillwater, OK: New Forums Press.

Wulf, W.A. 1998. Diversity in Engineering. *The Bridge* 28 (4), *http://www.nae.edu/Publications/Bridge/CompetitiveMaterialsandSolutions/DiversityinEngineering.aspx.*

SURVEY INSTRUMENT FOR DEPARTMENTS, CHAIRS, AND DEANS

This survey instrument is to help academic departments, chairs, and deans organize their thoughts and comment on the ASEE and NSF-sponsored report, *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education* (http://www.asee.org/about/board/committees/CCSSIE). The CCSSIE project team will assimilate comments received into a final (Phase 2) report. All contributions will be considered in confidence; the final report will provide commentary only in the aggregate with direct quotes, if any, given in complete anonymity and all identifying elements removed.

Instructions

The survey has six brief parts. Parts 1-4 are intended to be completed by a department faculty committee that can knowledgeably consider a broad set of faculty, graduate, and undergraduate issues. We ask the department chair to form such a committee or assign the survey to a standing committee if such a committee already exists within the department. Parts 5 and 6 are intended for the department chair and dean of the college to complete. Please return the completed survey no later than *June 15th* to mbsacre@engr.pitt.edu.

Instructions for the Faculty Committee

1. Please read the report, *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education,* and the entire survey prior to answering the questions.
2. Your part of the survey is divided into four parts.
   - Part 1 asks you to briefly describe your committee, i.e., composition.
   - Part 2 provides an opportunity for your committee to synthesize and share its collective thoughts around two overarching questions.
   - Part 3 focuses on 12 specific statements related to the major sections of the report.
   - Part 4 provides an opportunity for your committee to provide additional information.
3. Complete a **draft** response to the survey.
4. If possible, share the report and the draft response with as many of the department faculty as possible and then prepare a **final** response. We anticipate that the synthesis of faculty opinions and preparation of the written response will take approximately 2 hours.
5. Return the survey with your final response to the department chair for their completion of Part 5.

Instructions for the Department Chair

- Please read the report and your department committee's final response, briefly answer the question in Part 5, and then forward your survey to the dean of the college.

Instructions for the Dean of the College

- Please read the report. After receiving the two department surveys and completing Part 6, please submit the final responses for the two surveys to mbsacre@engr.pitt.edu no later than June 15th 2010.

PART 1

Please tell us who prepared the response to this survey, i.e., the number of committee members, distribution by rank, whether it is a standing or ad hoc committee, and whether the final response includes input from department faculty beyond the committee.
Enter text here:

PART 2

1. As a committee, please identify the most compelling parts of the report. Specifically, comment on the top three priorities that can advance a culture of scholarly and systematic innovation in engineering education in your department.
   Enter text here:
2. As a committee, please identify the principal opportunities your faculty have and/or challenges they face to achieve the top three priorities described in question 1.
   Enter text here:

PART 3

As a committee, please rate each of the following 12 items in terms of their importance in advancing a culture of scholarly and systematic innovation in engineering education. In addition, for each item, please rate the degree to which your department currently practices the item described. Please provide an explanation where desired.

	Importance	Degree of Practice	Use this space to provide explanation, if desired
1. Collaborate with the following stakeholders in educational innovations:			
a. Mathematics and natural sciences	Choose one	Choose one	
b. Humanities and social sciences	Choose one	Choose one	
c. Business, architecture, law, etc.	Choose one	Choose one	
d. Education, learning science, psychology, etc.	Choose one	Choose one	
e. Engineering technology	Choose one	Choose one	
f. Industry and employers	Choose one	Choose one	
g. Pre-colleges and community colleges	Choose one	Choose one	
2. Exercise the following pedagogies in undergraduate instruction:			
a. Inquiry-based learning	Choose one	Choose one	
b. Experiential learning (e.g., PBL)	Choose one	Choose one	
c. Collaborative learning	Choose one	Choose one	
3. Exercise the following pedagogies in graduate instruction:			
a. Inquiry-based learning	Choose one	Choose one	
b. Experiential learning (e.g., PBL)	Choose one	Choose one	
c. Collaborative learning	Choose one	Choose one	
4. Engage undergraduate students in the following learning environments:			
a. Laboratories	Choose one	Choose one	
b. Cooperative education and internships	Choose one	Choose one	
c. International programs	Choose one	Choose one	
d. Research	Choose one	Choose one	
e. Entrepreneurship programs	Choose one	Choose one	
f. Engineering competitions	Choose one	Choose one	
g. Service learning programs	Choose one	Choose one	
5. Engage graduate students in the following learning environments:			
a. Laboratories	Choose one	Choose one	
b. Cooperative education and internships	Choose one	Choose one	
c. International programs	Choose one	Choose one	
d. Research	Choose one	Choose one	
e. Entrepreneurship programs	Choose one	Choose one	
f. Engineering competitions	Choose one	Choose one	

	Importance	Degree of Practice	Use this space to provide explanation, if desired
g. Service learning programs	Choose one	Choose one	
6. Support additional learning environments through:			
a. Mentoring programs	Choose one	Choose one	
b. Engineering extracurricular activities	Choose one	Choose one	
7. Create next generation engineering educators by:			
a. Integrating instruction/ practice of pedagogy into graduate programs	Choose one	Choose one	
b. Providing graduate students with opportunities in engineering education research	Choose one	Choose one	
c. Encouraging industry experience for faculty and future faculty	Choose one	Choose one	
8. Engage career-long development programs in teaching and learning	Choose one	Choose one	
9. Carry out the innovation cycle of educational research and practice (page 6 of the report)	Choose one	Choose one	
10. Create the physical infrastructure necessary to facilitate the innovation cycle	Choose one	Choose one	
11. Obtain fiscal resources to sustain practicing the innovation cycle	Choose one	Choose one	
12. Have policies and practices to support the innovation cycle	Choose one	Choose one	

PART 4

Please comment on anything that you would like to add that has not been included above.
Enter text here:

PART 5 (for the Department Chair)

Please answer the following question in light of your department's response to the survey.

In your role as chair of the department, what are the principal opportunities you have and/or challenges you face helping your department create a culture of scholarly and systematic innovation in engineering education?
Enter text here:

PART 6 (for the Dean of the College)

1. Please answer the following question for all of your departments but particularly in light of the two departments that responded to the survey.

   In your role as dean of the college, what are the principal opportunities you have and/or challenges you face in helping all your departments to creative a culture of scholarly and systematic innovation in engineering education? *Note: You only need to answer this question for one of the two surveys being collected from your college.*
   Enter text here:

2. Please provide the name of your institution and the two departments that conducted the survey. Note: All contributions are kept in strict confidence. This information is used to determine if sample size has been met.

   Institution: *Department 1:* *Department 2:*

3. Please submit the final responses for both surveys to mbsacre@engr.pitt.edu no later than June 15th 2010.

THANK YOU FOR YOUR CONTRIBUTIONS!

Appendix B

Summary of Survey Results

Table B1. Grouped Survey Responses

Item	Practice routinely	Practice lagging	Practice occasionally	Practice reluctantly	*N*
Exercise these pedagogies in undergraduate instruction					
Collaborative learning	57.8%	27.5%	13.8%	0.9%	110
Experiential learning (e.g., PBL)	56.9%	33.0%	10.1%	0.0%	110
Inquiry-based learning	36.7%	42.2%	20.2%	0.9%	110
—in graduate instruction:					
Inquiry-based learning	58.6%	27.6%	13.8%	0.0%	88
Experiential learning (e.g., PBL)	54.1%	25.9%	20.0%	0.0%	87
Collaborative learning	44.8%	29.9%	21.8%	3.4%	88
Engage undergraduate students in these learning environments					
Laboratories	94.5%	2.8%	0.9%	1.8%	109
Cooperative education and internships	56.0%	23.9%	18.3%	1.8%	109
Research	53.2%	22.9%	18.3%	5.5%	109
Engineering competitions	44.4%	19.4%	28.7%	7.4%	108
International programs	30.3%	22.0%	43.1%	4.6%	109
Entrepreneurship programs	16.5%	31.2%	46.8%	5.5%	109
Service learning programs	14.8%	21.3%	61.1%	2.8%	108
—graduate students in these learning environments					
Research	88.4%	11.6%	0.0%	0.0%	86
Laboratories	67.4%	16.3%	16.3%	0.0%	87
Entrepreneurship programs	17.9%	23.8%	56.0%	2.4%	85
Cooperative education and internships	21.8%	16.1%	60.9%	1.1%	87
International programs	12.6%	17.2%	67.8%	2.3%	87
Engineering competitions	14.0%	14.0%	70.9%	1.2%	86
Service learning programs	6.3%	10.0%	82.5%	1.3%	82
—undergraduate and graduate students in these environments					
Engineering extracurricular activities	49.1%	22.6%	23.6%	4.7%	106
Mentoring programs	39.0%	30.5%	26.7%	3.8%	105
Collaborate with these stakeholders in educational innovation					
Industry and employers	68.8%	24.8%	6.4%	0.0%	110
Mathematics and natural sciences	38.9%	47.2%	13.9%	0.0%	110
Educ., learning science, psych., etc.	15.6%	46.8%	35.8%	1.8%	110
Business, architecture, law, etc.	16.5%	35.8%	45.0%	2.8%	110
Humanities and social sciences	16.5%	22.9%	55.0%	5.5%	110
Pre-college and community colleges	16.5%	22.0%	59.6%	1.8%	110
Create next generation of engineering educators by:					
Engaging in career-long development programs in teaching and learning	21.2%	51.9%	26.9%	0.0%	104
Integrating instruction/practice of pedagogy into PhD programs	17.6%	50.6%	28.2%	3.5%	85
Encouraging industrial experience for faculty and future faculty	23.3%	34.0%	40.8%	1.9%	103
Providing PhD students opportunities in engineering education research	9.4%	24.7%	65.9%	0.0%	85
Encourage educational innovation through:					
Supportive policies and practices	9.9%	64.0%	25.2%	0.9%	102
Obtaining fiscal resources	13.5%	63.5%	22.1%	1.0%	104
Creating physical infrastructure	16.3%	51.0%	32.7%	0.0%	104
Carry out innovation	11.4%	41.9%	46.7%	0.0%	105

Note: Practice routinely—item important or highly important and practiced routinely or leaders in this; Practice lagging—item important or highly important and practiced somewhat or not practiced; Practice occasionally—item somewhat important or not important and practiced somewhat or not practiced; Practice reluctantly—item not important or somewhat important and practiced routinely or leaders in this. The *N* values vary because some programs did not answer some items. For example, BS granting institutions did not answer items referring to graduate education.

APPENDIX C

SUGGESTED ACTIONS

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. Below we provide a list of suggested actions categorized by the seven recommendations and coded by the principal stakeholders. Some actions originated with the early framing of the Phase 1 report; others emerged at the October 2008 workshop. Still others grew out of continued discussions as increasing circles of stakeholders were engaged in providing feedback on both the Phase 1 and Phase 2 reports. Some were suggested by reviewers. To facilitate the presentation, individual actions have been listed with one of the seven recommendations where it best aligned. Clearly, many actions could also be aligned with more than one recommendation.

While it is easy to speak of American engineering programs as if they are all alike, they are as different as their histories, their location, 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 and will, in particular, serve as a source of ideas on how to get started in implementing the broader recommendations.

Recommendation 1 — Value and expect career-long professional development in teaching, learning, and education innovation for engineering faculty and administrators, beginning with pre-career preparation for future faculty.

Engineering Faculty, Chairs, and Deans

- Assure that all graduates entering the professoriate are prepared to teach in informed and reflective ways (Bransford, Vye, and Bateman, 2002; Fink, 2003; Pellegrino, 2006). 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.
- Incorporate similar opportunities into appointments for academia-bound postdoctoral students.
- 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, for instance, 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.

- Ensure more faculty have contemporary engineering experience, either before or during their academic career, such as "spin-in/spin-out" semester/summer programs with industry or national labs, "bridge programs" for longer sabbatical-style immersion, and specific academic positions for professionals, for example, professor of engineering practice.
- Make engineering education tools and resources an integral part of orientation/onboarding for new faculty (Felder, Brent, and Prince, 2011).
- Make career-long professional development an expectation for all faculty.
- Support, recognize, and reward faculty who participate in teaching/learning workshops.
- Partner with the graduate college to create future faculty development and certification programs.

ASEE

- Partner with disciplinary professional societies to offer teaching/learning workshops in conjunction with discipline conferences.
- Form virtual 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 consortia 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, as an incentive for active leadership.

National Academy of Engineering

- Use programs such as the Frontiers in Engineering Education to add legitimacy to engineering education innovation efforts of junior and mid-career faculty.

Professional Engineering Societies

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

ABET

- Strengthen training of evaluators to celebrate innovation; ultimately reduce focus on compliance.

Industry

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

Recommendation 2 — Expand collaborations and partnerships between engineering programs and (a) other disciplinary programs germane to the education of engineers as well as (b) other parts of the educational system that support the pre-professional, professional, and continuing education of engineers.

Engineering Faculty, Chairs, and Deans

- 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.
- Foster partnerships with faculty across engineering and other STEM disciplines, as well as with faculty in business, policy, the social-behavioral sciences, and the creative arts.

Professional Engineering Societies

- Create education-focused interest groups, publications, and meetings.
- Integrate graduate student activities/conferences with undergraduate student conferences promoting broader communities of practitioners.

Recommendation 3 — Continue current efforts to make engineering programs more engaging and relevant and especially expand efforts to make them more welcoming.

Engineering Faculty, Chairs, and Deans

- Develop "educational incubators" where engineering faculty may experiment with new pedagogies with professional support and minimal risk.
- Integrate the design experience vertically by including K-12, freshmen, sophomores, juniors, and graduate students in engineering design projects. Examples include the EPICS program first introduced at Purdue (Coyle, Jamieson, and Oakes, 2006) or competitive team pursuits such as the Concrete Canoe, Future Car, Future Truck Challenge, North American Solar Car Challenge, and Future City contests.
- Horizontally integrate the design experience with elements that affect the translation of an engineering design

solution to a real-world solution. These include business aspects (fundraising, communication, marketing, cost-effectiveness), societal impact (on people and the environment), and policy and governmental issues.

- 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.)
- 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 and the 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).
- The actions outlined in the bullet on Learning through Entrepreneurship are also applicable to educating the global engineer.
- 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 actions outlined in the bullet on Learning through Entrepreneurship are also applicable to programs to develop leaders.
- 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. Examples are the American Indian Housing Initiative at Penn State or EPICS).

- The actions outlined in the bullet on Learning through Entrepreneurship are also applicable to service-learning programs.

ASEE

- Facilitate the dissemination of educational innovations, such as a web site of funding opportunities.
- Create a visiting education innovator or innovator-in-residence program.

Professional Engineering Societies

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

ABET

- Help promulgate exemplary teaching and learning tools and techniques.

Industry

- Increase the number of experiences for students, especially international co-op experiences and internships.
- Encourage engineering line personnel to participate in benchmark surveys, serve as adjunct faculty, and engage in 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.

Recommendation 4 — Increase, leverage, and diversify resources for engineering teaching, learning, and educational innovation.

Engineering Faculty, Chairs, and Deans

- Create administrative support to facilitate "technology transfer" and "commercialization" of educational innovation in a fashion similar to technology innovation.
- Review and modify, as appropriate, end-of-course/faculty evaluations of course/teaching effectiveness to ask questions focused on student learning.
- 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.
- Create endowed chairs or professorships on engineering education innovation.

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.
- Support programs for faculty preparation and development, especially programs that help faculty learn about the many facets of educational scholarship, such as framing a project, choosing methods of investigation, and writing proposals and papers.
- Establish competitive long-term programs for faculty-practitioner "trading places" programs. Such programs help establish legitimacy. The National Science Foundation GOALI program is an example.
- 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).

Recommendation 5 — Raise awareness of the proven principles and effective practices of teaching, learning, and educational innovation and raise awareness of the scholarship of engineering education.

Engineering Faculty, Chairs, and Deans

- Support junior to mid-career faculty to participate in engineering education conferences and workshops such as the National Effective Teaching Institute. Support 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).

ASEE

- Lead the development of a national network of seminars, workshops, webinars, and modular continuing education courses on education theory, research findings, and proven practices for engineering learning. 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.
- Partner with the National Academy of Engineering to offer a prestigious engineering education workshop for senior faculty and for chairs and deans.

National Academy of Engineering

- Create an engineering education section, including outlining criteria that would allow leading engineering educators to be elected to NAE membership in significant numbers because of their impact on engineering education.

- Partner with ASEE to offer a prestigious engineering education workshop for senior faculty and for chairs and deans.
- Expand the current Grand Challenge to "advance personalized learning" to a broader list of Grand Challenges in Engineering Education.

Funding Agencies

- Exert their role as influencers, not just funders. For example, require research projects in education to build on scholarship in pedagogy and employ rigorous methodology for assessment; support follow-on efforts for propagation of proven successful efforts.

ABET

- Increase the emphasis on 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).

Industry

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

Recommendation 6 — Conduct periodic self-assessments within our individual institutions to measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation—innovation with impact—in engineering education.

Engineering Faculty, Chairs, and Deans

- 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.
- Publish educational innovations alongside technological innovations in department, college, and university magazines or through professional society newsletters, e-forums, etc.
- Consider the suggestions in the National Academy of Engineering report (2009), *Developing Metrics*

for Assessing Engineering Instruction: What Gets Measured is What Gets Improved.

ABET

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

Recommendation 7 — Conduct periodic engineering community-wide self-assessments to measure progress in implementing policies, practices, and infrastructure in support of scholarly and systematic innovation—innovation with impact—in engineering education.

ASEE

- 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 intersociety strategy to facilitate engineering education innovation.
- In partnership with the NAE and funding agencies, establish a community-wide assessment schedule and conduct periodic assessments both of the state of engineering education and the state of the culture for scholarly and systematic innovation in engineering education.

National Academy of Engineering

- In partnership with ASEE and funding agencies, establish a community-wide assessment schedule and conduct periodic assessments both of the state of engineering education and the state of the culture for scholarly and systematic innovation in engineering education.

Professional Engineering Societies

- Sponsor major honors for educational innovation.

ABET

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

- Modify General Criterion 6 to include continuing development in education and contributions to educational scholarship as potential components of the qualifications for some of the institution's faculty.

Funding Agencies

- Support community-wide periodic assessments both of the state of engineering education and the state of the culture for scholarly and systematic innovation in engineering education.

APPENDIX D

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Leah H. Jamieson

Jack R. Lohmann

EXECUTIVE LEADERSHIP (PHASES 1 & 2)

Leah H. Jamieson, Purdue University
Project Co-Chair

Jack R. Lohmann, Georgia Institute of Technology
Project Co-Chair

James L. Melsa, Iowa State University (Emeritus)
Project PI, ASEE President 2007-08

Sarah A. Rajala, Mississippi State University
ASEE President 2008-09

J.P. Mohsen, University of Louisville
ASEE President 2009-10

Renata S. Engel, Pennsylvania State University
ASEE President 2010-11

Don P. Giddens, Georgia Institute of Technology
ASEE President 2011-12

Frank L. Huband, American Society for Engineering Education
Executive Director Emeritus

Norman L. Fortenberry, American Society for Engineering Education
Executive Director

William E. Kelly, American Society for Engineering Education
Manager of Public Affairs

PHASE 1 TEAM MEMBERS

Robin S. Adams, Purdue University

Stephanie G. Adams, Virginia Commonwealth University
Vice Chair, Working Group on Scholarly Educational Practice

Ashok Agrawal, St. Louis Community College

Alice Agogino, University of California, Berkeley

Neal E. Armstrong, University of Texas at Austin

Cynthia J. Atman, University of Washington

Rodica Baranescu, Navistar

Mary Besterfield-Sacre, University of Pittsburgh

Steve Beyerlein, University of Idaho

Maura J. Borrego, Virginia Tech
Vice Chair, Working Group on Report Impact and Research

Lori Breslow, Massachusetts Institute of Technology

April S. Brown, Duke University

Walter W. Buchanan, Texas A&M University

Daryl E. Chubin, American Association for the Advancement of Science

Michael L. Corradini, University of Wisconsin-Madison
Chair, Working Group on External Contexts

Monica F. Cox, Purdue University

Lesia Crumpton-Young, University of Central Florida

Lorraine N. Fleming, Howard University

Norman L. Fortenberry, National Academy of Engineering
Chair, Working Group on Scholarly Educational Practice

Gary A. Gabriele, Villanova University

Andrew Green, Lockheed Martin

Kamyar Haghighi, Purdue University

Daniel E. Hastings, Massachusetts Institute of Technology

Thomas O. Hunter, Sandia National Laboratories

James H. Johnson, Howard University

Wayne Johnson, Hewlett-Packard

Muhammad Kehnemouyi, Montgomery College

Maria Klawe, Harvey Mudd College

John S. Lamancusa, Pennsylvania State University

Lisa R. Lattuca, Pennsylvania State University

Mark E. Law, University of Florida

Donna C. Llewellyn, Georgia Institute of Technology
Vice Chair, Working Group on Faculty Preparation and Development

Theresa A. Maldonado, Texas A&M University

Gary S. May, Georgia Institute of Technology
Chair, Working Group on Faculty Preparation and Development

James McClellan, Georgia Institute of Technology

Richard K. Miller, Franklin W. Olin College of Engineering

Lueny Morell, Hewlett-Packard

Ray Morrison, ACETS Consulting

David C. Munson, Jr., University of Michigan
Chair, Working Group on University (Internal) Contexts

Indira Nair, Carnegie Mellon University

Wendy C. Newstetter, Georgia Institute of Technology

Barbara M. Olds, Colorado School of Mines
Chair, Working Group on Report Impact and Research

Paul S. Peercy, University of Wisconsin-Madison

James W. Pellegrino, University of Illinois at Chicago

Sarah K.A. Pfatteicher, University of Wisconsin-Madison

David F. Radcliffe, Purdue University

M.P. Ravindra, Infosys Technologies (Retired)

Tess Reinhard, CDW

Michael Richey, The Boeing Company

Sheri D. Sheppard, Stanford University
Chair, Working Group on Engineering Education Research

Larry J. Shuman, University of Pittsburgh

Karl A. Smith, Purdue University and the University of Minnesota

Mark J.T. Smith, Purdue University

Patrick T. Terenzini, Pennsylvania State University
Vice Chair, Working Group on Engineering Education Research

Matthew Tirrell, University of California, Santa Barbara

J. Kim Vandiver, Massachusetts Institute of Technology

Bevlee A. Watford, Virginia Tech

Karan L. Watson, Texas A&M University
Vice Chair, Working Group on External Contexts

William J. Wepfer, Georgia Institute of Technology

David C. Wisler, GE Aviation

Maria C. Yang, Massachusetts Institute of Technology

PHASE 1 ATLANTA MEETING PARTICIPANTS

Ron Barr, University of Texas at Austin
Joseph Cecchi, University of New Mexico
Phillip Cornwell, Rose-Hulman Institute of Technology
Rob Ettema, University of Wyoming
Delores Etter, Southern Methodist University
Dennis Fallon, The Citadel
Ralph Flori, Missouri University of Science and Technology
James Holloway, University of Michigan
Alan Jacobs, Autodesk
Aditya Johri, Virginia Tech
Gretchen Kalonji, University of California
Jennifer Karlin, South Dakota School of Mines and Technology
Mostafa Kaveh, University of Minnesota
Sue Kemnitzer, National Science Foundation (observer)
Kathy Kilmer, The Walt Disney Company
Tom Litzinger, Pennsylvania State University
Ray Luechtefeld, Missouri University of Science and Technology
Krishna Madhavan, Clemson University
Taylor Martin, University of Texas at Austin
Louis Martin-Vega, North Carolina State University
Jessica Matson, Tennessee Technological University
Roger Mayes, Idaho National Laboratory
Patricia Mead, Norfolk State University
Tamara Moore, University of Minnesota
Richard Okine, Dupont
Russell Pimmel, National Science Foundation (observer)
Michael Prince, Bucknell University
Teri Reed-Rhoads, Purdue University
Sue Rosser, Georgia Institute of Technology
Jeffrey S. Russell, University of Wisconsin-Madison

Brian Self, California Polytechnic State University at San Luis Obispo

Larry Shuman, University of Pittsburgh

Lynne Slivovsky, California Polytechnic State University at San Luis Obispo

Allen Soyster, National Science Foundation (observer)

Sally Wood, National Science Foundation (observer)

David Woodall, Oregon Institute of Technology

David Wormley, Pennsylvania State University

RESEARCH TEAM, PHASE 2

Drs. Barbara M. Olds, National Science Foundation
Chair

Maura J. Borrego, Virginia Tech

Mary Besterfield-Sacre, University of Pittsburgh

Monica F. Cox, Purdue University

PHASE 2 SURVEY RESPONDENTS AND FINAL REPORT PEER REVIEWERS

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