

Systemic Engineering Education Reform A Grand Challenge

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WE CANNOT KNOW EXACTLY what the future will bring; however, we can predict with certainty that engineering schools and engineers will be called upon to satisfy a multiplicity of needs in the years to come. These needs may relate to knowledge and expertise, for example, in more secure and efficient physical facilities and information networks, advanced asynchronous learning systems, earth systems, and ecoefficient design of complex systems. Engineers will ponder problems involving world cultures, religions, ethics, and economics, as well as new technologies. They will also be concerned with other unforeseen questions of local, national, or global significance. The new paradigm for engineering education goes beyond the need to keep students at the cutting edge of technology and calls for a better balance in the various areas of engineering school scholarship. Commitment to the realization of the new paradigm will yield renaissance-engineer graduates with the tools to face an unpredictable future with confidence in their abilities and yield untold benefits to the world in which they will live. After presenting a brief historical background on engineering education reform, this article summarizes related problems and the current status of various reform efforts. Both a basic understanding of the new paradigm and the need and urgency of engineering education reform can be grasped from a reading of the four questions and answers in the screened box.

SOME HISTORICAL PERSPECTIVES

A myriad of articles, papers, books, and workshop and conference proceedings have made a compelling case for systemic engineering education reform. Among these are the 1994 joint project report on *Engineering Education for a Changing World* by the Engineering Deans Council and Corporate Roundtable of the American Society for Engineering Education (ASEE) [1], the 1995 Report by the Board on Engineering Education of the National Research Council (NRC) [2], and the recent call for change by the National Academy of Engineering (NAE) leadership, William A. Wulf, president, and George M.C. Fisher, *IL A '62*, chair [3]. Although there has been progress, resistance to change continues unabated in spite of the numerous calls for action, increasing competition from alternate service providers, as well as student-pipeline and job-security issues [4, 5]. A survey conducted by the Boyer Commission indicated that research universities have invested considerable effort in

improving undergraduate education in recent years; *“but it also suggests that most efforts have been directed at the best students; the challenge for almost all is to reach a broader spectrum of students”* [6].

The introduction of new, outcomes-based accreditation criteria, *Engineering Criteria 2000* (EC 2000) by the Accreditation Board for Engineering and Technology (ABET), and the funding of a number of programs

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related to systemic engineering education reform by the National Science Foundation (NSF) in the early 1990s are seminal events on the path to a new paradigm for engineering education. The 1998 Engineering Foundation Conference provided further impetus. Co-chair Edward W. Ernst, *IL A '49*, University of South Carolina, reminded the participants that intense discussions beginning in the late 1980s, coupled with several conferences, workshops, and studies *“produced a consensus about what engineering education should be—what the stakeholders expect in the content of the curriculum, innovative approaches to teaching, and involvement of students. Achieving the change needed in engineering programs across the country has become the*

current barrier that must be surmounted for engineering education to realize the new paradigm for engineering education and to serve the stakeholders even better.” [7]

Achieving change via engineering education reform presents a formidable challenge, given academe's interest in preservation of the status quo where publications and research funding drive rewards and recognition. It is part of the overarching challenge of change faced by universities and colleges throughout our nation, as described by former president of the University of Michigan, James J. Duderstadt, *CT A '64*, [8] in his

Systemic Engineering Education Reform: Some FAQs

- 1. Why is a large change such as that implied by “engineering education reform” needed?** Engineering graduates need to be significantly better prepared for the 21st-century engineering workplace. Although the (now) traditional engineering education offered at most of our engineering schools provides a good education about the technical aspects of engineering, other areas such as communication competence, ethics and professionalism, sustainable development and the environment, working in teams, the current approach to quality, focus on customer needs, “business” practices, fundamentals of entrepreneuring and “intrapreneuring,” and other non-technical areas seem to receive little or no attention in many engineering programs. Therefore, many engineering graduates do not have the breadth of jobs available to them they could have. Qualified engineering students at the freshman and sophomore level fail to see engineering as a profession that helps people—one that focuses on meeting people’s needs—and/or they find the learning environment unsatisfactory and transfer to another field of study.
- 2. Why can’t incremental change make the needed changes in an appropriate time frame?** Fundamental structural, sometimes concurrent, changes are needed—not just changing a few courses. Active, integrative project-based learning needs to replace much of the passive lecture-based instruction. Instructional programs and strategies should focus on attracting and retaining more of the “best and brightest” students with diverse learning styles. To make these changes, faculties need to change their view of what engineering education should be.
- 3. Why do we need to recognize leadership and systemic change in engineering education now?** Those taking leadership roles in engineering education reform will need to devote a significant portion of their time and energy for an extended period to implement the engineering education reforms needed. We also need to involve some of the best minds among our faculties. Without recognition and reward for their efforts, the “best” likely will choose other places to put their efforts, e.g., disciplinary research and securing funding.
- 4. What are attributes of the new paradigm driving engineering education reform?** No doubt, some details in the following list of attributes will change over time; however, programs that reflect these attributes should yield graduates better prepared for the 21st century engineering workplace: Encouragement of diverse student academic backgrounds and faculty dedicated to developing emerging professionals; Connection of solid mathematics and scientific knowledge foundation with engineering practices; Maintenance of regular, well-planned interaction with industry—including industry-based projects; Integration of subject matter, concepts, issues, and principles—including relationships to earlier subject matter; Emphasis on inquiry-based learning and preparation for lifelong learning, with much less dependence on lectures; Stress on integrative, systems thinking, coping with change, communication skills (listening, speaking, reading, and writing), teamwork, and group problem-solving skills (from identification through analysis and resolution); Focus on design issues involving life-cycle economics, environmental impact, sustainable development, ethics, timeliness, quality, health & safety, manufacturability, maintainability, social, legal, standards, and *ad hoc* concerns.

comprehensive analysis of the issues and the need for new paradigms. This is a complex age of rapid change where different points of view and conflicting interests characterize the stakeholders who often resemble disconnected parties.

Recent times have seen no clear path forward and an apparent absence of focused, action-oriented leadership. Also, the engineering education reform movement has been clouded by mixed, and sometimes disquieting, messages of equivocation that could be interpreted as disclaimers or “escape clauses”—saying, in effect, that there need be no sense of urgency about engineering education reform [9]. So systemic change continues to proceed at geologic speed despite the ardent efforts of Norman R. Augustine, *NJ A '57*, and Charles M. Vest, *WV A '63*, during the mid-1990s. Why might this be so, and what might be done to accelerate the pace of change? The answers to these questions are complex,

institution dependent, and not amenable to a one-size-fits-all resolution. However, it is possible to identify a few of the major barriers to change along with courses of action that are now helping to catalyze change.

THE BARRIERS TO CHANGE

There is more behind the reticence of some of our engineering schools to adopt change than complacency, indifference, forgetfulness, and even the routine resistance to change that characterizes organizations and institutions that consider themselves “successful” in doing what they are currently doing. Apparently, powerful interrelated counter-reform forces are working to maintain the status quo. These forces can be attributed, in part, to a cultural problem that stems from the patterning of the academic engineering community after the academic scientific community—where published research is prime—rather than professional communities

such as legal and medical. Consequently, engineering faculty are largely deficient in the practices of engineering and have little or no firsthand knowledge or experience to pass on to students being educated for careers in engineering practice as opposed to research. Systemic engineering education reform is at least partially dependent on the resolution of this and other interrelated problems; of these, the following are considered core problems:

ACADEMIC RESISTANCE TO CHANGE AND TO ABET OVERSIGHT

In the academic variant of the “innovator’s dilemma” [10], many of our research-intensive universities, faced with enormous financial pressure, struggle to maintain and grow the (largely) government-fueled, resource-intensive infrastructure created to pursue their research missions [8]. Apparently, they feel that they cannot afford to invest significant resources in undergraduate engineering education reform where they perceive little, if any, near-term gain in the way of financial rewards or other payoffs that will help support their primary research mission.

It has been recommended that the ASEE engineering dean’s council work cooperatively with ABET in its reassessment of accreditation criteria in accordance with a wide variety of suggested changes [2]. These changes are not likely to take place in most engineering programs without a strong forcing function, for example, pressure from prime customers—industry and students—that may be reflected in ABET criteria. The apparent opposition-to-reform strategy is to treat ABET in an adversarial manner, providing as little support as possible—reflecting the relatively low value placed on activities that are not related to the school’s research mission. Also, if undergraduate engineering education is not a high priority item on campus, how can overburdened faculty be expected to consider ABET-related work important? The relationship between industrial firms and OSHA offers an insight into the adversarial relationship between engineering schools and ABET.

In view of increasing competition and advanced technology delivery systems, it has been argued [11] that it is in the long-term-economic self interest of our engineering schools to position themselves in the shifting educational marketplace by implementing programs that reflect change, such as those outlined in the references [1, 2, 7]. This could be a situation where anecdotal and inferential evidence is all that we will have; after the shift arrives in force, it will be too late for the schools to deal with it—the market already will have decided.

Achieving and maintaining the needed changes in academic culture is a long-term effort. It requires the identification, support, and nurturing of change agents in engineering schools across the country. A related issue appears to be maintaining sustained administrative support for change. Engineering deans cannot realistically mandate a culture change, but they can set a tone and use their limited discretionary funds to help assure that change is not stifled when it appears. Again, we need to ensure that engineering education receives significant

attention from some of the best minds in the engineering community. Those who make innovative undergraduate engineering education a dominant part of their contributions will do much to improve student retention and encourage graduate study, to the ultimate benefit of the academic research community.

If you keep doing what you have always done, you’re going to get what you always got.

Roderick G.W. Chu

LACK OF RECOGNITION FOR EDUCATORS

The dearth of prestigious, national-level rewards and recognition for high-quality contributions to engineering education—particularly, election to membership in the NAE—is considered to be one of the root causes for the slow and halting progress of systemic engineering education reform. The problem stems from the relatively low value placed on undergraduate engineering education reform by many engineer-researchers and the institutions that profit from their contributions. It is likely that some academic institutions will not want to “waste” effort and political capital, as well as risk missing a possible increase in *US News and World Report* rankings, on faculty candidates from a “who-cares” area—engineering education—with relatively low-payoff in terms of prestige and peer recognition. This presents a great opportunity for the NAE to focus the attention of the academic community on the high value it places on engineering education.

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Karl Martersteck

LACK OF FORCEFUL INDUSTRY INPUT

Without strong input from industry, the academic engineering community is not likely to institute changes in engineering programs, a point well made by Karl Martersteck, a retired corporate executive and member of the NAE: “Industry must establish the ‘requirements’ for the quality and education of the engineers they hire. Unless, and until, major industrial leaders whose views are generally respected speak out and say that they will not hire engineers unless the engineers have the broader ‘new paradigm’ education, academics will continue to pursue their present course” [11]. Unfortunately, the long-term views of industrial leaders often are not communicated to company representatives on ABET committees and engineering-school advisory boards or to project managers and campus recruiters who write and execute requisitions—knowing their firms are being evaluated in the marketplace by share price and they on near-term results. Industrial leaders can also work to treat engineers as professionals rather than as “commodities” [5].

SURMOUNTING THE BARRIERS TO CHANGE

Notable leaders in engineering education such as: Wayne Bennett, *MD A '57*; Joseph R. Bordogna, *PA Δ '55*; Edward W. Ernst, *IL A '49*; Lyle D. Feisel, *IA A '61*; Eli Fromm, *PA Z '62*; Jerrier A. Haddad, *NY Δ '45*; Irene C. Peden, *WA A '47*; and John W. Prados, *TN A '54*, have helped fashion a compelling argument for a Campaign for Systemic Engineering Education Reform. The ultimate aims of the campaign are to surmount the barriers to change and so provide students with significantly better preparation for the 21st century engineering workplace and to help attract and retain more of the “best and brightest” students on campus, as well as to involve some of the best minds among our faculty.

The campaign is all about enlightening and motivating the various stakeholders in engineering education—showing that the (remarkably consistent) changes recommended by ASEE, NRC, and by the NAE’s Wulf and Fisher [1-3], are not only feasible, but that it is in the current and future self interest of our engineering schools to embrace the changes appropriate to the context of their institutions, student bodies, faculties, and objectives. To this end, the International Engineering Consortium published *Engineering Education Reform: A Trilogy* [9], as a service to academe, government, and industry. It is now serving as the white paper for the campaign.

There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things.

Niccola Machiavelli, *The Prince*, circa 1512

Substantial progress has been made on the distribution of the *Trilogy* and discussion of its aims. The various stakeholders in the future of engineering education have been contacted—including administrators, faculty, department-head associations, students, parents, professional societies, and organizations, as well as governmental and business leaders. This distribution strategy represents a crosscutting, bottom-up/top-down approach to promoting debate of the issues surrounding systemic engineering education reform. The objective is to have readers of the *Trilogy* use the publication to raise awareness of the issues surrounding systemic engineering education reform as well as of “what works” and “what could work”—ultimately leading to campus action. A key success factor will be the widespread promulgation of the ideas related to systemic reform via massive networking—moving stakeholders to awareness-to-understanding-to-commitment-to-action. Well-reasoned arguments, perseverance, and a multitude of voices will catalyze conversations essential to progress. Although these conversations may very well continue for years, they will nevertheless hasten the time to the realization of systemic reform. As will be seen in the following, progress is being made on multiple fronts.

NOTEWORTHY ACTIVITIES AND POSSIBILITIES

A number of engineering schools have made significant changes in their undergraduate programs—on their own or with the help of NSF and other grants [11]. These changes encompass all or some of the attributes of the new paradigm. Also, there is much to be mined from the work done by the NSF-supported engineering-education coalitions and research centers, as well as from pacesetter engineering schools. An outcomes assessment of the tools, processes, and methodologies that have already been developed, as well as the breadth and depth of their adoption and penetration, would be of value. For example, under the direction of Sheri D. Sheppard, *WI A '78*, a Carnegie Foundation project is focusing on this kind of assessment [12]. The project uses a model of engineering practice as it studies

engineering education and addresses the basic question: “what are the teaching and learning practices that comprise an engineering education, and how are these related to engineering practice?” Assessments of this type could provide the basis for a modular recipe book of best practices—models of “what works” for schools willing to participate in the next wave of change. The next step involves making it attractive for schools to commit themselves to change from what they do now to something approaching an appropriate model. Examples of other related activities follow.

Under the leadership of Jeffrey S. Russell, *OH B '85*, chair of a task committee of the American Society for Civil Engi-

The introduction of ABET Engineering Criteria 2000 and the establishment of the NSF’s engineering education coalitions are seminal events on the path to implementing a new paradigm for engineering education.

neers, progress is being made with education reform within the civil engineering profession as it develops a vision for the full realization of a policy regarding the first professional degree—and a strategy for achieving that vision [13]. Second, the Electrical and Computer Engineering Department Heads Association is pursuing several activities that can lead to change in engineering education—including sessions at their annual meetings that deal with trends in curricula and the sponsorship of a special edition of the *IEEE Transactions on Education* that is focused on the future of electrical and computer engineering education. As a last example, the International Engineering Consortium is developing asynchronous-learning resources in the form of web portals for high-

school and university students—addressing student-pipeline issues, especially the attraction and retention of women and minorities—and for university students, providing materials and courses similar to their *ProForums* and *iForums* that can be used as supplemental education modules that offer professional enrichment materials and information about the industrial workplace.

ABET PLAYS A KEY ROLE

Resistance to ABET oversight and accountability notwithstanding, the outcomes-based structure of ABET EC 2000, coupled with its call for greater documented involvement of engineering education “constituencies,” provides a key for change and for keeping the change fresh on a program-by-program basis. A strong, credible, and respected accrediting organization plays an essential role in the realization of systemic engineering education reform. ABETs industry advisory council can support industrial representatives on the various ABET committees and commissions—identifying what is needed and insisting that change occurs.

THE NATIONAL ACADEMY'S FOUR-PART STRATEGY

The NAE announced the establishment of a Center for the Advancement of Scholarship in Engineering Education in September 2002—capping a commendable four-part strategy to raise the prominence and effectiveness of engineering education. A purpose of the center is to provide the education research base that will support systemic reform of engineering education. During the 1999-2001 period, the NAE established a committee on engineering education, expanded its criteria for membership to more fully recognize contributions to engineering education, and established the Bernard M. Gordon [MA B '48] prize for innovation in engineering and technology education, a \$500,000 award to emphasize the importance of education to the future of engineering.

The expansion of the criteria for NAE membership is a most encouraging first step. It has been suggested that the academy give consideration to a follow-up action—recognition of engineering education as a principal NAE activity—assuring a sustainable election process for worthy candidates and focusing the attention of the academic community on the high value the NAE places on engineering education [9]. It has also been suggested that the academy help facilitate the development of a strong, credible, and respected ABET—encouraging ASEE's engineering deans council, engineering professional societies, and other appropriate groups to follow the NRC recommendation to work with ABET in its reassessment of accreditation criteria in accordance with the types of changes outlined in its report [2].

NSF COALITIONS AND CENTER ANNOUNCEMENTS

Through cross-collaboration, the NSF engineering education coalitions developed intellectual exchange and resource links among undergraduate engineering programs. Annual *Share the Future Conferences* were initiated in 2000. These workshops have centered on topics relevant to coalition goals—providing the extended engineering education community an opportunity to share in the research findings and experiences. The 2003 *Share the Future IV Conference* held in March was organized by the foundation coalition's Jeffrey E. Froyd, IN B '75, [14].

The NSF-sponsored Center for the Advancement of Engineering Education (CAEE) opened in January 2003 with an initial five years of support. Cynthia J. Atman,

WV A '79, University of Washington, serves as the director of this center that also includes Stanford University, Howard University, and Colorado School of Mines. CAEE will pose and answer basic questions about how students learn engineering, how to support faculty in learning about and adopting more advanced teaching methods, and how to foster the development of future generations of engineering education researchers, as well as leaders and change agents in engineering education.

Despite the challenging environment and the difficulties involved, resiliency can be seen in the effort to realize the new paradigm for systemic engineering education—resiliency that is essential in responding to what ought to be considered among the grander challenges of the 21st century.

The NSF also announced the Center for the Integration of Research, Teaching, and Learning. A five-year grant will allow this center to focus on

questions surrounding science, technology, engineering, and mathematics (STEM) Ph.D. education, as well as the integration of teaching into this education. The center is a collaboration of faculty and educational researchers at the University of Wisconsin-Madison, Michigan State University, and Pennsylvania State University who will work to develop: a future national STEM faculty, enabling all students to achieve STEM literacy; teaching that enhances recruitment into STEM careers; and leadership that ensures the continued advance of STEM education. The center will treat the improvement in teaching as a research problem and may well change the way that science and engineering are taught.

Recent remarks by J.R. Bordogna, NSF deputy director and chief operating officer, focused on the overlapping roles and responsibilities of educators and engineers in the continuing progress of society—providing opportunities to explore elements of a framework for crossing boundaries and working together [15]. In addition to the aforementioned NSF program investments, he also referred to its *workforce-for-the-21st-century* and *faculty-for-the-future* programs to illustrate additional directions for productive collaboration among engineers and educators.

THE UPSHOT AND A LOOK FORWARD

The challenge of gaining acceptance and endorsement of the value of the reform's aims and related pedagogical innovations presents a unique opportunity for collaborative efforts on the part of faculty, administrators, students, departmental associations, industrial leaders, national and professional organizations, and funding agencies. The new NSF and NAE centers will certainly enhance the educational knowledge base and skill pool to help propel ever more engineering schools to build on the successes of others to broaden the reach of systemic reform. Proven methodologies and knowledge gained as to what does and does not work should make it possible for most engineering schools to devise revitalization programs that fit the context of their institutions, students, faculties, and objectives. Despite the challenging environment and the difficulties involved, resiliency can be seen in the effort to realize the new paradigm for systemic engineering education—resiliency that is essential in responding to what ought to be considered among the grander challenges of the 21st century.



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