The Green Report - Engineering Education for a Changing World

Introduction

We live in a time of revolutionary change. Not only is the world relying increasingly on technology for economic growth and job development, but the nation is making the difficult transition of refocusing a significant amount of its technology investment from national security to international economic competitiveness. At the same time, we view technology as important in helping solve many difficult societal problems, from creating environmentally-sustainable development and improving communications, to devising more effective and cost-efficient health care systems. Communications developments alone are leading to profound redefinitions of such concepts as "community," "library," "corporation," and even "university."

Within this technological context, engineers play an ever more significant role. They develop new manufacturing processes and products; create and manage energy, transportation and communications systems; prevent new and redress old environmental problems; create pioneering health care devices; and, in general, make technology work. Through these activities, engineers create a huge potential for the private sector to develop national wealth. As noted by Richard Morrow, past chairman of the National Academy of Engineering, "the nation with the best engineering talent is in possession of the core ingredient of comparative economic and industrial advantage."

And just as important as their specific technical skills, engineers receive valuable preparation for a host of other careers in such areas as finance, medicine, law and management. These professions require analytical, integrative and problem-solving abilities, all of which are part of an engineering education. Thus, engineering is an ideal undergraduate education for living and working in the technologically-dependent society of the twenty-first century.

Responding to Changing Needs

One of the strengths of engineering education in the United States is the broad spectrum of engineering colleges whose development has been unconstrained by a single, centrally-prescribed mission. The more than 300 colleges of engineering range from highly research-intensive institutions to those that focus largely on undergraduate education, with many variations in between. Even with the considerable differences in missions, undergraduate engineering education programs maintain universal core curriculum content and minimum standards through the Accreditation Board for Engineering and Technology (ABET), a national partnership between academics and practicing engineers. Additionally, most engineering schools have forged close relationships with industry and benefit from annual assessments of their programs by external advisory boards that have strong industry participation.

While U.S. engineering education has served the nation well, there is broad recognition that it must change to meet new challenges. This is fully in keeping with its history of changing to be consistent with national needs. Today, engineering colleges must not only provide their graduates with intellectual development and superb technical capabilities, but following industry's lead, those colleges must educate their students to work as part of teams, communicate well, and understand the economic, social, environmental and international context of their professional activities. These changes are vital to the nation's industrial strength and to the ability of engineers to serve as technology and policy decision makers.

Most important, engineering education programs must attract an ethnic and social diversity of students that better reflects the diversity of the U.S. and takes full advantage of the nation's talents. Not only does the engineering profession require a spectrum of skills and backgrounds, but it should preserve its historical role as a profession of upward mobility.

In response to these needs, engineering colleges throughout the country are experimenting with new approaches to curricula, rethinking traditional teaching modes, and developing innovative ways to recruit and retain students from underrepresented groups. The largest and potentially most revolutionary effort is led by the consortia of colleges funded by the National Science Foundation's Engineering Education Coalitions program. These national engineering college consortia each include a variety of schools ranging from predominantly undergraduate institutions to the most research intensive. The consortia are working to redesign curricula and improve teaching methodologies, each offering a different perspective and strategy.

While it is too early to gauge the success of the coalitions, they exemplify the engineering education community's leadership and willingness to adjust to change. We applaud and encourage these efforts, but also stress the importance of including partnerships with industry and government in reformulating engineering education.

Studies of Engineering Education

Given the national importance of engineering education and the major changes taking place in higher education and society, it is no surprise that in recent years engineering education has stimulated a variety of thoughtful reports. For example, in the late 1980s ASEE published the major study, "Quality of Engineering Education," and the ASEE Engineering Deans Council produced specific reports on the supply of engineering faculty and students.

In 1991, the National Academies' National Research Council (NRC) created a Board on Engineering Education, which has conducted a wide-ranging study of the future of engineering education. The Board's work has included a series of hearings throughout the country and has had a valuable influence on this project.

Those studying engineering education have proposed many ways to make engineering programs more relevant and cost-effective for all students, as well as more attractive to historically underrepresented groups. Their recommendations have created an environment for change and experimentation.

The Action Plan

The aim of this project is to evaluate recommendations of previous studies, combine them with the recommendations of the workshop conducted as part of the present study, and then develop key action items based on a series of policy statements. Because certain key changes in engineering education will be most effective if implemented with the aid of all sectors of the community, this project focuses on action items that require partnerships. Some of the action items are short-term, others longer-term; none is necessarily easy to accomplish. Over the next few years, this project will further refine the action items, assess the accomplishments of engineering colleges toward those goals, and establish a series of milestones for measuring future progress within the engineering education community.

In today's world and in the future, engineering education programs must not only teach the fundamentals of engineering theory, experimentation and practice, but be RELEVANT, ATTRACTIVE and CONNECTED:

RELEVANT to the lives and careers of students, preparing them for a broad range of careers, as well as for lifelong learning involving both formal programs and hands-on experience;

ATTRACTIVE so that the excitement and intellectual content of engineering will attract highly talented students with a wider variety of backgrounds and career interests?particularly women, underrepresented minorities and the disabled?and will empower them to succeed; and

CONNECTED to the needs and issues of the broader community through integrated activities with other parts of the educational system, industry and government.

Engineering colleges' ability to make their programs both relevant and attractive will depend, to a large extent, on how well they connect their programs to all community sectors, that is, on how well they build partnerships.

Focusing On Partnerships

While engineering deans are principally responsible for leading engineering education, they work in partnership with their faculties, presidents, senior university administrators, and often, with industry representatives. Such partnerships must also extend to elementary and secondary schools, the broader university, the local community, government and other engineering colleges, and build even closer ties to industry. These sectors make up the broad constituency of engineering education. Collaboration with these groups ensures the vitality and relevance of engineering programs, and enables the sharing of resources in a fiscally-constrained era. Ultimately, engineering colleges?like their successful counterparts in industry?must be part of a seamless system that links all of their constituents in education, industry, and the broad public community.

Action Items

1. Individual Missions For Engineering Colleges

Following the expansion of government resources for university research after World War II, many universities and their engineering colleges aspired to the model of the "research-intensive" university. This model focused on developing research excellence in scientific and engineering fields, and on creating research-oriented doctoral degrees. While not all universities and engineering colleges adopted the research-intensive model, many have viewed it as a standard of excellence.

The world now demands new models. There is greater competition for federal research funding, with fewer current employment opportunities for new, research-oriented Ph.D.s. The nation is shifting the focus of engineering work and research from a heavy emphasis on national security needs and space exploration to a more applications-oriented focus on economic growth and environmental preservation. Moreover, burgeoning communications technologies are enabling engineering schools to expand their reach and accessibility, and to experiment with alternate modes of teaching and learning.

This shift creates new opportunities for redesigning curricula and programs, expanding relationships with industry and educating students who are both technically capable and broadly sophisticated.

These developments have also created a new opportunity for engineering colleges to redefine themselves and to even develop specific niches within the broader engineering education community. While retaining a unified core of knowledge, engineering colleges must become more "context-based," that is, more relevant to the needs of their constituents.

To accomplish this redefinition, each engineering college?including the dean, faculty and administrators, in concert with the partners discussed previously?must identify the constituents it serves, assess the school's activities, identify its comparative advantages, and develop an institution-specific vision. Then, from that vision, the engineering school must articulate its mission.

The need will continue for schools that educate engineers with sound fundamentals to practice the profession. But a variety of models in engineering education will result from the process of schools reexamining their individual missions. For example, some colleges may opt to combine elements of traditional technology-based engineering education with a strong emphasis on broader skills such as written and oral communication, management, economics and international relations. This type of program would aim to prepare individuals for technological decision-making and policy-setting as well as for non-engineering professions.

Other engineering colleges may choose to become more like "professional" schools, preparing students for professional engineering practice through the master's level. Such programs would model themselves after schools of law and medicine, in which engineering practitioners from industry would work on-site, providing clinical training and assistance. Unlike the other models, however, that of the engineering professional school would continue to incorporate undergraduate as well as graduate education.

As some engineering schools are already doing, the practice-oriented master's degree could be the result of a five- or six-year program that incorporated a four-year bachelor's degree. This type of master's program is particularly attractive to high-technology industries that want engineering graduates who understand basic management, manufacturing, large-scale systems engineering and leadership. An issue is whether industry will fund such programs in significant measure, as they now support master's in business administration degrees for their engineers.

Still other engineering colleges may decide to focus on Ph.D.-related research and preparing graduates for research and teaching careers. This decision must be taken with the full understanding, however, that the nation's support system for research is changing, and there will likely be fewer research positions a available through industry, the federal government and academe.

Engineering education needs these and other models, combinations of models, and more. No one model suits every engineer or every organization that engineers serve. This diversity in the engineering educational system encourages creativity and satisfies the varied interests and needs of employers and students in the United States and abroad.

Every engineering college should identify the constituencies it serves, establish a clear vision, define its mission through a conscious examination of the school's current activities and comparative advantages, and then set future strategic directions.

Within the context of the overall institutional vision, every engineering educational program should be driven by a periodically reviewed planning process. This process should identify the program's objectives and lead to a specific plan, with milestones, for accomplishing them. Internal and external reviews of each engineering education program, which should include industrial participation, should encourage progress toward meeting those stated objectives.

2. Re-Examining Faculty Rewards

In whatever way an engineering college defines its mission, to be successful, it must ensure that its faculty reward system supports its goals. Faculty members often face the difficult task of trying to balance the several activities they need for professional advancement?such as research and undergraduate teaching?with a host of new activities their colleagues, students and the public expect them to accomplish. These can include curricula development, interdisciplinary collaboration, work with industry, development of continuing education programs, community outreach, and mentoring of other faculty members and students. As engineering colleges develop institutional missions, they have an opportunity to recraft their faculty reward system to better synchronize faculty rewards with their new, or re-affirmed, institutional expectations.

Changing the faculty reward system will not be an easy task. Faculty rewards are heavily driven by incentives created across the entire university and are part of a nationwide network. Nevertheless, it is important that rewards reflect the goals of the institution and it is important to begin the conversation now. As each institution establishes its vision and charts new directions, it should ensure that its faculty reward system supports the institutional goals.

3. Reshaping the Curriculum

Through its accreditation process, the U.S. engineering education system has continually reexamined and re-energized the engineering curricula. Engineering fundamentals have been and will continue to be the core of the engineering curriculum. But because engineers now operate in a world where their accomplishments are often more limited by societal considerations than by technical capabilities, they are engaging in a wider range of activities throughout their professional lives. Thus, engineering education must take into account the social, economic, and political contexts of engineering practice; help students develop teamwork and communication skills; and motivate them to acquire new knowledge and capabilities on their own. Because many modern engineering projects require a combination of several disciplines, students also need exposure to the integrative field of systems engineering.

In essence, an engineering education today aims to prepare an engineer to be successful in the changing workplace. It aims to equip students with technical knowledge and capabilities, flexibility and an understanding of the societal context of engineering.

Engineering schools should not seek to develop these contextual and process skills through separate courses, but by incorporating them into existing curricula and through non-classroom activities. Coursework should feature multidisciplinary, collaborative, active learning; and take into account students' varied learning styles.

One factor that will promote development of students' "process" skills is widespread use of multimedia, worldwide information networks. Using this resource, students can access new information and coursework, as well as interact with other students, researchers, practicing engineers in industry and government, and experts from around the world. These changes in the teaching and learning environment will make engineering education more attractive to both students and faculty, if faculty are given the opportunity to stay up-to-date.

Finally, all engineering colleges must address the issue of ethics. While ethics is a complex and difficult topic, engineering administrators and faculty must help students understand that throughout their careers they will encounter ethical issues which they will need to recognize and deal with rationally. Whether engineers are conducting engineering research, managing a company, or building bridges and office buildings, their decisions affect the lives and property of the greater community. Students must understand the importance of upholding that public trust.

While recognizing and encouraging diverse institutional missions and changing industry needs, colleges of engineering must re-examine their curricula and programs to ensure they prepare their students for the broadened world of engineering work. This process has begun among most engineering colleges and must be accelerated with the aim to incorporate:

- team skills, including collaborative, active learning;
- communication skills;
- leadership;
- a systems perspective;
- an understanding and appreciation of the diversity of students, faculty, and staff;
- an appreciation of different cultures and business practices, and the understanding that the practice of engineering is now global;
- integration of knowledge throughout the curriculum;
- a multi-disciplinary perspective;
- a commitment to quality, timeliness and continuous improvement;
- undergraduate research and engineering work experience;
- understanding of the societal, economic and environmental impacts of engineering decisions; and
- ethics.

4. Lifelong Learning

Employment practices among major corporations are changing dramatically; few future engineers will experience lifelong employment with a single corporation or organization. Many may perform professional work as consultants or serve as contract employees on specific projects. To adapt to this new work environment, engineering graduates must understand that career-long learning is their own responsibility and must acquire the skills for self-learning. Although many engineering colleges offer continuing education, such programs are often degree-oriented and constrained by the academic-year cycle.

To be relevant to new graduates, as well as to practicing engineers at every stage of their careers, engineering colleges must re-think and repackage continuing education programs. They should focus their offerings on providing students with new capabilities, as well as degrees. Courses should take various forms?with some targeted to business and financial management?and be adaptable to the time constraints of working engineers. In this regard, it will be crucial that continuing education programs take full advantage of the evolving National Information Infrastructure (NII).

Industry should require and pay for engineering employees to take courses to sustain their technological and managerial competence, just as it pays to maintain its other assets.

Federal agencies that fund education should help universities and their industrial partners identify creative approaches to lifelong learning by funding pilot projects and experiments.

Engineering colleges should create innovative advanced degree programs, including practice-oriented degrees. Such degree programs might include course material on engineering systems; finance and accounting; and technology policy, management and decision-making. Courses should feature team-based activities and case studies. In some instances, engineering schools will develop such degree programs in collaboration with business schools and industry.

Engineering colleges, in collaboration with industry, should develop innovative ways of providing continuing education to practicing engineers by instituting non-degree, career-enhancing programs. This will be facilitated by new communications technologies.

5. Broader Educational Responsibility

The engineering profession has played a little-recognized but extremely important role in providing upward mobility for generations of young people. There is now a major opportunity for the profession to do the same for underrepresented minorities, women and the disabled. But engineering differs from most other professions in that one must make the decision early in secondary school to preserve the option to become an engineer. Engineering colleges must reach out and connect to K-12 schools in their communities to ensure that students, particularly in middle school and high school, have the information they need to make informed decisions about an engineering career. Engineering colleges should view this outreach as a partnership with school administrators and teachers, as well as with local industry.

Joint activities might include developing summer and evening courses for teachers on-campus or at a local corporate facility; forming a speakers bureau; providing mentors; and offering laboratory classes taught by faculty, engineering students and corporate engineers. Activities should focus on needs expressed by K-12 school administrators and teachers, not just those activities engineering educators and their corporate colleagues are presently prepared to provide.

Outreach activities should not only strive to improve mathematics, science and technology instruction, but to motivate students to consider engineering careers. These activities are also important for helping all students better understand the implications of technology for society.

Each engineering college, in cooperation with local industry, should partner with at least one local school at the K-12 level. The aim is to improve mathematics and science instruction, provide role models, and give students and teachers a greater understanding of engineering's role in society.

6. Personnel Exchanges

Exchanging faculty, graduate students, and engineers from industry and government is one of the most effective ways of promoting technology transfer, and ensuring that faculty and students are exposed to engineering practice. Time spent by engineering faculty and graduate students in industry can enhance transfer of new technologies to industry, as well as provide practical experience and an understanding of business policies. Time spent by industry experts in engineering colleges can help make engineering coursework and research more relevant to actual practice.

At many colleges of engineering, effective personnel exchange mechanisms are already in place through adjunct faculty positions, student/faculty internships and cooperative work study programs. However, we believe there is value in enabling industry executives and technical specialists to spend time on-campus as full-time faculty members. Rather than simply teaching occasional courses, these "industrial professors" would participate directly in specific educational projects. Such projects might, for example, include integrating manufacturing, design, cost, and environmental technology issues into the curriculum.

To be most effective, personnel exchange experiences must be incorporated into the career plans of top-quality employees. Companies must be willing to allow those individuals to participate in exchange programs during their active technical and managerial years without fear of falling off their career tracks. Similarly, engineering colleges must find the means to enable their own faculty to participate in such programs without fear of being deflected from their tenure objectives or losing research support for their laboratories and graduate students. As one alternative, engineering colleges should consider using their sabbatical leave policies to encourage faculty members to spend time in industry or government.

The federal government, in partnership with engineering colleges and industry, should develop a national program to foster creation of "industrial professorships" in engineering colleges. Financing might include tax incentives for industry.

Each engineering college, or group of colleges in a region, should develop reciprocal personnel exchange programs with local and regional corporations. Companies and engineering colleges should encourage participation in these exchanges by providing incentives to individuals who are selected to participate. These partnerships must also focus on meeting the real needs of both corporate and university participants, and feature a variety of exchange modes, including industrial professorships and university sabbaticals in industry.

7. Across-the-Campus Outreach

Engineering colleges must be more effective and visible partners within the broader university community. This partnership should be enhanced for non-classroom activities as well as for formal research and education. Engineering colleges, their faculty and students have much to offer the broader campus community. For example, engineers can provide the real-world context to show nonengineering students the applications of the mathematical and scientific concepts they are learning. Engineering educators and their colleagues in science can also provide leadership in helping their campuses initiate computer networking and make effective use of the information super highway. Industry can help foster this cross-campus interaction by bringing multifaceted problems to the university that require the talents of several disciplines to solve. Industry representatives who sit on university advisory boards should also stress this approach in their recommendations to the institution.

Conversely, engineering education programs have much to gain from other disciplines. New insights can be provided, for example, by chemistry in developing environmentally friendly technologies, by political science in teaching the value of issues advocacy, by art in designing new consumer products, by business in aiding the understanding of international trade issues, and by law in treating intellectual property rights. Both engineering students and faculty would benefit from such interdisciplinary collaboration.

Engineers working with other colleagues across the university can also promote technological literacy for all students. Engineering colleges should accept responsibility for providing technical literacy programs to liberal arts students. Activities can include developing and teaching courses that provide laboratory or design experience for nonengineers, examine the history of science and technology, or discuss the interaction of technology and society.

At the same time, student participation in university-wide activities, such as student government, professional societies, athletics, and performing arts can help them develop the leadership and communications skills that are an important part of an engineering education.

Engineering deans should actively encourage their faculty members to participate in research, educational and leadership activities beyond the engineering college. Industrial advisory board members should stress cross-campus interaction in their recommendations to the college. Activities should include connections with such units as the schools of business, medicine, arts, sciences, and education.

Engineering deans and faculty should actively encourage students to participate in university-wide activities. These activities can include participation in student government, student professional societies, athletics, performing arts, debate, study abroad, and similar activities. The aim is to promote leadership and communications skills as well as a sense of the integration of engineering into the broader world.

Engineering deans should take responsibility for helping nonengineering majors on their campuses better understand the importance and relevance of technology in their lives, and seek to better equip those students to prosper in an increasingly technological world. Engineering schools may develop specific courses, seminars, guest lectureships, and cross-campus projects.

8. Research / Resource Sharing

Given the changing direction and magnitude of support for research sponsored by the federal government and industry, coupled with the increased competition from federal laboratories and international groups, engineering colleges must look for new opportunities to establish collaborative research alliances. Some alliances may be local or regional; others will be "virtual," that is, national or international alliances established through the emerging global information superhighway.

Regional consortia of engineering colleges, for example, may share research facilities, teaching laboratories and faculty. Faculty tenure might even reside with a consortium and not with the individual institutions. Other types of consortia could combine the resources of universities and industry, universities and federal facilities?such as national laboratories?or a combination of all three. The aim is not to create new bureaucracies and expense, but to facilitate high-quality research and teaching that is both effective and efficient.

The National Science Foundation has taken the lead in funding experiments in research and education resource-sharing, and in creation of virtual research and education teams. Such experiments also should be encouraged through the Engineering Research Center (ERC) and Science and Technology Center (STC) programs. Lessons learned by the NSF Engineering Education Coalitions in creating "virtual" research and education teams should be applied to these experiments.

To ensure high-quality research and education, federal funding for science and technology must be distributed through open competition, based on peer review. To enhance technology transfer and industry-university research partnerships, universities, corporations and federal agencies should ensure they have flexible and negotiable policies governing intellectual property rights.

Federal agencies that fund research and education should explore ways of encouraging educational institutions, research organizations, federal laboratories, and industry to share resources. They should provide special consideration for funding projects that are developed by consortia of institutions.

Federal funding for science and technology should be allocated in open competition, based on peer review.

To enhance technology transfer and industry-university research partnerships, universities, industries, and federal agencies should develop flexible and negotiable policies governing intellectual property rights.

Engineering education today is adapting to the changing context of engineering practice, but more can be done to speed and improve the process. A crucial means of accomplishing needed change is through partnerships with industry, government, and the broader educational communities. The policy statements and action items developed in this project are intended to help ensure that engineering education will be RELEVANT, ATTRACTIVE and CONNECTED well into the next century.

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