Engineering for a Changing World

A Roadmap to the Future of American Engineering Practice, Research, and Education

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We live in a time of great change, an increasingly global society, driven by the exponential growth of new knowledge and knitted together by rapidly evolving information and communication technologies. It is a time of challenge and contradiction, as an ever-increasing human population threatens global sustainability; a global, knowledge-driven economy places a new premium on technological workforce skills through phenomena such as out-sourcing and offshoring; governments place increasing confidence in market forces to reflect public priorities, even as new paradigms such as open-source software and open-content knowledge and learning challenge conventional free-market philosophies; and shifting geopolitical tensions are driven by the great disparity in wealth and power about the globe, manifested in the current threat to homeland security by terrorism. Yet it is also a time of unusual opportunity and optimism as new technologies not only improve the human condition but also enable the creation and flourishing of new communities and social institutions more capable of addressing the needs of our society.

The Challenges to American Engineering

During the past several years such considerations have led numerous groups, including the National Academies, federal agencies, business organizations, and professional societies to conclude that new paradigms in engineering practice, research, and education that better address the needs of a 21st-century nation in a rapidly changing world (e.g., see Augustine, 2005; Duderstadt, 2005; Clough, 2004, 2005; Sheppard, 2008; NSB 2003, 2007). Among the many concerns these studies have raised about American engineering are the following.

Engineering Practice

The implications of a technology-driven global economy for engineering practice are particularly profound. The globalization of markets requires engineers capable of working with and among different cultures and knowledgeable about global markets. New perspectives are needed in building competitive enterprises as the distinction between competition and collaboration blurs. The rapid evolution of high-quality engineering services in developing nations with significantly lower labor costs, such as India, China, and Eastern Europe, raises serious questions about the global viability of the United States engineer, who must now produce several times the value-added to justify wage differentials. Both new technologies (e.g., info-bio-nano) and the complex mega systems challenges arising in contemporary society (e.g., massive urban, transportation, and communications infrastructure) require highly interdisciplinary engineering teams characterized by broad intellectual span rather than focused practice within traditional disciplines. As technological innovation plays an ever more critical role in sustaining the nation's economic prosperity, security, and social well-being, engineering practice will be challenged to shift from traditional problem solving and design skills toward more innovative solutions imbedded in a complex array of social, environmental, cultural, and ethical issues.

Yet, despite the growing importance of engineering practice to society, the engineering profession still tends to be held in relatively low esteem in the United States compared to other learned professions such as law and medicine. Perhaps this is not surprising, both because of the undergraduate nature of its curriculum and the evolution of the profession from a trade (a "servile art" such as carpentry rather than a "liberal art" such as law, medicine, or theology). Yet today this is eroding prestige and influence is intensified by the tendency of many companies to view engineers as consumable commodities, discarding them when their skills become obsolete or replaceable by cheaper engineering services from abroad. Students sense the eroding status and security of engineering careers and increasingly opt for other more lucrative and secure professions such as business, law, and medicine. Today's engineers no longer hold the leadership positions in business and government that were once claimed by their predecessors in the 19th and 20th century, in part because neither the profession nor the educational system supporting it have kept pace with the changing nature of both our knowledge-intensive society and the global marketplace. In fact, the outsourcing of engineering services of increasing complexity and the offshoring of engineering jobs of increasing value threaten the erosion of the engineering profession in America and with it our nation's technological competence and capacity for technological innovation.

Engineering Research

There is increasing recognition throughout the world that leadership in technological innovation is key to a nation's prosperity and security in a hypercompetitive, global, knowledge-driven economy (Council on Competitiveness, 2003). While our American culture, based upon a highly diverse population, democratic values, free-market practices, and a stable legal and regulatory environment, provides an unusually fertile environment for technological innovation and entrepreneurial activity, history has shown that significant federal and private investments are necessary to produce the ingredients essential for innovation to flourish: new knowledge (research), human capital (education), infrastructure (e.g., physical, cyber), and policies (e.g., tax, property).

One of the most critical elements of the innovation process is the long-term research required to transform new knowledge generated by fundamental scientific discovery into the innovative new products, processes, and services required by society. In years past this applications-driven basic research was a primary concern of major corporate R&D laboratories, national laboratories, and the engineering schools associated with research universities. However, in today's world of quarterly earnings pressure and inadequate federal support of research in the physical sciences and engineering, this longer-term, applications-driven basic engineering research has largely disappeared from the corporate setting, remaining primarily in national laboratories and research universities constrained by inadequate federal support. This has put at considerable risk the discovery-innovation process in the United States.

Numerous recent studies (COSEPUP, 1998-03; Duderstadt, 2005; Clough, 2002; Vest, 2003; Augustine, 2005) have concluded that stagnant federal investments in basic engineering research, key to technical innovation, are no longer adequate to meet the challenge of an increasingly competitive global economy. There is further evidence that the serious imbalance between federally supported research, now amounting to less than 26% of national R&D, along with the imbalance that has resulted from the five-fold increase in federal support of biomedical research during a period when support of research in the physical sciences and engineering has remained stagnant, threatens the national capacity for innovation.

Engineering Education

In view of these changes occurring in engineering practice and research, it is easy to understand why some raise concerns that we are attempting to educate 21st-century engineers with a 20th-century curriculum taught in 19th-century institutions. The requirements of 21st-century engineering are considerable: engineers must be technically competent, globally sophisticated, culturally aware, innovative and entrepreneurial, and nimble, flexible, and mobile (Continental, 2006). Clearly new paradigms for engineering education are demanded to: i) respond to the incredible pace of intellectual change (e.g., from reductionism to complexity, from analysis to synthesis, from disciplinary to multidisciplinary); ii) develop and implement new technologies (e.g., from the microscopic level of info-bio-nano to the macroscopic level of global systems); iii) accommodate a far more holistic approach to addressing social needs and priorities, linking social, economic, environmental, legal, and political considerations with technological design and innovation, and iv) to reflect in its diversity, quality, and rigor the characteristics necessary to serve a 21st-century nation and world (Sheppard, 2008).

The issue is not so much *reforming* engineering education within old paradigms but instead *transforming* it into new paradigms necessary to meet the new challenges such as globalization, demographic change, and disruptive new technologies. As recent National Science Board workshops involving representatives of industry, government, professional societies, and higher education concluded, the status quo in engineering education in the United States is no longer sufficient to sustain the nation's technological leadership (NSB, 2007).

The critical role of our engineering schools in providing human capital necessary to meet national needs faces particular challenges (Clough, 2004, 2006; Duderstadt, 2005). Student interest in science and engineering careers is at a low ebb–not surprising in view of the all-too-frequent headlines announcing yet another round of layoffs of American engineers as companies turn to offshoring engineering services from low-wage nations. Cumbersome immigration policies in the wake of 9-11, along with negative international reaction to U.S. foreign policy, are threatening the pipeline of talented international science and engineering students into our universities and engineering workforce. Furthermore, it is increasingly clear that a far bolder and more effective strategy is necessary if we are to tap the talents of all segments of our increasingly diverse society, with particular attention to the participation of women and underrepresented minorities in the engineering workforce.

The current paradigm for engineering education, e.g., an undergraduate degree in a particular engineering discipline, occasionally augmented with workplace training through internships or co-op experiences and perhaps further graduate or professional studies, seems increasingly suspect in an era in which the shelf life of taught knowledge has declined to a few years. There have long been calls for engineering to take a more formal approach to lifelong learning, much as have other professions such as medicine in which the rapid expansion of the knowledge base has overwhelmed the traditional educational process. Yet such a shift to graduate-level requirements for entry into the engineering profession has also long been resisted both by students and employers. Moreover, it has long been apparent that current engineering science-dominated curricula needs to be broadened considerably if students are to have the opportunity to learn the innovation and entrepreneurial skills so essential for our nation's economic welfare and security, yet this too has been resisted, this time by engineering educators.

Here part of the challenge–and key to our objectives–must be an appreciation for the extraordinary diversity in engineering and training to meet the ever more diverse technological needs of our nation. Different types of institutions and programs are clearly necessary to prepare students for highly diverse roles: from system engineers capable of understanding and designing complex systems from the atomic to the global level; master engineers capable of the innovative design necessary to develop products, processes, and services competitive in a global economy; engineering scientists capable of conducting the fundamental research necessary to address compelling global challenges such as energy sustainability; and engineering managers capable of leading global enterprises. And all of these institutions, programs, and roles must strive to provide exciting, creative, and adventurous educational experiences capable of attracting the most talented of tomorrow's students.

From a broader perspective, one might argue that as technology becomes an ever more dominant aspect of social issues, perhaps the discipline of engineering should evolve more along the lines of other academic disciplines such as physics and biology that have become cornerstones of the liberal arts canon. Perhaps the most urgent need of our society is a deeper understanding and appreciation for technology on the part of all college graduates rather than only those seeking engineering degrees. These, too, should be concerns of engineering educators.

A Framework for Change

So what should our nation seek as both the nature and objectives of engineering in the 21st century, recognizing that these must change significantly to address rapidly changing needs and priorities? Here we need to consider the implications for American engineering from several perspectives: i) as a *discipline* (similar to physics or mathematics), possibly taking its place among the "liberal arts" characterizing a 21st-century technology-driven society; ii) as a *profession*, addressing both the urgent needs and grand challenges facing our society; iii) as a *knowledge base* supporting innovation, entrepreneurship, and value creation in a knowledge economy; and iv) as a diverse *educational system* characterized by the quality, rigor, and diversity necessary to produce the engineers and engineering research critical to prosperity, security, and social well being.

Here we begin with several premises:

- In a global, knowledge-driven economy, technological innovation–the transformation of knowledge into products, processes, and services–is critical to competitiveness, long-term productivity growth, and the generation of wealth. Preeminence in technological innovation requires leadership in all aspects of engineering: engineering research to bridge scientific discovery and practical applications; engineering education to give engineers and technologists the skills to create and exploit knowledge and technological innovation; and the engineering profession and practice to translate knowledge into innovative, competitive products and services.

- To compete with talented engineers in other nations with far greater numbers and with far lower wage structures, American engineers must be able to add significantly more value than their counterparts abroad through their greater intellectual span, their capacity to innovate, their entrepreneurial zeal, and their ability to address the grand challenges facing our world.

- It is similarly essential to elevate the status of the engineering profession, providing it with the prestige and influence to play the role it must in an increasingly technology-driven world while creating sufficiently flexible and satisfying career paths to attract a diverse population of outstanding students. Of particular importance is greatly enhancing the role of engineers both in influencing policy and popular perceptions and as participants in leadership roles in government and business.

- From this perspective the key to producing such world-class engineers is to take advantage of the fact that the comprehensive nature of American universities provide the opportunity for significantly broadening the educational experience of engineering students, provided that engineering schools, accreditation agencies such as ABET, the profession, and the marketplace are willing to embrace such an objective. Essentially all other learned professions have long ago moved in this direction (law, medicine, business, architecture), requiring a broad liberal arts baccalaureate education as a prerequisite for professional education at the graduate level.

In summary, we believe that to meet the needs of the nation, the engineering profession must achieve the status and influence of other learned professions such as law and medicine. Engineering practice in our rapidly changing world will require an ever-expanding knowledge base requiring new paradigms for engineering research that better link scientific discovery with innovation. The complex challenges facing our nation will require American engineers with a much higher level of education, particularly in professional skills such as innovation, entrepreneurship, and global engineering practice. To this end, we set the following objectives for engineering practice, research, and education:

1. To establish engineering practice as a true learned profession, similar in rigor, intellectual breadth, preparation, stature, and influence to law and medicine, with extensive post-graduate education and a culture more characteristic of professional guilds than corporate employees.

2. To redefine the nature of basic and applied engineering research, developing new research paradigms that better address compelling social priorities than those methods characterizing scientific research.

3. To adopt a systemic, research-based approach to innovation and continuous improvement of engineering education, recognizing the importance of diverse approaches–albeit characterized by quality and rigor–to serve the highly diverse technology needs of our society.

4. To establish engineering as a true liberal arts discipline, similar to the natural sciences, social sciences, and humanities, by imbedding it in the general education requirements of a college graduate for an increasingly technology-driven and -dependent society of the century ahead.

To achieve these objectives for American engineering, this study recommends the following actions.

Transforming the Profession

When physicians are asked about their activities, they generally respond with their professional specialty, e.g., “I’m a cardiologist” or “I’m a neurosurgeon.” So too, lawyers are likely to respond with a specialty such as corporate law or litigation. In sharp contrast, when asked about their profession, most engineers will respond with their employer: "I work for Ford" or Boeing or whomever. Hence the first goal is to transform engineering from an occupation or a career to a true *learned profession*, where professional identity with the unique character of engineering practice is more prevalent than identification with employment.

Part of the challenge here is that there are so many types of and roles for engineers, from low-level technicians or draftsmen to master design engineers to engineering scientists to technology managers. Hence as we explore possible futures for the engineering profession, it may be necessary to consider defining more formally through statute or regulation the requirements for various engineering roles. For example, one might distinguish these by degree levels, e.g., routine engineering services (sales, management) might require only a baccalaureate degree (B.S.) perhaps augmented by an M.B.A.; design engineers would require training at the masters level (M.S.); engineering scientists engaged in research would require a Ph.D.; and so forth, with the definition of role and degree requirements established by statute, as they are in medicine and law. As we will suggest later in this chapter, the changing nature of engineering and its increasing importance in an ever more technology-driven world may require even more senior engineering roles requiring advanced, practice-based engineering degrees.

Of course there will be strong resistance by many employers to elevating the education level required for the engineering profession, since many companies will prefer to continue to hire baccalaureate-level engineering graduates at lower cost, although such graduates are usually less capable of high value-added activities such as radical technological innovation. So too, many students and parents will question whether the extension of engineering education beyond the baccalaureate level will add sufficient personal return to justify the additional time and expense requirements. Hence key in any effort to elevate the educational requirements and thereby the value, prestige, and influence of the engineering profession will be a coordinated effort by engineering professional and disciplinary societies to raise public awareness of the intensifying educational demands of engineering practice. Furthermore, as other learned professions have demonstrated, it will also be important for the engineering profession to become more influential in both defining and controlling the marketplace for engineers and engineering services if they are to break through the current resistance of employers, clients, and students to more advanced educational requirements for engineering practice.

Hence attaining the necessary prestige and influence will almost certainly require a major transformation of the culture of engineering practice and the engineering profession itself. To this end, the following proposal is offered.

> *Proposal: Engineering professional and disciplinary societies, working with engineering leadership groups such as the National Academy of Engineering, the National Society for Professional Engineers, the American Association of Engineering Societies, ABET, and the American Society for Engineering Education, should strive to create a "guild-like" culture in the engineering profession, similar to those characterizing other learned professions such as medicine and law, that aims to shape rather than simply react to market pressures.*

The initial goal should be to create (actually, re–create) a guild culture for engineering, where engineers identify more with their profession than their employers, taking pride in being members of a true profession whose services are highly valued by both clients and society. While engineering does have some elements of these modern guilds, the great diversity of engineering roles, professional organizations, and clients (employers) prevent engineering from exerting the influence or control over the marketplace enjoyed by many other contemporary guilds. Hence our proposal is for a more concerted effort on the part of engineering organizations–professional and disciplinary societies, engineering education, and those engineers with influence in public policy and politics–to exert a more coordinated and strategic effort to establish a strong guild structure for the engineering profession. The necessary transformation is suggested by a transition in both language and perspective. Engineers would increasingly define themselves as *professionals* rather than employees. They primary markets would be *clients* rather than employers. And society would view engineering as a *profession* rather than an occupation.

Expanding the Engineering Knowledge Base

For over fifty years the United States has benefited from a remarkable discovery-innovation engine that has powered our economic prosperity while providing for our national security and social well being. As Charles Vest suggests, for America to prosper and achieve security, it must do two things: (1) discover new scientific knowledge and technological potential through research and (2) drive high-end, sophisticated technology faster and better than anyone else. We must make new discoveries, innovate continually, and support the most sophisticated industries (Vest, 2005).

Two federal actions at mid-century, the G.I. Bill and the government-university research partnership, provided the human capital and new knowledge necessary for the innovation that drove America's emergence as the world's leading economic power. Both federal actions also stimulated the evolution of the American research university to serve the nation by providing these assets critical to a discovery-innovation-driven economy. Today it has become apparent that the nation's discovery-innovation engine needs a tune-up in the face of the profound changes driven by a hypercompetitive, knowledge-driven global economy. Further federal action is necessary to generate the new knowledge, build the necessary infrastructure, and educate the innovators–entrepreneurs necessary for global leadership in innovation.

In 2005 the National Academy of Engineering completed a comprehensive study of the challenges facing engineering research in America and recommended a series of actions at the federal level to respond to the imperatives of a flattening world (Duderstadt, 2005). Among the more important recommendations contained in this report are the following:

Proposal: The federal government should adopt a more strategic approach to research priorities and R&D funding. In particular a more balanced investment is needed among the biomedical sciences, physical sciences, and engineering is necessary to sustain our leadership in technological innovation. Long-term basic engineering research should again become a priority for American industry. The nation should secure an adequate flow of next-generation scientists and engineers through major federal fellowship-traineeships program in key strategic areas (e.g., energy, info-nano-bio, knowledge services), similar to that created by the National Defense Education Act. Immigration policies and practices should be streamlined (without compromising homeland security) to restore the flow of talented students, engineers, and scientists from around the world into American universities and industry. The federal government in close collaboration with industry, universities, and the states should explore new research paradigms that better link fundamental scientific discoveries with technological innovation to build the knowledge base essential for new products, process, and services to meet the needs of society.

Similar concerns raised by leaders of industry, higher education, and the scientific community, culminating in the National Academies' *Rising Above the Gathering Storm* study, have stimulated the federal government to launch two major efforts aimed at sustaining U.S. capacity for innovation and entrepreneurial activities: the administration's *American Competitiveness Initiative* and Congress's *America COMPETES*

Act (the latter being including an awkward acronym for "Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science".) If fully implemented, over the next decade these efforts will involve doubling federal investment in basic research in physical science and engineering; major investments in science and engineering education; tax policies designed to stimulate private sector in R&D; streamlining intellectual property policies; immigration policies that attract the best and brightest scientific minds from around the world; and building a business environment that stimulates and encourages entrepreneurship through free and flexible labor, capital, and product markets that rapidly diffuse new productive technologies.

Transforming Engineering Education

Many nations are investing heavily in developing their engineering workforce within cultures in which science and engineering are regarded as exciting, respected fields by young people and as routes to leadership roles in business and government, in contrast to the relatively low popularity and influence of these fields in American society. But the United States does have one very significant advantage: the comprehensive nature of the universities in which most engineering education occurs, spanning the range of academic disciplines and professions from the liberal arts to law, medicine, and other learned professions. American universities have the capacity to augment education in science and engineering with the broader exposure to the humanities, arts, and social sciences that are absolutely essential to building both the creative skills and cultural awareness necessary to compete in a globally integrated society. Furthermore their integration of education, research, and service–that is, learning, discovery, and engagement–provides a formidable environment for educating 21st-century engineers. By building a new paradigm for engineering education that takes full advantage of the comprehensive nature and unusually broad intellectual span of the American university, we can create a new breed of engineer, capable of adding much higher value in a global, knowledge-driven economy.

To take advantage of this unique character of American higher education, its capacity to integrate learning across the academic and professional disciplines, it will be necessary to separate the concept of engineering as an *academic discipline* from engineering as a *learned profession*. To this end, consider five specific proposals: 1) to establish graduate professional schools of engineering that would offer practice-based degrees at the post–baccalaureate level, 2) to restructure undergraduate engineering programs as a "liberal arts" discipline, 3) to develop a structured approach to lifelong learning for engineering professionals, 4) to include the academic discipline of engineering (or more broadly technology) in a 21st-century liberal arts canon suitable for all undergraduate students, and 5) to challenge the engineering community to commit itself to reflecting among its members the great diversity characterizing both our nation and the world. Let us consider each proposal in turn:

> *Proposal: Working closely with industry and professional societies, higher education should establish graduate professional schools of engineering that would offer practice-based degrees at the post-baccalaureate level as the entry degree into the engineering profession.*

Perhaps the most effective way to raise the value, prestige, and influence of the engineering profession is to create true post-baccalaureate professional schools similar to medicine and law, which are staffed with practice-experienced faculty and provide clinical practice experience. More specifically, the goal would be the transformation of engineering into a true learned profession, comparable in rigor, prestige, and influence to medicine and law, by shifting the professional education and training of engineers to post-baccalaureate professional schools offering two- or three-year, practice-focused degree programs in contrast to research-focused graduate degrees such as the M.S. and Ph.D. The faculty of these schools would have strong backgrounds in engineering practice with scholarly interests in the key elements of engineering, e.g., design, innovation, entrepreneurial activities, technology management, systems integration, and global networking, rather than research in engineering sciences. Students would be drawn from a broad array of possible undergraduate degrees with strong science and mathematics backgrounds, e.g., from the sciences or mathematics or perhaps a broader engineering discipline similar to the pre-med programs preparing students for further study in medicine.

The M.Eng. degree programs developed for practicing engineers by many engineering schools might be a first step toward such professional schools, much as the M.B.A. suffices for the business profession. However, more extended programs akin to law and medical education would have greater impact on both student capabilities and the prestige of the profession. While a more extended post-graduate professional degree program would encounter the usual resistance from employers and students, if designed properly, the value-added provided by a graduate professional degree in engineering would likely outweigh any loss of income from a similar time period spent while employed following a baccalaureate engineering degree.

Clearly the educational content would be quite different from the engineering science curriculum characterizing most undergraduate engineering programs today. At the professional level, a practice-oriented and experienced faculty could develop topics such as design and synthesis, innovation, project and technology management, systems analysis, entrepreneurship and business development, and global engineering systems, as well as more abstract topics such as leadership and professional ethics. Additional electives could be offered in areas such as business (particularly management, strategic planning, and finance), policy (science, technology, and public policy), and other fields of particular student interest (e.g., biomedical and health, international relations, defense and security).

If the professional elements of an engineering education were shifted to a post-graduate professional school, this might provide a very significant opportunity to address many of the challenges that various studies have concluded face engineering education today at the undergraduate level. In particular, removing the burdens of professional accreditation from undergraduate engineering degree programs would allow them to be reconfigured along the lines of other academic disciplines in the sciences, arts, and humanities, thereby providing students majoring (or concentrating) in engineering with more flexibility to benefit from the broader educational opportunities offered by the comprehensive university.

Proposal: Undergraduate engineering should be restructured as an academic discipline, similar to other liberal arts disciplines in the sciences, arts, and humanities, thereby providing students with more flexibility to benefit from the broader educational opportunities offered by the comprehensive American university, with the goal of preparing them for a lifetime of further learning rather than simply near-term employment as an engineer.

Here we propose that the discipline of engineering would be taught by existing engineering schools through both degree programs at the undergraduate and graduate level, including courses provided to all undergraduates as a component of a new 21st-century liberal arts core curriculum. Of course, part of the challenge is the basic codification of the engineering discipline, still a subject of some uncertainty and requiring further study (e.g., see Vincenti, 1990). Furthermore, because of the strong research interests and background of most current engineering faculty, the curriculum and degrees offered in the discipline of engineering would initially have more of an applied science character and would not necessarily require ABET certification, thereby allowing more opportunity for a broader liberal education on the part of undergraduates.

The current pedagogies used in engineering education also need to be reconsidered. Although the science and engineering curriculum includes laboratory experiences, most instruction is heavily based on classroom lectures coupled with problem-solving exercises. Contemporary engineering education stresses the analytic approach to solving well-defined problems familiar from science and mathematics–not surprising, since so many engineering faculty members received their basic training in science rather than engineering. To be sure, design projects required for accreditation of engineering degree programs are introduced into advanced courses at the upper-class level. Yet design and synthesis are relatively minor components of most engineering programs. Clearly those intellectual activities associated with engineering design–problem formulation, synthesis, creativity, innovation–should be infused throughout the curriculum. This will require a sharp departure from conventional classroom pedagogy and solitary learning methods. Beyond team design projects, engineering educators should make more use of the case method approaches characterizing business and law education. More use might also be made of internships as a formal part of the engineering curriculum, whether in industry or perhaps even in the research laboratories of engineering faculty where engineering design is a common task.

An equally serious challenge to engineering education arises from the ever narrower specialization among engineering majors, more characteristic of the reductionist approach of scientific analysis rather than the highly integrative character of engineering synthesis. While this may be appropriate for careers in basic research, it is certainly not conducive to the education of contemporary engineers nor to engineering practice. Although students may be stereotyped by faculty and academic programs–and perhaps even campus recruiters–as electrical engineers, aerospace engineers, etc., they rapidly lose this distinction in engineering practice. Today's contemporary engineer must span an array of fields, just as modern technology, systems, and processes do.

There is yet another concern about engineering education that arises from the fundamental purposes of a college education and its foundation upon the concept of a liberal education. Two centuries ago Thomas Jefferson stated the purpose of a liberal education: "To develop the reasoning faculties of our youth, enlarge their minds, cultivate their morals, and instill into them the precepts of virtue and order." Note how appropriate the concept of a liberal education seems today as preparation for the profession of engineering. And note as well that most of the concerns that have been raised about today's engineering education could be addressed by simply accepting the broader objectives of a liberal education for our engineering students.

It is proposed that one views engineering education at the undergraduate level as a discipline suitable both for engineering majors as well as for other students interested in particular aspects of engineering, e.g., technology management and public policy. Engineering schools would continue to offer multiple degrees as they do now, e.g., ABET-accredited B.S. degrees in engineering, broader B.S. or B.A. degrees in engineering science, and of course an array of graduate degrees (M.S., Ph.D.). Students seeking an engineering background as preparation for further study in fields such as medicine, business, or law would continue to enroll in specific engineering majors, much as they do now. Many students would continue to enroll in ABET-accredited engineering degree programs to prepare them for entry into technology–based careers, although as we have noted earlier, these would require further professional education and training at the graduate level to enter the engineering profession. Students interested in research careers would major in either ABET-accredited or engineering science degree programs in preparation for further graduate study in engineering science (M.S. and Ph.D.).

However, of most interest here is the possibility that those students intending to enter the profession of engineering would no longer be subject to the overburdened curriculum characterizing ABET-accredited undergraduate degree programs. Instead they could earn more general liberal arts degrees in science, mathematics, engineering science, or even the arts, humanities, or social sciences with an appropriate pre-engineering foundation in science and mathematics, as preparation for further study in an engineering professional school. In this way they would have the opportunity for a true liberal education as the preparation for further study and practice in an engineering profession characterized by continual change, challenge, and ever–increasing importance.

Here one must always keep in mind that while engineering educators certainly have a responsibility to address the needs of industry, government, and society, their most fundamental commitment must be to the welfare of their students. There is an old saying that the purpose of a college education should not be to prepare a student for their first job but instead prepare them for their last job. This will sometimes require turning aside from the demands that engineering graduates be capable of immediate impact and instead stressing the far greater long-term value to the student–and our society more broadly–of a truly liberal education.

In recent years even science-intensive professions such as medicine have accepted the wisdom of broadening their admissions requirements to allow the enrollment of students from undergraduate majors in the social sciences and humanities. They seek more well-rounded students who can be molded into caring and compassionate physicians, who understand better the broader context of medical decisions and patient treatment. Although recent surveys have highlighted the difficulties that students currently have in transferring from other majors into engineering programs, the creation of graduate professional schools in engineering would provide the opportunity to broaden substantially the undergraduate requirements for engineering careers. Furthermore, the recent development of multiple course sequences to provide a concentration or minor in engineering for students in liberal arts colleges provide yet another route for broadly educated undergraduates to consider engineering careers after further graduate study, just as they can through the science sequences offered for pre-med students.

Broadening the undergraduate experience of engineering students would also provide a more sound foundation for lifelong learning. Today the United States faces a crossroads, as a global knowledge economy demands a new level of knowledge, skills, and abilities on the part of all of our citizens. To address this, the Secretary of Education's Commission on the Future of Higher Education in America has recently recommended: "America must ensure that our citizens have access to high quality and affordable educational, learning, and training opportunities throughout their lives. We recommend the development of a national strategy for lifelong learning that helps all citizens understand the importance of preparing for and participating in higher education throughout their lives." (Miller, 2006) The Commission believed it is time for the United States to take bold action, completing in a sense the series of these earlier federal education initiatives, by providing all American citizens with universal access to lifelong learning opportunities, thereby enabling participation in the world's most advanced knowledge society. The nation would accept its responsibility as a democratic society in an ever more competitive global, knowledge-driven economy to provide all of its citizens with the educational, learning, and training opportunities they need, throughout their lives, whenever, wherever, and however they need it, at high quality and affordable costs, thereby enabling both individuals and the nation itself to prosper.

This recommendation has particular implication for professions such as engineering where the knowledge base is continuing to increase at an ever-accelerating pace. The shelf life of education acquired early in one's life, whether K-12 or higher education, is shrinking rapidly. Today's students and tomorrow's graduates are likely to value access to lifelong learning opportunities more highly than job security, which will be elusive in any event. They understand that in the turbulent world of a knowledge economy, characterized by outsourcing and offshoring to a global workforce, employees are only one paycheck away from the unemployment line unless they commit to continuous learning and re–skilling to adapt to every changing work requirements. Furthermore, longer life expectancies and lengthening working careers create additional needs to refresh one's knowledge and skills on a continuous basis. Even today's college graduates expect to change not simply jobs but entire careers many times throughout their lives, and at each transition point, further education will be required–additional training, short courses, degree programs, or even new professions. And, just as students increasingly understand that in a knowledge economy there is no wiser personal investment than education, many nations now accept that the development of their human capital through education must become a higher priority than other social priorities, since this is the only sure path toward prosperity, security, and social well-being in a global knowledge economy.

Hence one of the important challenges to engineering educators is to design their educational programs not as preparation for a particular disciplinary career but rather as the foundation for a lifetime of continuous learning. Put another way, the stress must shift from the mastery of knowledge content to a mastery of the learning process itself. Moreover this will require a far more structured approach to continuing engineering education, more comparable to those provided for other learned professions such as medicine characterized by a rapidly evolving knowledge base and profound changes in professional practice. It seems clear that continuing education can no longer be regarded as simply a voluntary activity on the part of engineers, performed primarily on their own time and supported by their own resources. Rather it will require a major commitment by employers–both in industry and government–to provide the opportunity and support, and by engineering schools and professional societies to develop and offer the necessary instructional programs. It likely will also require some level of mandatory participation through regulation and licensure, similar to the medical and legal professions.

> *Proposal: In a world characterized by rapidly accelerating technologies and increasing complexity, it is essential that the engineering profession develop a structured approach to lifelong learning for practicing engineers similar to those in medicine and law. This will require not only a significant commitment by educators, employers, and professional societies but possibly also additional licensing requirements in some fields.*

This brings us to a broader proposal for a 21st-century college education. The liberal arts is an ancient concept that has come to mean studies that are intended to provide general knowledge and intellectual skills, rather than more specialized occupational or professional skills. The term liberal in liberal arts is from the Latin word *liberalis*, meaning "appropriate for free men" (social and political elites), and they were contrasted with the servile arts. The liberal arts thus initially represented the kinds of skills and general knowledge needed by the elite echelon of society, whereas the servile arts represented specialized tradesman skills and knowledge needed by persons who were employed by the elite. The scope of the liberal arts has changed with an evolving civilization. It once emphasized the education of elites in the classics; but, with the rise of science and humanities and a more pragmatic view of the purpose of higher education, the scope and meaning of "liberal arts" expanded during the 19th century. Still excluded from the liberal arts are topics that are specific to particular occupations, such as agriculture, business, dentistry, engineering, medicine, pedagogy (school–teaching), and pharmacy.

Yet here William Wulf reminds us of another important belief of Thomas Jefferson: one cannot have a democracy without informed citizens. Today we have a society profoundly dependent upon technology, profoundly dependent on engineers who produce that technology, and profoundly ignorant of technology. As Wulf observes, "I see this up close and personal almost every day. I deal with members of our government who are very smart, but who don't even understand when they need to ask questions about the impact of science and technology on public policy" (Wulf, 2003). He goes on to suggest that the concept of a liberal education for 21st-century society must include technological literacy as a component. Here he contrasts technological literacy with scientific and quantitative literacy, noting that everyone needs to know something about the process by which the knowledge of science is used to find solutions to human problems. But everyone also needs an understanding of the larger innovation engine that applies technology to create the wealth from which everyone benefits.

From this perspective, one could make a strong case that today engineering–or better yet technology–should be added to the set of liberal arts disciplines, much as the natural sciences were added a century ago. Here we are not referring to the foundation of science, mathematics, and engineering sciences for the engineering disciplines, but rather those unique tools that engineers master to develop and apply technology to serve society, e.g., structured problem solving, synthesis and design, innovation and entrepreneurship, technology development and management, risk-benefit analysis, and knowledge integration across horizontal and vertical intellectual spans.

Proposal: The academic discipline of engineering (or, perhaps more broadly, technology) should be included in the liberal arts canon undergirding a 21st-century college education for all students.

The final proposal addresses the challenge of building an engineering workforce with sufficient diversity to tap the full talents of an increasingly diverse American population and address the needs and opportunities of an increasingly diverse and competitive global society. Here the objectives have been forcefully stated in a recent National Academy of Engineering study, "All participants and stakeholders in the engineering community (industry, government, institutions of higher education, professional societies, et. al.) should place a high priority on encouraging women and underrepresented minorities to pursue careers in engineering. Increasing diversity will not only increase the size and quality of the engineering workforce, but it will also introduce diverse ideas and experiences that can stimulate creative approaches to solving difficult challenges. Although this is likely to require a significant increase in investment from both public and private sources, increasing diversity is clearly essential to sustaining the capacity and quality of the United States scientific and engineering workforce." (Duderstadt, 2005, Marburger, 2006)

To this end, it is appropriate to conclude with the following proposal:

Proposal 7: All participants and stakeholders in the engineering community (industry, government, institutions of higher education, professional societies, et. al.) should commit the resources, programs, and leadership necessary to enable participation in engineering to achieve a racial, ethnic, and gender diversity consistent with the American population.

Concluding Remarks

America's leadership in engineering will require both commitment to change and investment of time, energy, and resources by the private sector, federal and state governments, and colleges and universities. Bold, transformative initiatives are necessary to reshape engineering research, education, and practice to respond to challenges in global markets, national security, energy sustainability, and public health. The proposals suggested in this paper involve not only technological but also cultural issues that will require the collective commitment of the engineering profession and engineering educators and the support of industry, federal and state government, and foundations.

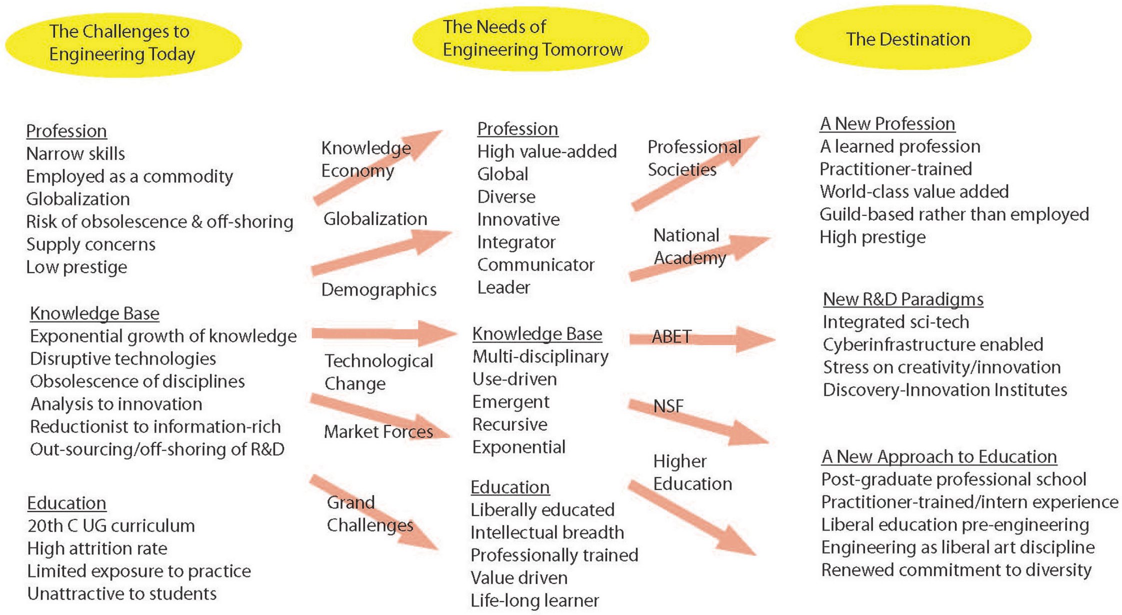
Sometimes a crisis is necessary to dislodge an organization from the complacency that arises from past success. The same holds for a nation–and a profession, in fact. It could be that the emergence of a hypercompetitive, global, knowledge-driven economy is just what the United States and the profession of engineering need. The key to America's global competitiveness is technological innovation. And the keys to innovation are new knowledge, human capital, infrastructure, and enlightened policies. Not only must the United States match investments made by other nations in education, R&D, and infrastructure, but it must recognize the inevitability of new innovative, technology-driven industries replacing old obsolete and dying industries as a natural process of "creative destruction" (a la Schumpeter) that characterizes a hypercompetitive global economy.

The same challenge faces the engineering profession. The growing tendency of American industry to outsource engineering services and offshore engineering jobs should serve as a wakeup call in our times similar to that provided to industry by the outsourcing of manufacturing the 1980s. The global knowledge economy is merciless in demanding that companies seek quality services at minimal cost. When engineers in Bangalore, Shanghai, and Budapest produce high-quality results at one-fifth the cost of similar efforts in the U.S., America's engineering profession simply must recognize that our engineering core competency is no longer particular technical skills or narrowly tailored engineering careers. It requires new paradigms for engineering practice, research, and education. The magnitude of the challenges and opportunities facing our nation, the changing demands of achieving prosperity and security in an ever more competitive, global, knowledge-driven world, and the consequences of failing to sustain our engineering leadership demand bold new initiatives.

Yet we also acknowledge that the resistance to the bold actions proposed in this paper will be considerable. Many companies will continue to seek low-cost engineering talent, utilized as commodities similar to assembly-line workers, with narrow roles, capable of being laid off and replaced by offshored engineering services at the slight threat of financial pressure. Many educators will defend the status quo, as they tend to do in most academic fields. And unlike the professional guilds that captured control of the marketplace through licensing and regulations on practice in other fields such as medicine and law, the great diversity of engineering disciplines and roles continues to generate a cacophony of conflicting objectives that inhibits change.

Yet the stakes are very high. During the latter half of the 20th century, the economic leadership of the United States was largely due to its capacity to apply new knowledge to the development of new technologies. With just 5% of the world's population, the U.S. employed almost one-third of the world's scientists and engineers, accounted for 40% of its R&D spending, and published 35% of its scientific articles. Today storm clouds are gathering as inadequate investment in the necessary elements of innovation–education, research, infrastructure, and supportive public policies–threatens this nation's technological leadership. The inadequacy of current government and industry investment in the long-term engineering research necessary to provide the knowledge base for innovation has been revealed in numerous recent reports. Furthermore, the growing compensation gap between engineering and other knowledge-intensive professions such as medicine, law, and business administration coupled with the risks of downsizing, outsourcing, and offshoring of domestic engineering jobs has eroded the attractiveness of engineering careers and precipitated a declining interest on the part of the best U.S. students. Current immigration policies combined with global skepticism about U.S. foreign policy continue to threaten our capacity to attract outstanding students, scientists, and engineers from abroad.

If one extrapolates these trends, it becomes clear that our nation faces the very real prospect of losing its engineering competence in an era in which technological innovation is key to economic competitiveness, national security, and social well being. Bold and concerted action is necessary to sustain and enhance the profession of engineering in America–its practice, research, and education. It is the goal of this report both to sound the alarm and to suggest a roadmap to the future of American engineering. While it is important to acknowledge the progress that has been made in better aligning engineering education to the imperatives of a rapidly changing world and to commend those from the profession, industry, and higher education who have pushed hard for change, it is also important to recognize that we still have many more miles to travel toward the goal of better positioning American engineering to serve a rapidly changing world.



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