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Rebuilding Engineering Education

By Norman R. Augustine

The importance of setting rigorous standards for engineering education to reflect changing professional realities and anticipate tomorrow's needs cannot be overstated. This would be a grave responsibility in any industrial country. But for the United States -- which is so dependent on technology for its standard of living and its ability to compete in the world marketplace (in turn, often helping to set the standard for the rest of the world) -- the responsibility has global implications.

We take it for granted that skyscrapers will not collapse during a hurricane, that elevators will deliver us to the floor we wish to reach, that dams will not fail, and that our automobiles will not break down on the hottest days or the coldest nights. We also assume that our vast electrical-power grid will deliver energy to millions of homes and enable us simultaneously to cook our pizza and to keep the ice cream frozen, that advanced medical devices such as pacemakers will function for years in our bodies without significant deterioration, and that a trillion dollars in electronic transactions will be entered flawlessly into millions of bank accounts each day.

Clearly, engineering, along with many other professions, needs a set of standards rigorous enough to insure that its graduates competently carry out their integral roles in the world's most technologically advanced economy.

Granted, we know of tragic engineering failures: the collapse of a bridge, such as occurred at the Tacoma Narrows; the failure of a building, such as the walkways in the Kansas City Hyatt hotel; or the faulty design of a space vehicle, such as the *Challenger*. As the movie *Apollo 13* recently reminded us, our engineering skills, while extraordinary, are subject to human error.

But in general, our amazing engineering-based technology functions smoothly. The logical conclusion is that the educational standards set by the body that evaluates engineering curricula -- the Accreditation Board for Engineering and Technology -- are working well. If the system is not broken, why fix it?

My answer is that engineering itself has changed, and will continue to change, dramatically. Our system of education and accreditation must reflect that evolution.

How has the profession changed in recent years? What adjustments would allow engineering education and its accreditation process to confront such changes more effectively?

First, the subject matter of engineering has changed. The company that I serve employs more software engineers than any other type, yet that discipline did not even exist when I graduated from college. Studies indicate that the half-life of material covered in many engineering courses is five to ten years. Few engineers now end their careers in the type of engineering for which they originally prepared.

A second, even more profound change is that political and economic limitations, rather than technical ones, increasingly are decisive in determining what engineers can accomplish. The laws of politics are replacing the laws of nature as the principal factor establishing the feasibility of many engineering projects, whether it is building a space station, sending humans to Mars, or building commercial nuclear-power generators, to cite but a few examples.

Ethical issues also are assuming growing importance in engineering, posing more-complex and morally challenging questions for engineers. For instance, what should an engineer do upon learning of new research that suggests an existing structure might fail, even though the structure meets all relevant building codes? This happened with the 59-story Citicorp Center, built in midtown Manhattan in the 1970s. The project's leading structural engineer found that the building's innovative bracing system might fail during an unusually powerful storm. He faced the dilemma of whether he should keep quiet, hoping that such a freak storm would never occur, or speak up and expose his firm to the risk of increased costs, lawsuits, and embarrassment. Providing a textbook example of ethical behavior, he immediately shared the new information with Citicorp, and he was able to oversee the installation of additional bracing. The scale and cost of contemporary projects have raised the stakes of this kind of ethical question enormously.

Students are keenly aware of such dilemmas. When two engineering professors at Texas A&M University decided to offer an ethics course a few years ago, they were astonished at the outpouring of interest. The class, which enrolled 20 students in 1990, drew 250 last year. The engineering department is considering a proposal to make it a required course for all engineering students.

Yet another trend suggests a deep-rooted problem in the education of engineers: the lack of practical experience in applying their academic knowledge. Teaching the fundamentals of engineering -- mathematics, physics, chemistry, logic, and the like -- is the *sine qua non* of the profession, of course. But many of my colleagues in industry share my belief that engineering schools are becoming increasingly detached from engaging students in practical applications of basic knowledge. Similar charges are made by practitioners of other disciplines, of course, but given engineers' ultimate responsibility for people's safety and lives, the need for hands-on experience assumes particular importance.

True, it may take an engineering professor six years to earn a Ph.D. and seven more years to gain tenure, years so full of publishing and research that little time is left to gain practical experience. Further, candidates for tenure usually are expected to supply supporting letters from other academics, not from practicing engineers. But in light of the fact that about 80 per cent of all engineers start their careers in industry, we need to find some way to enhance the importance of real-world experience in engineering education. Practicing engineers do serve on accrediting teams, but other strategies should be developed.

Some engineering schools are giving students hands-on assignments that introduce the realities of accountability, budgeting, and teamwork -- a frequently overlooked set of increasingly important engineering skills. Engineering freshmen at the University of Maryland, for example, work in teams to define, design, test, and validate a solar reflector using no more than $100 in parts. By their senior year, student teams are working alongside representatives of industry to tackle specific engineering challenges.

Engineers live on the front lines of the global marketplace. While American doctors and lawyers rarely compete head-to-head with their counterparts in other countries, engineers are in direct competition with their counterparts around the world, every day. Not only do we compete to sell the products we design and build, but we also must compete for jobs. With electronic communication now so easy, American companies often find it financially attractive to move engineering tasks to other countries, such as India, where world-class engineers are paid one-tenth the salaries of U.S. engineers, or to Russia, where highly capable engineers make one-tenth the salaries of Indian engineers.

A final significant change in engineering is that more and more engineering projects cut across established fields. Consider the multidisciplinary engineering teams involved in building a product as complex as the space shuttle, which drew together specialists in such fields as propulsion, electronics, guidance and control, aerodynamics, structural engineering, and human factors.

Further evidence is the fact that the modern field devoted to the integration of a variety of engineering elements -- "systems engineering" -- has taken on increasing importance since the 1950s. However, few academic institutions even offer a degree in the field.

While many outstanding systems engineers have developed their skills after specializing in a particular field of engineering, the time has come for engineering schools to offer students the chance to concentrate their studies in the field of systems engineering.

Lockheed Martin has demonstrated its commitment to this emerging field by endowing a chair and supporting a program in systems engineering at the University of Maryland School of Engineering.

Reciting the changes faced by engineers today gives one a renewed appreciation of the challenges ahead for educators and accreditors. How might we reform the standard engineering curriculum to address these changes?

Although we should continue to emphasize the basics of science and engineering, we should consider requiring engineers to study other important subjects as well -- economics, history, political science, and possibly even law -- in addition to the liberal-arts requirements already in place. Such study will equip engineers with a better understanding of issues that shape the practice of their profession. Further, we need to add courses in systems engineering, ethics courses specifically oriented toward engineers, and courses to help graduates write and communicate clearly. We should encourage engineers to study abroad for a semester or a summer. And engineering students need to practice working in teams, ideally in conjunction with local industrial firms.

How can we accomplish all of these diverse goals in four years of education? The answer is simple: We can't.

This conclusion leads me to three more recommendations, which involve not the content of an engineering education, but rather the process of providing it.

First, we should require a five- to six-year course of study for an engineering degree, making the master's degree the basic degree of the profession. We could make the bachelor's degree in engineering equal to, say, paralegal training. Today it takes seven years to train a lawyer and eight years to produce a physician, but only four years to educate an engineer. In fact, the veterinarian who vaccinates my neighbor's basset hound is required to have substantially more formal training than the engineer who designs a bridge over which millions of people will travel.

Second, we should broaden the range of engineers from industry who participate in the accreditation process, in particular by including systems engineers. This would increase the emphasis on applied engineering experience and focus more attention on the need to develop young engineers who understand the challenges of building "the systems of systems" in the future. Although expert in assessing the curricula of engineering schools, members of the Accreditation Board for Engineering and Technology cannot be expected to be expert in all of the different and developing arenas in which today's engineers work. I also suggest including representatives of the liberal arts on accrediting teams, to reflect the importance of a broader education.

Third, we need to establish a mandatory licensing examination, to serve as the final quality control on those who would practice the engineering profession. Much of the increasingly complex work of engineers, if not properly conducted, can put the lives of large numbers of individuals at risk. The "consumers" of engineering products are entitled to the assurance that those in whom they place their faith have met at least some minimum standards of competence -- just as doctors, lawyers, and certified public accountants are required to do.

Since the beginning of recorded history, scientists and engineers frequently have been responsible for the physical improvements that we have come to enjoy and even to expect in our lives. But it is not realistic to assume that the same techniques used to train engineers to build steam engines and bridges are the best ways to train engineers to build worldwide telecommunications networks and to explore the planetary system. We need new approaches to prepare engineering students who can handle the professional challenges of the next century.

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