Change in Engineering Education: One Myth, Two Scenarios, and Three Foci

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Abstract

Change is coming to engineering education, but many reform efforts have proceeded without explicitly examining the current prime movers of change, the forces that resist change, or the facets or foci of the system that are most in need of change. This essay frames the current debate by examining these things. Specifically, change is seen as being motivated by external competitive and technological forces. Resistance to change is viewed as being reinforced by the *fundamental myth of engineering education* that asserts the supremacy of basic research over all other engineering academic activities. After providing evidence that the myth resulted largely from an overestimation of the role of science and an underestimation of the role of engineering in World War II, the essay considers needed organizational, integrative, and programatic changes. Key among these are the proposal to create student-faculty teams responsible for delivering a quality education, a proposal for bottom-up alliances with industrial clients, and a number of proposals aimed at helping the profession explore its human, philosophical, and historical underpinnings. The essay concludes by warning that times of great change risk making matters worse through the *unintended consequences* of reform. A principled methodology of reform is suggested that advocates distributed and competitive implementation together with planning and evaluation based on understanding the special risks of losing systemic knowledge that is difficult to *articulate*.

1 Introduction

Change in engineering education is in the air. These pages and those of its companion magazine *ASEE Prism* are bursting with new ideas, programs, directions, and plans. Although the increased publication signals that change is taking place—or, at least, is being talked about—the *motivation* behind the change has less often been articulated. Moreover, few explanations have been offered as to why change is occurring now, or—to put it somewhat differently—why change has been delayed until now. As a result, many of the suggestions for change are being made piecemeal, without explicit regard for the motivation for change, the factors that have resisted change, or the possible unintended consequences of the changes being considered.

This essay attempts to frame the current debate by delineating the motivation, environment, and categories for the changes necessary in engineering education as we approach the millennium. Specifically, the essay starts by suggesting that change is being brought about by compelling competitive and technological factors. It continues by explaining the resistance to change in the *fundamental myth of engineering education* and by examining three foci of change. After suggesting specific action steps within each focus, the essay concludes by sounding a warning that times of great change carry the risk of making matters worse as a result of the *unintended consequences* of reform and by systematically deemphasizing that knowledge which is difficult to *articulate.* A principled approach to change is proposed to address these difficulties.

2 Why Change?

The current business literature accepts sweeping change as being necessary, almost obvious. Creech's (1994, p. 3) argument is characteristic:

> It's a new game, and the nation has yet to awaken adequately to its new rules, and their portent for the future. I am convinced that getting back to a position of leadership in international competitiveness—including against the Japanese—is well within reach. But we can't go on as we are. Our management practices must change. Adequate though not ideal for earlier times, they are thoroughly unsatisfactory in an era of intense competition. The proof is in. This new era presents new realities such as borderless marketplaces and discriminating consumers who are unmoved by appeals to select home-built products for patriotic reasons. Consumers look for the best value (quality and durability considered) and buy that product. In doing so they are indifferent to the macroeconomic effects of their decision. However, the cumulative effects of their individual decisions are profound—that's all too clear. And the trend toward choosing foreign-made products in America is accelerating, not diminishing. The effect eventually reaches every business and every individual in society, not just those involved in international commerce.

The view from the ivory tower is somewhat different. Change is viewed with suspicion if at all, and many consider it largely unnecessary because American universities are the envy of the world (Rosovsky, 1990, p. 29):

> In much of the foregoing, readers may have sensed a certain pride taken by the author in his profession. I do not deny it. To me, some parts of American higher education are one of the country's greatest glories. In fact, I make bold to say to our critics—and they are many these days—that fully two thirds to three quarters of the best universities in the world are located in the United States. (That we also are home to a large share of the world's worst colleges and universities is not now my concern.) What sector of our economy and society can make a similar statement? One can think of baseball, football, and basketball teams, but that pretty much exhausts the list. No one has suggested that today America is home to thirds of the best steel mills, automobile factories, chip manufacturers, banks, or government agencies

As former Dean of Faculty of Arts and Sciences at Harvard University, perhaps Dr. Rosovsky has some right to feel proud of his and other elite American universities, but when such self-regard is used to deflect rather than listen to serious, thoughtful criticism from observers and consumers of one's services, pride has crossed the line into hubris. If one replaces the words "higher education" by "auto industry" and "universities" by "auto makers" the revised paragraph could easily have been written by a Ford, GM, or Chrysler vice-president some time during the late 1960s or early 1970s at the beginnings of the Japanese onslaught. But drawing that connection may raise some hackles, because competition is not usually a concept that academics feel they must deal with in other than abstract terms.[1] After all, the university has long existed, and has always been insulated from external competitive market pressures. What could possibly change this situation? The remainder of section 2 tries to answer this question by discussing the competitive and technological forces that are bearing down on engineering education today. Rather than doing so in abstract terms, I construct two concrete scenarios that illustrate how competition may indeed be real, imminent, and dangerous to the health of our institutions as currently constituted.

2.1 Scenario I: The Little Red School House

Imagine that we are businesspeople who are interested in starting a business to teach engineering *at a profit.* Let's go through a simple breakeven analysis and see if current costs and tuitions are in the ballpark of a profitmaking enterprise.

To simplify our thinking, we make some straightforward assumptions. First, assume that a single instructor will be asked to teach 16 hours of coursework per semester (this assumption gives us the name "Little Red School House" because a single teacher is imagined to be responsible for teaching all the subjects of a given class, but of course, the assumption remains valid in a multi-class setting as long as all instructors teach a course load sufficient to cover the average total coursework of a single class.) Many faculty will object to these

[1] In all fairness, Dr. Rosovsky, an economist, follows his horn tooting with a fairly lengthy discussion of the virtues of competition that he uses to help explain why U.S. universities excel, but his competition is largely *from within.* What he describes is a clubby oligopoly of established players who are willing through custom or collusion to compete on largely non-price terms. This essay entertains the possibility of a far more brutal form of price and quality competition that plausibly lurks around the corner.

teaching loads, but they are not much different than those that existed in the 1950s and 1960s, and certainly no successful businessperson would permit his or her most expensive factor of production to be engaged in revenue-generating activities for fewer hours than this.

Next, assume that we hire a faculty member at rates paid to entry-level faculty today, say $40,000/academic year. Include roughly 20% for benefits, 30% for support staff, and another 50% to cover fixed capital costs, including classroom and office space, furniture, and computers. All told, salary plus other fixed costs totals roughly $80,000 per year.

On the income side of the ledger, let's be pessimistic and assume that we can charge rates no higher than those charged by state-subsidized universities. Using numbers from the University of Illinois as representative, we obtain roughly $3,400/year in tuition and $900/year in fees exclusive of room and board. We assume that the fees are used for their intended purpose and do not throw off a contribution margin against fixed costs (I have often suspected that education at state-subsidized universities is priced as a loss leader to enable marginally less money to be lost on room, board, and football). Of the tuition funds, we assume a third of the money goes toward miscellaneous variable costs, leaving a contribution margin of roughly $2,300/student/year. Dividing the contribution margin into the total fixed costs of $80,000, we obtain a breakeven class size of approximately 35 students.

Thus, by asking instructors to teach nominal course loads, by assuming low-end market prices, and without seeking even the simplest economies of scale, *we can make money teaching engineering* to class sizes no bigger than those that typically exist in our universities today. The numbers become even more compelling if we can charge the premium rates of some private institutions. Assuming a private school tuition of $12,000/year and the same proportion of variable costs as assumed above we are left with a contribution margin of $8000/student/year. Assuming the same level of fixed costs as above, the breakeven class size reduces to $80,000/8,000 = 10$.

These numbers should be startling, because they (1) show dramatically how inefficient we've become and (2) suggest that the market may not long tolerate such inefficiency. In a moment, I'll argue that competition is already rising and that more is on the way, but before that, I acknowledge that some will object to this argument on a number of grounds. Some will quibble with my particular choice of numbers and suggest that better figures would show the university in a better light. Certainly changing the numbers will change the breakeven values, but as long as tuition continues to grow faster than inflation and as long as the growth of salaries and other costs can be held at or below the rate of inflation, not many years need pass before the estimates of this paper are compelling. Moreover, the point here is not to create an ironclad business plan and obtain money from a venture capitalist (although that thought may be worth entertaining); rather we seek a rough idea whether plausible free-market alternatives exist to the status quo.

Others will complain that the calculation ignores the value of research and public service, but students should not be charged for the direct value of research or service outputs. These are purchased by the public or privates funds that sponsor them. It may be reasonable to charge students a premium for learning from a famous researcher, but certainly students have been told repeatedly that not only is their financial contribution to the university being used toward education alone, but that their education is subsidized heavily by public or endowment funds. If a businessperson can profitably provide a comparable service at lower cost, then it becomes an inescapable conclusion that student funds are subsidizing inefficiency, research, service, or other non-educational items.

In addition, the arguments of this section have been made without attempting to achieve even the simplest economies. The next section argues that the new telecommunications technology is changing the delivery and cost equations dramatically to the point where massive economies of scale will become practical and the possibility of competition will become a certainty.

2.2 Scenario II: The Rise of a "Ted Turner" of Engineering Education

There is much excitement surrounding modern multimedia, computer, and telecommunications technology. 500-channel cable television, point-to-point multimedia technology, and the information superhighway are the focus of big plans, big mergers, and big money. In the "Ted Turner Scenario" we imagine that these software, hardware, and media are available and are married to the "Little Red School House." Why should a gifted instructor labor in front of only 35 or so students, when a television audience of many more can be reached at a large number of sites at a profit? Why should students tolerate poor preparation, amateurish delivery, or lack of motivation when a star instructor can be sought and delivered to a TV audience anywhere in the world?

The answers to these questions are that the marketplace won't long tolerate current educational practices once the costs of the new technology drop and make its use practical. How much imagination is required to envision an "Oprah Winfrey" of Statics or a "Phil Donahue" of Circuits recruited by the equivalent of a "Ted Turner" of engineering education? With enough leverage, professional programming and course materials would be feasible and offer better course delivery at lower cost to a wider audience.

Concerns over the loss of personal contact in such a distance learning system are justified, but these could be satisfied by having graduate engineers work with students in small recitation sections to help with unanswered questions, laboratory assignments, problem sets, and general human interaction. Moreover, the portability of such training would make it feasible to put engineering education at the point of sale (in factories and design shops), where training would include real-world applications with hands-on exercises and actual projects. In this way, larger corporations could train exactly the kind of employees they needed; smaller corporations could hire from relatively small schools that combined the network programming with individual interaction and feedback.

These arguments can be made more quantitative along the lines of the previous section. The history of falling prices in computer and telecommunications technology makes it less necessary to do so. For the purposes of this essay, it seems clear that a cost level will soon be reached where a sufficiently large audience can be reached at a profit outside the normal university setting.

2.3 If You're So Smart, Why Aren't You Rich?

If these arguments are so good, where's the predicted competition? One answer to this question is that it's coming if we look for it. For example, a professional school was started in 1992 under assumptions akin to those of the "Little Red School House" scenario. Described in a recent article in the Wall Street Journal (Boot, 1994), the Massachusetts School of Law (MSL) was set up to provide a more practice-oriented legal education. Charging 60% of the median private-school tuition—$9,000 a year—MSL turned a first-year (1992–93) operating deficit of $18,000 into an estimated $1.4 million surplus in 1993–94 by watching productivity and squeezing costs. Although the school is organized as a non-profit corporation, its model of operation is businesslike and it pays professors on the basis of merit, not seniority.

For-profit companies are also getting into the higher-education act. A recent article (Kelly & Burrows, 1994) reported that Motorola spends 4% of payroll on training, and that each Motorola employee gets 40 hours of training a year. The centerpiece of this educational strategy is Motorola University with a budget of $120 million, a headquarters in Schaumberg, IL, and 14 branches around the world. It is easy for academics to dismiss corporate training programs (without even examining their content or methodology) as lacking "intellectual gravity and seriousness," but the sheer magnitude of the program should give some pause; if determined corporations such as Motorola become convinced that they can do a better job providing a college education to existing or future employees and that such efforts will give their firm a competitive advantage, our scoffing, skepticism, and uninformed dismissals are unlikely to deter their efforts.

On the technological front, many engineering academics are familiar with National Technological University or NTU and its efforts in delivering coursework via satellite, but these efforts are centralized and have been set up to protect the interests of the participating institutions. The genie of competition is coming out of the bottle, and aggressive newcomers are setting up courses and degrees via online services and the Internet. One such operation is EUN or the Electronic University Network offered via America Online to anyone who has a home computer and a modem (Lichty, 1993). These services are encouraged by the low cost of online and Internet access, but they are ultimately limited by their low bandwidth. Low-cost, high-bandwidth multimedia will make interactive video coursework a reality, and this can only encourage the formation of more services.

3 Resistance to Change: The Fundamental Myth

Against this backdrop of competitive and technological pressure, it seems almost odd that colleges of engineering haven't moved more swiftly to fight back. After all, our inefficiency did not grow overnight, nor did the new technology emerge full-fledged at the dawn. Why hasn't there been more of a response to the growing threat?

The parable of the frog (Senge, 1990) goes a long way toward explaining the problem. When a frog is thrown into a pan of boiling water it will recognize the temperature difference and immediately try to escape from danger. When a frog is thrown into a pan of water at room temperature and the water is slowly boiled, the frog will not become sufficiently aroused to take corrective action and will eventually die. We have been cooking in our own complacency for some time, but our situation is somewhat worse than the frog's. Not only is it the case that we have usually failed to notice the slowly rising water temperature, but when an errant faculty member does complain about the heat, we concoct elaborate tales to rationalize the problem away and actively resist action.

In the present case I believe that there is a tale—what I call the *fundamental myth of engineering education*—that has been used to create, justify, and reinforce the status quo. The myth struck me between the eyes when I received a memo recently that described an encounter with a prominent engineering educator:

> Dr. X spoke about what is happening in engineering education today in a very pessimistic tone and is afraid we might return to the kind of engineering education which existed when he was a student. At that time there was little emphasis on research. Because of this, when World War II came along physicists were forced to do work that should have been done by engineers. In fact it was this result that led to the rise of engineering science. Dr. X is afraid that we will sacrifice the kind of education that leads to understanding in order to *satisfy the immediate needs of industry.*

When I read the memo, I was struck—not by the content of Dr. X's views—but that I had heard almost the exact same tale repeated by faculty members at a number of institutions in almost the exact same form. The embellishments change, but the outline of the story is remarkably consistent:

1. Before World War II engineers were scientifically and mathematically deficient and as a result most critical progress in the war effort fell to others.
2. After the war, engineers realized they were beaten at their own game and they healed themselves by (a) installing engineering science in the curriculum where little or none had existed and by (b) doing academic engineering research where little or none had been previously done.

Like many myths, this one started with elements of truth, but the caricature that gets repeated is clearly flawed. Contrary to the folktale, engineers played a key role in the war effort, science and math had an important presence in the engineering curriculum prior to the war, and engineering faculty performed research before and during the war. For example, in explaining underlying causes for the Allied victory in World War II, historian Paul Johnson credits the American economy (Johnson, 1991, pp. 401):

> But the real engine of Allied victory was the American economy. Within a single year the number of tanks built had been raised to 24,000 and planes to 48,000. By the end of the first year of the war America had raised its army production to the total of all three Axis powers together, and by 1944 had doubled it again—while at the same time creating an army which passed the 7 million mark in 1943.

And who were the heroes of this miracle of wartime production? Johnson names names, and they are engineering names (pp. 402):

> The war put back on his pedestal the American capitalist folk-hero. Henry Kaiser, Henry Morrison and John McCone, the San Francisico engineers, who created the Boulder Dam (and who had been systematically harassed during the New Deal by Roosevelt's Interior Secretary, Harold Ickes, for breaches of federal regulations), led the field in the wartime hustle. They built the world's biggest cement plant and the first integrated steel mill. Told to build ships at any cost, they cut the construction time of a 'Liberty' ship from 196 to twenty-seven days and by 1943 were turning one out every 10.3 hours.

Other stories of wartime engineering-business heroics can be given—for example, the creation of the P-51 Mustang fighter aircraft by North American Aviation in 100 days (Hayes, R. H., Wheelwright, S. C., & Clark, K. B., 1988)—but there will be those who object that building ships and airplanes is one thing and inventing radar and atomic bombs is another. Isn't the real justification for our post-war worship at the altar of basic research these high-tech accomplishments?

Even these high-tech justifications do not hold up under close scrutiny. For example, the mother of all WWII "triumphs of science"—the Manhattan Project and the development of the atomic bomb—saw engineers in both lead and essential supporting roles (Groueff, 1967). History seems to remember the physicists, but as engineers, why not remember the organizational genius, intuition, and determination of General Leslie Grove, the West Point trained engineer who pushed, prodded, planned, and got the job done? Why not recall the ingenuity required of George Watt, a University of Illinois trained mechanical engineer, who designed the compressor essential to the critical gaseous-diffusion project? Why not assuage our physics envy by recounting the triumph of Clarence Johnson, an MIT-trained chemical engineer, who removed the final obstacle to building the gaseous-diffusion project by discovering a method for constructing an appropriately porous barrier?

Without much heavy lifting it is easy to accumulate evidence that the fundamental myth is mainly fiction, but accuracy is not primary when the subject is folklore. Rather folktales and myths are important for the conclusions that listeners are supposed to draw from the tales—what is usually called the *moral* of the story—and from the actions the moral encourages individuals to take.

When we examine the moral of the story and the implied action set of this tale, the consequences of continued propagation of this myth are less benign. The moral of the tale is that basic research is the overarching mission of an engineering college; it is the thing from which all good comes. I exaggerate only somewhat in following the usual line of reasoning in the following: only through basic research can we achieve respectability; only through basic research will be able to compete with physicists; only through basic research will we be able avoid being caught with our pants down again; only through basic research can we keep the curriculum current. But as the historical examples already have shown, this kind of reasoning is seriously in doubt. Why was the myth originally necessary and why has it been so long lived? The answer, as with so many other things in human affairs is summed up by a single word, *money.* The myth and its moral became necessary the day after Dr. Vannevar Bush made his famous recommendation for the Federal funding of basic research (Bush, 1946, p. 69):

> The Federal Government should accept new responsibilities for promoting the creation of new scientific knowledge and the development of scientific talent in our youth. In discharging these responsibilities, Federal funds should be made available.

With these simple words, Dr. Bush, an electrical engineer and war-time director of the Office of Scientific Research and Development (OSRD), helped unleash powerful economic forces that ultimately required engineering academics to justify the expedient pursuit of basic research dollars on morally higher ground. Dr. Bush expressed concern that Federal funding might squeeze out private monies, but he did not foresee the full consequences of his act. Today the myth lives on in extreme form, and the "virtue" of basic research seems to imply a "vice" in the pursuit of the applied. It also suggests that college involvement with industry is suspect because such effort might not have sufficient theoretical basis or "intellectual gravity;" that courses that are immediately useful to companies constitute "trade-school training" and are beneath the dignity of researchers who want to traffic with physicists. To put it bluntly, the myth encourages us to turn our backs on engineering as practiced by the students we educate; it encourages us to think of ourselves as scientists and to deny—at least, ignore—the creative, business, and interpersonal skills necessary to the delivery of real products and services in the real world.

Having said this, I should make it clear that I am not advocating a return to bygone pastoral days of the once-sleepy engineering college. For one thing, at many of this country's engineering schools, no such days ever existed. For example, the very earliest times on the campus of the University of Illinois were marked by fundamental inquiry driven by a curious faculty who pushed the boundaries of technology ever outward (Kingery, Berg, & Schillinger, 1967). For another, as a passionate, front-line researcher I know the joy of basic discovery, the freshness research brings to my teaching, the sharpness that proposal writing and the hunt can bring to my thinking, and the independence that funds under my control can bring to my decision making. So the question is not one of personally or institutionally abandoning basic engineering research—we will continue to do these things because we are curious human beings, because they are largely their own reward, and because sometimes people will pay us to do them. The question is whether we will continue to propagate a world view that has been used to justify basic research to the exclusion of many other activities, which in turn has kept us at arms length from our profession, its present and future practitioners, and the vineyards and the fruits of its labors.

Even if we acknowledge some need for the primary prescription of the fundamental myth—that postwar engineering science and research needed a shot in the arm—continued adherence to this tale, its moral, and its implied action set in the 1990s when basic research, engineering science, and analysis have become the dominant activities at many engineering colleges is a sign that we, like many generals, are preparing to fight the previous war. It is unclear how staying this course will answer the increasing criticism (Anderson, 1992; Bloom, 1987; Roche, 1994; Sowell, 1993; Sykes, 1988) we face from students, industry, the public, and the government. Nor is it clear how a largely singleminded emphasis on basic research will help us prepare our students and ourselves to face the increasingly fast-paced and competitive business environment characteristic of the end of this most technological and fast-paced of centuries.

4 We Live in a Different Environment

Perhaps hindsight helps us understand the roots of the fundamental myth in an exaggerated perception of the relative importance to the war effort of science over engineering, productive capacity, and management acumen. Yet, U.S. technology and productivity have marched on (sometimes with and sometimes without the aid of science), and so, too, have the technological and productive capabilities of our global competitors. As a result, the world we live in today is a good bit different than the one that followed World War II or even the one of the 1960s and 70s.

Transportation and information technology are changing everything. Jet planes wisk us anywhere in the world in under a day. Computers, multimedia, and networks are changing the way we work. Both of these are bringing down transaction costs and reducing the cost-effective size of all organizations (Coase, 1988).

The economy is increasingly competitive and global. Bits respect no geographic boundaries or borders, and the same information technology that is changing the workplace is making capital and other information increasingly transportable. As a result, organizations (including universities) must compete beyond old regional boundaries with the global low-cost, high-quality producer.

Engineering employers are increasingly cost, skill, and process conscious. These same competitive pressures are forcing employers to reexamine their hiring, training, and management practices. More and more, engineers are asked to join organizations and get up to speed more quickly, with less training, in more complex work arrangements (teaming, concurrent engineering, etc.). As a result, the modern engineering graduate is being asked to come to work closer to being fully "assembled."

Education costs continue to spiral. The primary cost component of an engineering education continues to be labor. Because education is carried out in institutions that are shielded from market forces in the short term, faculty salaries now command a premium to engineering salaries in the private sector. This is particularly true when the risks of corporate restructuring and the benefits of faculty autonomy are accounted. Originally, retention of rainmakers (researchers who bring in large grants) helped justify these salary increases, but these research funds were purchased with a concomitant reduction in teaching loads. Thereafter, reduced teaching loads were granted to faculty members who were less successful at the funding game, and salary increases trickled down as well. As a result, low teaching productivity and relatively high salaries have propagated throughout our universities, regardless of whether faculty generate the external funding that helped justify these costs in the first place. The status quo is sustainable only if governmental funding can continue at ever-increasing levels, but ...

Our customers are less able or willing to bail us out. Multi-hundred-billion dollar federal budget deficits on top of a multi-trillion dollar federal debt are making it less likely that previous levels of governmental support, both federal and state, can continue to be sustained, let alone increased. In the past, spiraling costs and inefficiencies in delivering our product mix of research and teaching were covered by a combination of increased tuition fees, state funding, and federal research dollars. All three sources have about reached their limits, and all three are increasingly questioning the value returned for the money.

From the universities' point of view, the situation should be fairly alarming. If you were in business and a single client was responsible for 50–70% of your dollar volume and that client went into Chapter 11 bankruptcy proceedings, you might become more than somewhat concerned. You might watch that client's moves very carefully, and you might also look for other clients. Many universities face these circumstances with the Federal government, of course, playing the role of the bankrupt client. The Fed's ability to print and borrow money delays the day of reckoning somewhat, but it cannot be forestalled indefinitely. As a result, it is essential to develop a vision of the future that enables us to provide high quality services effectively, efficiently, and with better respect for the multifaceted nature of our profession.

5 A Different Vision

Thus, the immediate problem with the post-war vision of engineering education is that it is unsustainable. Front-line researchers hear the giant sucking sound of Federal coffers drying up and the complaints of industry that academic research is increasingly irrelevant. Front-line admissions people hear the doppler shift of the receded baby boom and the relative quiet in the trough of the baby-bust. Front-line placement officers hear the growing complaints of a mismatch between what students bring to work and what is needed. Each of these is evidence of a fundamental disconnect between the engineering college and the clients it ultimately serves. A fair argument (Roche, 1994) can be made that this disconnect came about through a Gresham's law of educational funding, where easy federal dollars unintendedly drove out dearer industrial and private funds. Yet, assessing blame does no solution offer. Instead, to rectify the situation we must seek better internal organization, better external integration with our end users, a more consistent approach to continuing adaptation and innovation, and better knowledge and confidence in the true nature of our profession.

The future belongs to the well organized. One of the realizations of the current drive for quality in industry is that *functional organization*—the separation of structure by specialty or discipline—can itself be a major impediment to the provision of quality products and services. The argument is straightforward and suggests that separation of function impedes the *cooperation* needed among disparate disciplines to create a complex product or service and that it reduces the pride of *ownership* necessary to reliably overcome everyday obstacles or hurdles.

To answer the limitations of functional organization some practitioners of *total quality management* (TQM) prescribe the formation of cross-disciplinary teams (Creech, 1994). The idea is that a team with larger responsibility and authority can be entrusted to make good decisions if goals and a larger sense of mission are well communicated. There has been a good bit of discussion regarding TQM efforts in academic circles (American Society for Engineering Education, 1994; Horine, Hailey, & Rubach, 1993), but it appears that many of the efforts have been addressed to staff functions, and even when TQM is applied to line tasks (teaching and research) that students are rarely involved.

Some careful thinking about TQM in the setting of an engineering college suggests that the primary locus of teaming should be a combined student-faculty team established upon a student's entrance to the university. The ideal team would contain a modest group of students (25-50) and the faculty members (5–10) accountable for their advising, teaching, and overall education. At first this does not sound like a radical departure from the traditional organization, but at present a faculty member has little at stake in the education of any given undergraduate student. Depending upon the size of a class, a faculty member may or may not get to know a student's name over the course of a semester and may or may not be involved with a particular student ever again. Under the proposed system, the faculty member and the student have good reasons to get to know and cooperate with one another, because they will work together for at least four years. Ideally, a team should be entrusted to design its own solutions to common tasks—advising, studying, evaluation, to name a few—but it is relatively easy to imagine that the larger team will sometimes be divided into smaller teams with authority and responsibility for a given task.

One objection to such teamwork might be that it might corrupt the student and teacher evaluation process; that students are both a university's customers and products is a serious challenge. The current approach to evaluation, which might be characterized as centralized evaluation of teachers combined with decentralized evaluation of students, is itself not without flaws as witnessed by the widespread quality problem of grade inflation. This is a critical area, but I suspect if the creative energies of teams of faculty, students, and other stakeholders are turned to the problem we will get a sequence of increasingly effective proposals that lead to better, more rigorous feedback for both students and faculty alike.

The future belongs to the integrator. The same pressures that are causing industry and their suppliers to become more tightly integrated through practices of concurrent engineering and just-in-time manufacturing will cause the university to become more tightly coupled with its suppliers and external customers. The college must be prepared to listen to industry, to its students, to the K-12 teachers of its students, and be prepared to adapt more quickly to the rapid changes taking place. In part, these comments echo calls for integration made elsewhere (Bordogna, Fromm, & Ernst, 1993) with the added twist that it is important for engineering students and professors to become more involved with practitioners. By doing so, in one fell swoop we get the the integrative holism recommended by Bordogna et al. in the context of problems that matter.

Here in General Engineering, industrial integration has been underway for the past 23 years through our industrial-sponsored senior design course, GE 242 (Carnahan, Thurston, & Ruhl 1992). The program puts teams of three students together with one faculty member to solve a real problem sponsored by industry ($6,500/project). Over the years, these efforts have trained general engineers to solve tough technical problems and appreciate the time pressures, ambiguity, and human dimensions of real engineering work. At the same time, sponsoring companies have come to view the department as a source of engineers who are ready to hit the ground running.

One of the almost counterintuitive lessons of these experiences has been in the area of funding. Industry funds cover course expenses and enable software, prototypes, or equipment to be purchased. But the most important things the funding buys are twofold: (1) the industrial client's attention and (2) the department's commitment to do a quality job. That a supplier of a service for a fee would feel obligated to do a better job than a volunteer supplier is not difficult to understand; however, asking a client to pay for the privilege of paying attention sounds odd at first, but poker for fun is somehow less interesting than poker played for pennies, quarters, or table stakes; the amount of the ante is less important than that there be an ante. Our experience in GE 242 is that, for industrial clients, money talks and helps determine where time will be spent. Compared to other courses that do not charge, we have little or no problem getting client assistance and cooperation. Elsewhere, the major challenge of running a real-world design course is trying to get information, even a decent problem definition, out of the client. In this way, by supporting student solutions of real problems both financially and intellectually, industry not only receives the benefit of the concentrated effort and output of talented student engineers, it also buys its own attention to the solution of that problem, and it buys a stake in the educational process itself.

Thus, not only can funds flowing from industry to the university be a significant source of support, they help reconnect industry to the university, giving companies a stake in what we do and how well we do it. The surface has barely been scratched in exploring the limits of these integrative efforts. A new program here in General Engineering has successfully combined summer internships and subsequent senior design projects. Last summer two summer interns were placed at two different companies and they were subsequently placed on senior design projects for their respective companies. In both cases, excellent projects and happy customers resulted. On one project for a manufacturer of hobby supplies in Northern Illinois, a student who worked as a summer intern was placed in the fall on a GE 242 project involving the redesign of a packaging line. Largely because of that student's knowledge of the company and his commitment to them as a result of his summer job, the project team worked very well and the resulting redesign exceeded company expectations; it is now in the capital budget for immediate implementation. On another project, a summer intern for a robotics equipment manufacturer in Eastern Iowa was placed on a GE 242 project to design a rotating robotics table for that manufacturer. Again, the project exceeded company expectations and the design is now part of the manufacturer's product line.

A portion of these successes came from *placement* activities that preceded the design projects. These successes have reinforced our earlier departmental decision to augment traditional centralized placement activities with a major departmental effort, the General Engineering Placement System (GEPS), to serve our students and their employers. Because of limited resources, we made the decision to mount our campaign through alumni and industrial friends using direct mail, and we have been rewarded with a positive response (10–20%) that exceeded our expectations and direct-mail norms. Although these efforts have not replaced (were not intended to replace) centralized college placement efforts, they have directly helped a number of students get permanent and summer jobs, they have provided a steady quantity of leads for industrial design projects, and they have opened an important avenue of feedback from alumni and industrial friends.

As a result, we are looking to other avenues of integrating with our external clients. One promising direction is "tailored" electives. All general engineers are required to take what we call a *secondary field*, 12 hours in a coherent area of study. Unlike the technical electives of many traditional curricula, general engineering permits non-technical secondary fields, and historically over half of GE students elect engineering management or marketing. The historic flexibility of the secondary field, combined with its popularity among students and employers alike has inspired us to try to use it to meet critical underserved needs of the largest employers of our students. Efforts are underway to create new secondary field options in non-traditional areas such as systems integration and consulting, multimedia engineering, and telecommunications. Again, we think it is important bind our industrial friends to the process by asking for both financial and intellectual support. As with GE 242, we expect this approach to help create the needed activity at the same time it helps "buy" attention to the product, process, and success of the outcome.

The future belongs to the innovative. "Whosoever desires constant success must change his conduct with the times." Machiavelli lived at the dawning of the Renaissance, another time when technology and social innovation were bringing about vast changes in human affairs. A number of the innovations discussed above are, at root, attempts to get our organizations to be more regularly receptive to innovation, but the current attitudes of many faculty and administrators more closely resemble the self-satisfied remarks of Dean Rosovsky quoted above. Indeed, engineering education in the United States is an institution of which we can be justifiably proud. On the other hand, I can't help fearing that B. C. Forbes's words are operational here:

> The man who is cocksure he has arrived is ready for the return journey.

Only if we continue to innovate, only if we continue to adapt to changing circumstances, will our institutions continue to prosper.

The future belongs to those with quiet confidence. It seems to me that much of what has driven our profession—particularly the academic engineer—are feelings of insecurity or inferiority. This is reflected in the ease with which the fundamental myth has gripped our collective consciousness. Engineers are involved in business, but they are not businessmen. Engineers use science, but they are not scientists. Much of the modern history of our profession is a tug of war between these poles with more than one engineer abandoning identification with the profession for one extreme or another (Layton, 1971). It is time that we reconcile ourselves to the reality of the engineer as necessarily businessperson-technologist. It is time that we recognize engineering as more than just applied science (Adams, 1991; Ferguson, 1992; Vincenti, 1990). It is time that we use a Pareto definition of optimality to guide our professional improvement rather than that of a single criterion. If this vision, takes us toward a position where sometimes we "satisfy the immediate needs of industry," so be it. At least we will know that we have been true to a vision of the profession that reflects what engineers really do in the world.

6 Action Steps

For six years I taught at the University of Alabama, and as my friends down there might say, I've long since crossed the line "from preachin' to meddlin'." So, perhaps a final list of action steps can do little marginal harm. I should point out before going further that although I have leveled a number of criticisms in this essay, my intent has only been to provoke discussion and thought. My comments have not been directed against particular individuals; unlike *Profscam* (Sykes, 1988), I see few villains and little evidence of conspiracy. Like an economist, I see individuals acting within a particular organizational structure under a given set of incentives and disincentives. With this in mind, it seems clear that we require realignment of both the organizational structure and the incentives if reform is to take place. Specifically, I offer a number of suggestions for changing our organizations, the way we interact with the industrial community, and the programs we provide and the manner in which they are delivered.

6.1 Organizational Innovations

We have a number of quality problems in the provision of our mainline services, but our functional structure, inattention to process, and aspiration toward the ideals of science as opposed to those of engineering make it easier to ignore these problems. To address these difficulties we should consider a number of specific steps:

Reorganize around student-faculty teams. Functional organizations make for easily drawn organizational charts and lousy human interaction. At least as far back as the 1924 Hawthorne experiments (Hersey & Blanchard, 1993) we've known that human motivation is the biggest factor in explaining the variation of systems involving human beings, and that this variation is poorly modeled as simple random fluctuation. Yet, even today we persist in perpetuating functional organizational structures that are built on the Taylorian assumption that human beings do tasks with average efficiency and quality, plus or minus sigma. The lessons of seven decades of research into human motivation in the workplace have converged to the point where we can say with some confidence that people work better when, together with other human beings, they can take pride in doing a total job. In the educational enterprise, the key to understanding quality is recognizing that our primary "products"—our students—are themselves human beings and are part of the overall process. Teams of students and faculty responsible for accomplishing a well-defined educational mission should do a better job than our current "over-the-wall" approach.

Identify customers and their needs. The terminology of marketing is largely foreign to the halls of the engineering academy, but if we are to face the coming competition squarely we must identify all of our customers, understand their needs, and do a better job filling them. Many of the curriculum debates that now go on seek no input from past or present students, research sponsors, or industrial clients. At best, these debates are introspective, at worst, they are theological, and in either case, the model building that goes on is egocentric: the ideal educational output—the ideal student—is one just like me; the ideal course is one like the one I took; the ideal curriculum is just like the one I followed when I attended Prairieview U. If we are ever to get beyond this low level of discussion we must set aside our tendency to use such *just-like-me models* and do a better job of understanding and articulating what our customers do with our outputs.

Measure and improve processes. The fundamental suggestion to reorganize along team lines can and should be augmented by other precepts of the quality movement. An orientation toward *measurement* and *process improvement* will go a long way in this regard, especially if a team-based structure is in place to effectively use the tools. On the other hand, it is easy—especially for engineers—to become enamored with the tools and forget that these innovations are fundamentally about human nature and motivation.

It is also important to choose measures carefully and to keep them simple. Teaching evaluation will remain a difficult nut to crack; however, involving alumni and industrial clients may be one way to cut the Gordian knot. By turning to alumni five to ten years out of school and their employers, it may be possible to get measurements of teaching effectiveness that have stood the test of time and practice, rather than the current short-term measurements that tend to emphasize style over substance and pleasure over rigor.

Privatize portions of the college. It may or may not be possible or desirable to provide education within the discipline of the marketplace, but pilot experiments involving the privatization of some functions of an engineering college deserve attention. Perhaps some staff functions such as maintenance or technical shops can be privatized, serving both the university and private enterprise as well. This suggestion does not stop at staff functions, however, and perhaps some service departments or research functions would benefit from the discipline of the marketplace as well as the opportunity to serve other clients. This step has particular benefits if faculty can become entrepreneurs—shareholders—in the educational enterprises within which they research and teach.

Institute leadership-teamwork training for faculty. If we are going to work on teams, and if we are going to preach teamwork to our students, we had better train faculty in the interpersonal, teamwork, and leadership skills necessary. Although we will still want faculty who can research and publish on their own, at the very least our lone wolves will have to learn to travel in more collaborative packs.

Experiment with a more flexible division of faculty labor. Felder (1994) has recently debunked what he calls the *myth of the superhuman professor.* Simply stated, the myth purports that all tenure-surviving professors are excellent teachers, researchers, and servicepersons. The truth of the matter today is that faculty are largely selected to maximize research capability subject to some very minimal standards of teaching competence. Felder has done a good job delineating the problems with such a system, and has suggested a rigid division of labor where a fixed proportion of faculty would be allowed to be teaching faculty. I agree with these sentiments, but would prefer to see a more flexible system where all faculty be asked to declare their intentions. Do they plan to be primarily researchers, teachers, or a balanced mix? Once they make that declaration, workloads can be assigned, but in all cases a high level of quality output should be expected. To put it in engineering terms, we shouldn't care whether the kinetic energy is translational, rotational, or vibrational as long as useful work is performed, but neither heat nor potential energy should count.

Some will argue that such a system opens the door to more *deadwood*, faculty who invest only minimal efforts following their receipt of tenure—and it wouldn't be the first scoundrel that hid behind the mantle of "teaching professor." But the proposed system should reduce, not encourage, deadwood, because it will *call their bluff.* If someone claims to be a teaching professor, and meets standards of excellence by (1) teaching a voluntary overload, (2) piloting difficult courses and laboratories, (3) working with student groups, (4) publishing innovative textbooks, teaching materials, and software, (5) writing instructional guides and papers on education, or (6) seeking funding for new educational programs and initiatives, why should such a person be denied a valued place on our faculties? If what the faculty member means instead is that he or she would like to teach the same number of courses as everyone else, attend a few committee meetings, and take long lunch hours, then that faculty member is exposed for what he or she is. By pretending that one size fits all, the present system fiddles at the margins, and encourages the formation of deadwood, because the disincentives against sloth are slight. Systematic division of faculty labor would create benchmarks of excellence in each category, thereby rewarding excellence and uncovering slackers. Modifying unproductive behavior would remain a non-trivial job, but it is certain that the current ostrich-like stance has not worked.

Investigate and build on extant models of faculty professional development. No one would dream of building a medical school without an explicit mechanism to encourage medical professors to keep up with their practice of medicine. If ours is also a real-world profession, its teachers should be encouraged to practice engineering through the invention, design, and manufacture of real products and services. The one-day-a-week consulting rule is supposed to encourage this, but the current reality is that these activities are frowned upon, largely because they take away from research. Faculty design studios, consulting and enterprise incubators, and other on-campus facilities and institutional arrangements that encourage professional practice should be investigated by appealing to other professional models (medicine, law, veterinary medicine, etc.). These activities are at the very least self-supporting, but there is no reason why they couldn't shed general funds that could be used to support instruction and other central activities.

Create relationship-building exercises for faculty. The natives have been kept happy largely through the distribution of monetary rewards. Unfortunately, the new fiscal realities mean there is no money to hand out, that cutbacks may be necessary, and that the natives will be getting increasingly restless. In such an environment it is important that faculty (1) feel a strong affiliation for their institutions and (2) have strong relations with their colleagues. A number of organizational behavior models (Hersey & Blanchard, 1993) emphasize the importance of both *task* and *relationship* toward the creation of a successful, long-term work environment. In many engineering colleges, the system stresses excellence in the research task without stressing the importance of good collegial relations or commitment to a larger good. Rethinking our business and changing measures and incentives to promote quality in all that we do will go a long way toward eliminating the radical individualism of the current system. Focusing explicitly on better collegial relations by encouraging some regular interaction through parties, receptions, focus groups, or seminars may also be of some value.

6.2 Industrial Integration Innovations

Internal reorganization is important if we are to do a better job in the provision of all our services, especially undergraduate education; however, internal reorganization is not enough, and better efforts must be made to integrate with our external clients, particularly industry. These efforts can be discussed at national levels, but to be done right they must be implemented from the bottom up. As industrial suppliers form close, long-term relations with the manufacturers they serve, we too must work to gain the trust of industrial firms that use our services.

Remove barriers. Remove university and college barriers to industry-university cooperation, including (1) the permanent or temporary reduction of institutional overhead on all university-industry educational agreements and (2) the implementation of more straightforward streamlined procedures for achieving umbrella research agreements more quickly.

Contracting or transaction costs are a major barrier to cooperation between different organizations, and many university-industrial activities run aground on the shoals of intellectual property rights. In efforts that are educational in nature it would do universities well to remember that companies are the *sine qua non* of real activities. Getting too greedy or sticky on university or student intellectual property rights is likely to kill the deal and the student is denied a real-world experience. From the industrial organization's point of view, it is important to remember that educational efforts are exactly that. In General Engineering we have had good success in turning out both practical and award-winning student design projects, but one of the costs of participating in education is that sometimes students fail (sometimes companies forget that they don't always bat 1,000).

When the agreement is more research oriented than educational, industrial concerns and universities should expect to negotiate more vigorously, and a fuller recuperation of costs by the university should be expected. A recent report (Lu, 1994) has turned to the German model of university-industry cooperation for some direction, and perhaps the legal and organizational details of these schemes deserve closer benchmarking.

Encourage integration of curriculum, placement, and problem solving. Real-world experiences like GE 242 provide working models of working industry-college integration, but these models do not go far enough. As I've suggested, placement, course development, and problem-solving (industrial research) activities are being integrated so that companies hire students for summer internships, the same students go on to work on design projects (paid for and supported by industry), and the students go on to take courses that are influenced by faculty-industry interaction (and funding). This level of integration is similar to efforts that are going on in industry to integrate manufacturers and suppliers.

6.3 Delivery and Programmatic Innovations

We are partially in our present predicament because technology continues to make the world a smaller place. We must better adapt to that technology, but we must remember that perhaps a larger portion of the problem comes from not possessing a shared vision about the nature of the engineering profession. Ours is a profession that works at the margins of a number of purer disciplines. Elsewhere (Goldberg, in press) I have called engineering the *gloriously marginal profession*, and we must do a better job articulating its many facets to our students. This section discusses innovations in both the delivery of our programs and the programs themselves.

Build bandwidth in addition to buildings. A number of engineering colleges have recognized the telecommunications boom and are expanding their multimedia facilities to accomodate it. There are many challenges to fully exploiting these technologies. Key among these is that the cool medium of television does not fill the basic human need for the warmth of direct contact with another. The most successful efforts will be those that recognize this and provide periodic interaction with an onsite lab or discussion instructor.

At a different level, this technology challenges organizations to find different ways of sharing resources or even merging together. The economies of scale in the "Ted Turner" scenario are open to our institutions if we choose to exploit them. Such integration will not be easy, however, and there will be resistance to the downsizing implicit in such economy.

Fortify life skill training for engineering students. The teaching of the human and professional dimension of engineering is a second-class citizen to the teaching of more technical topics. This is a mistake. We need to do a better job covering practical life and professional skills such as writing, presenting, human relations, time management, career management, teamwork, and leadership (Goldberg, in press). Large numbers of course hours are not needed, but effective teaching and learning, concentrating on key principles, are. In General Engineering, the traditional loci for discussing and exercising these topics have been our one-hour, senior seminar and the senior design project, but a good portion of this information would be helpful earlier in the curriculum, and we are moving a number of the topics to the freshman introduction course.

Establish positions in human behavior within engineering colleges. In 1993, a remarkable chair was created at the University of Illinois. Funded by a gift from Robert L. Severns, former President of Sierra Chemical Company, the William H. Severns Chair in Human Behavior was established to promote a better understanding of the human side of the engineering profession among our undergraduate students. After a nationwide search, the first holder of the chair is Pete DeLisle, a former leader of human resource development at Hewlett-Packard, the founding vice-president of human resources at Convex Computer, and most recently a trainer at the Center for Creative Leadership. Although not an engineer, Pete brings a remarkable set of skills and knowledge in working with engineers and their firms. In a short time he has had a remarkable impact, with students voluntarily flocking to his lectures and hands-on exercises to learn about a range of career, human relations, team building, and leadership issues. Although the chair is housed in Mechanical Engineering, its mandate is college-wide. For example, in General Engineering his material has been woven into both our freshman introduction course and senior seminar. Although the evidence at present is anecdotal, the Severns Chair is serving a critical role in bridging to the human side of engineering work, and other universities might do well to consider similar positions.

Develop new positions in the history and the philosophy of engineering. There are examples of engineering colleges where history and philosophy have found their way into the curriculum—Stanford's Department of Values, Technology, Science and Society comes to mind—but such efforts are not widespread, nor is it clear that they should be set apart from the mainstream in a separate department. If we are to proceed with self-confidence in our profession we must know where we've been and what we do.

The inclusion of historians and a philosophers as part of our colleges will give us a means of exploring and understanding the history and philosophy of our profession. The model of placing a non-engineer among engineers can work well if it is made clear that the individual has a mandate that goes beyond departmental lines. In addition, the growing experience with the Severns chair suggests that it is important to integrate the needed material into required courses rather than isolating it in electives.

7 A Cautionary Note

As we embark on large-scale reform, we must learn from the lessons of history. If we don't, we risk making substantial errors of omission and commission with the latter being the most offensive, because what was once done effectively is often changed for the worse. This sounds obvious enough, but avoiding the ill effects of educational reform is no easy task; complex social systems like education are characterized by their *interconnectedness* and *multifaceted* nature (Senge, 1990). Where reform is undertaken it is usually directed at a small number of facets, and implicit in the effort is the hope that it will remain localized to the particular facets under consideration. Unfortunately, the strong interconnectedness of the system rarely permits realization of these hopes. Although the facet under reform may improve in some narrow sense, other facets change for the worse, and as a result the reformed system is left worse off. Economists call this the *law of unintended consequences*, and Hazlitt (1979) gives a very readable account of many examples of its workings, but clearly the law is not welcome to a reformer's ears. If reform is thwarted by the very nature of the system being reformed, policy making sounds like a dicey line of work.

There is a way out of this apparent dilemma, and it comes from (1) better understanding how distributed systems should be reformed, and (2) better understanding of the kinds of knowledge that are contained in such systems. In competitive systems, change is most safely implemented at the lowest level possible, because competition will test the changes and they will be imitated if they are effective (Goldberg, 1989). If changes are promulgated centrally, they will not be tested competitively and will thus destroy the diversity within the population. In this essay, I have been careful to recommend such *bottom-up reform*. A portion of what needs undoing now is the direct result of errors made through centralized planning; decentralized implementation and competitively testing go a long way toward limiting the severity and quantity of errors that will be made in the future.

But competition and decentralization are not enough, because there is a difficulty of *time scales*. Complex systems respond at many time scales, and sometimes the short-term response can be a poor predictor of long-term response. To make matters worse, the focus of reform is often the fastest responding facet, with the harmful side effects responding more slowly. There is therefore a tendency, even in competitive, bottom-up reform, to see one's theories confirmed by the short-term evidence even though the system has not had enough time to reveal the full consequences of the decision. Although there is no ironclad way around this difficulty, a better understanding of the kinds of knowledge that are most likely to be lost is helpful in placing some useful constraints on reform efforts.

Sowell (1980) makes the key distinction between knowledge that is easily *articulated* and that which is not. As academics, we largely traffic in the articulated kind and tend to dismiss the other. This is a mistake and our profession has paid for it dearly. For example, the ongoing debate between design and analysis is largely a debate between unarticulated and articulated knowledge. Analysis courses are easy to teach because they have well-defined principles, procedures, and exercises, and design courses are difficult because they do not. Another case can be seen in the removal of engineering graphics courses from the engineering canon since the war (Ferguson, 1992; Goldberg, 1993), because the material was was hard to justify (hard to articulate) as compared to the engineering science and analysis courses that replaced it. We now face proposals for field theory courses in lieu of the traditional mechanics sequence, because the former can be argued on scientific grounds and the illogic, overlap, and incessant workload of the latter is hard to rationalize (is difficult to articulate). Of course, difficulty in articulation does not imply inferiority, however. In the last example, if we recognize that putting statics before dynamics, and strength of materials solutions before elasticity solutions implicitly teaches engineers *economy in modeling*, we can start to understand that there may be sophisticated reasons why our curriculum has evolved as it has even though these reasons may be hard to explain in words.

As a result, as we move toward reform, we need to do a better job of looking at not just the facets undergoing reform but those that may be affected by it. We need to pay attention to the gut feelings we have that are hard to articulate, try to give them voice, but sometimes listen to them even when we cannot. We need to pay attention to the consequences of our changes, look and listen for the slightest hints of their effects, and be ready to admit that we were wrong and return to what worked in days gone by.

8 Conclusions

This essay has assembled a framework for change in engineering education by examining the factors that augur change, the mindset that resists change, and the appropriate foci for the changes. Specifically, I have viewed change as having been been brought on by direct economic competition coupled with the new telecommunications technology. I have viewed resistance to change as a mindset that has overemphasized the ideals of science in the minds of the instructors of future engineers. I have suggested changes in the way we organize our efforts, in the way we integrate those efforts with the users of our products and services, and in the actual services we deliver and their means of delivery.

There will be some who feel I have overstated the case, but I believe the risks of inaction exceed the costs of greater vigilance and innovation. I have also argued that if change can be made in a more principled way—by implementing changes from the bottom up and by giving the benefit of the doubt to knowledge and processes whose wisdom is less easy to articulate—that deleterious effects of changes can be minimized.

If we move in these directions and pilot programs along these lines, the traditional strengths of American engineering education—our students, our faculty, and our rich history of excellence—will keep us strong and prosperous. If we don't there is the very real risk that others will seize the moment while we remain committed to paths of past glory.

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