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Why The Best Engineers Should Study Humanities

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There is a widespread and, I believe, quite accurate impression that television programs such as *LA Law*, *Dynasty* and *Dallas* contributed enormously to the high esteem in which the public holds the professions of law and finance. These programs provided efficient (though inadvertant) advertising for occupations whose contributions to society, important though they are, are surely no greater than the contributions of teachers, accountants, bankers, judges, manufacturers and, of course, engineers. When facing the persistent announcements of declining enrollment in science and engineering programs and the shortage of skilled engineers in the advanced disciplines, professors of engineering sometimes bemoan the absence of a TV program wistfully christened *The LA Engineer*.

How such a program would fare in the popularity ratings is a matter of concern only to TV producers and advertising agencies. My concern is that educators in the engineering professions are throwing away an inestimably valuable blue-chip advertising opportunity by passing in silence over the ubiquitous, epoch-making, mind-forming contributions of engineering to the development of world civilization. We educators of young engineers must instill in the minds of our students an appreciation for the impact of engineering on world history. But more than that, we must prepare them to compete and succeed in the complex and subtle social and institutional (as opposed to technological) environment which they will face in their careers outside the university.

There is no doubt that the good engineer must first and foremost be good at engineering. He must have a solid background in science and mathematics and he must master a range of technological subjects related to his discipline. But the engineer must operate in a world which *uses* technology, but which neither understands it nor behaves and develops according to patterns familiar to the scientifically trained mind.

Three ideas underlie the societal challenges which face the engineer. First, technology influences individuals, society, and the course of history. Second, and conversely, the development of technology is influenced by the cultural and intellectual milieu. This mutual influence is not a quantitative mechanistic cause-and-effect, like the gravitational interaction of masses. Social interactions are governed by personal and collective will, by the psychology of individuals and groups, by all the subtlety and deviousness of the human mind. While these first two ideas emphasize the bilateral *interaction* between technology and society, the third idea stresses that the *development* of technology is part of the broader development of ideas, attitudes and activities which give any civilization its vital character of growth and change.

To see why engineers should devote some portion of their precious university years to those disciplines whose goal is to understand the human experience, let us consider some practical implications of these three ideas for the engineer.

The fruits of engineering influence individuals, society and the course of history.

The obvious impact of technology on history need not be stressed. Since the age of *Australopithicus,* Man the Tool Maker has fashioned artefacts which enhance his security and comfort. But another type of impact of technology on civilization is far less obvious: the impact on how people think.

An example will make the point. Prof. Landes has explained with great elegance how mechanical clocks emerged in response to societal needs. Early mechanical clocks summoned the faithful to

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prayer in medieval monastaries. But technological innovations may be used for generations without anyone realizing their full implications, and so it was with the clock. The long-range influence of the mechanical clock on western civilization was the idea of "*time discipline* as opposed to *time obedience.* One can ... use public clocks to summon people for one purpose or another; but that is not punctuality. Punctuality comes from within, not from without. It is the mechanical clock that made possible, for better or for worse, a civilization attentive to the passage of time, hence to productivity and performance." [1, p.7]

It is from an appreciation of the subtle impact of technological innovation on the development of civilization that we appreciate the full extent of the engineer's dual responsibility. On the one hand, the technologist is a leader of society, forging a path to a better life. On the other hand, the engineer must protect or at least warn society against adverse developments. Prophets are rather rare these days, and no innovator can be held responsible for unforeseeable consequences. But it *is* the responsibility of the engineering community to collaborate in a broad and penetrating attempt to understand whither our innovations are taking us. We the engineers can shoulder this responsibility only if we have a thorough understanding of how societies change.

Let us briefly examine our own times as an example of the critical role of technical expertise in understanding the destiny which we ourselves, and especially the engineers among us, are shaping. The economic and social scene in England changed markedly some two centuries ago, with the advent of urban concentration of production, the commoditization of labor, the development of increasingly hierarchical specialization of labor, and the emergence of capital accumulation as a primary economic motive force. These and other changes characterize what we have come to call the industrial revolution, which was rooted in an intimate interaction between new technologies and new social concepts and mores. These characteristics are still with us, but in greatly altered form. It seems that perhaps capital — the abstract distillation of the means of production — is no longer the sole central axis of our industrial civilization. Rather, intellectual property, or more simply, information — the distilled basis of decision and control — is fast becoming the hard currency of success, power and economic growth. Though this is no more than a vague conjecture and may be far off the mark, some evidence for it lies in the vast monopolistic economic rents which accrue to technological innovation. What is certain is that much thought by the best qualified minds is demanded in order to anticipate anything at all of where these new winds are taking us. No projection of the course of civilization can be taken seriously unless it invokes the most careful analysis of technical realities and possibilities, and no one is more qualified for that task than the technological community.

But we needn't look only on the grand scale of the development of world civilization. Genetic engineering, ozone depletion, urban smog, nearly undepletable fusion energy, space travel, information highways and many other new technologies all present diverse and confusing challenges to existing values and lifestyles. On the most prosaic level, an engineer responsible for safety-related design decisions must make social choices for which purely technical training does not equip him. The issue is not ethical virtue or professional competence. The issue is the inextricable intertwining of social values in the development and consequences of technology.

Who can take up this challenge if the world's best technological universities are delinquent in their responsibility for educating their best students to confront the social implications of technology?

Engineers are influenced by the
cultural and intellectual context within which they work.

This idea has two manifestations in the working life of an engineer. First, innovation is bounded not only by the *possible,* but also by the *conceivable.* To the extent that design skills can be taught (and good engineering schools spend considerable resources to teach design), it requires instilling attitudes and methods for breaking out of preconceptions. The second implication is that innovation is bounded by social institutions.

The easiest example of the controlling effect of social institutions is legal limitation. The pre-industrial craft guilds imposed severe penalties for abandoning traditional products or methods of manufacture. For instance, after several dozen button manufacturers were executed for having deviated from time-honored forms of the trade, innovative button makers were probably hard to find for a while. A more modern (and more encouraging) example of the impact of institutions on technology is the growth, during the latter half of the 19th century, of formal engineering curricula based on sound scientific principles. Or, the more recent prevalent financial support by governments for technological research and development. Or, the growth of vast R & D establishments belonging to large hi-tech companies. Or, ...

It is the ambition of every technological entrepreneur to fill in those dots, and this requires much more than even a very good technological innovation. It calls for insight into organizing and promoting a techno-economic venture. It requires innovative exploitation of existing structures as well as modification when resources allow it or necessity requires it. The modes of production evolve over time, not only in the broad sweep of civilization as exemplified by the decline of feudalism or the emergence of industrialism. New techniques of social organization for the promotion of technological ventures are witnessed also on smaller scales. For example, the internationalization of commerce is a recent entry, and of profound importance for the success of any technological enterprise. Another example is the emergence of technological "incubators" in association with universities for nurturing promising ideas.

But why, it might be asked, should engineers concern themselves with what looks like "mere" economics or business management? We are nothing if we are not specialists, so some specialists advocate leaving these problems to other specialists.

One answer is simply that many potential engineering students seek an entry to the world of technological entrepreneurship. And these students are right when they suppose that the technically trained decision-maker will have a strategic advantage in the market place. Hi-tech business today deals not so much in physical objects as in intellectual property. The planner, developer or investor who understands *both* technology *and* its social potentials and limitations has a comprehensive handle on the challenge he faces.

But the challenge of cultural milieu is not only about economics and the organization of production. We must return to the first manifestation of the thesis we are considering: innovation is bounded by the *conceivable* as well as by the *possible.* The moral and social values of the innovator directly influence the solutions he will find. In the early 17th century, when England urgently sought a solution to the problem of navigation on the high seas for both commercial and military purposes, Newton provided the best answer he could think of: computations based on advanced celestial mechanics. The more mundane and "terrestrial" (and ultimately more successful) solution, based on technical improvements in clock manufacture, was beyond the pale of acceptability for Newton, to whom the handicrafts were lowly and despised occupations.

Training the engineer to think scientifically was the last great advance in engineering education, initiated in the 19th century. Science is now rightfully and fruitfully ensconced in the engineering curriculum. We must now establish a new equilibrium and prepare engineers for success in the market place. In addition, we must teach them not only to think scientifically, but to think with a methodical creativity which transcends the customs and attitudes of their peers and predecessors. It is the greatest ambition of the educator to teach creativity, and it is not fatuous, for it is characteristic of the exceptional human mind to seek new ideas. There are many catalysts for inventiveness, and one is the awareness of the full range of ones' preconceptions. It is not only the axioms of functional analysis or of quantum mechanics which make up our preconceptions. To stretch beyond ourselves we must also know who we are as a civilization.

The development of technology is part of the cultural development of ideas, attitudes and activities.

We began this essay with a discussion of the need for improving the prestige of the engineering profession. The importance of engineering needn't be 'sold' in over-dramatized themes like 'Science at War' or 'Engineering in the Service of Mankind'. On the contrary, the subtle and intellectually sophisticated interplay between science, technology, and man's understanding of nature and of himself draws the student to the highest levels of abstract thought. And on the other hand, the concrete role of technology in the pursuit as well as perversion of the noble ideals of society in all ages need not be skirted in favor of purely abstract analysis. The combined effect — theory and practice, abstraction and realization — portrays the grandest mission and ambition of the engineering professions. This mission must surely stir the imagination and enthusiasm of young and searching minds.

But the thesis that technological development is part of the broad growth of ideas has a further lesson for the leaders of engineering innovation. This lesson lies in comparing the concept of scholarship against the nature of the research and development which characterizes the forefront of advanced engineering.

R & D is a progressive concept: it emphasizes front line and state-of-the-art expertise. It strives to be up to date, to grow in a continual progression of improvements. R & D shuns the old idea against the new and untried, in a continual struggle to push back the boundary of the impossible.

The modern concept of R & D is a noble ideal with, however, one rather sensitive failing: its memory is very short. In the enthusiasm to conquer the next barrier, in the flush and flow of effort on an enormous scale, the tendency is strong to leave behind the subtleties of earlier thought. "Scholarship", wrote Thorstein Veblen is "an intimate and systematic familiarity with past cultural achievements." [2]. The best innovators are those whose professional profile is broad and deep, who understand the complexities and challenges which troubled the greatest contributors to their discipline. But these fine points are thoroughly filtered out by the progressive textbook tradition of engineering education. The ideology of modern R & D claims that what troubled Archimedes or Leonardo, Watt or Babbage, need not trouble us; we have advanced far beyond their level.

But would it not be incalculably valuable to sit James Watt down in front of the plans for a modern nuclear power plant and get his considered assessment? It's not his 'tricks of the trade' that we would ask of him, but his approach to the problem, his hunch on promising directions, his worries about where real difficulties lie. Searching the past masters, that is scholarship, and we've lost the scent for that aspect of learning. Is there really nothing in Rayleigh's *Theory of Sound* [3] for vibration engineers to learn? Do Charles Babbage's reflections on "memory and foresight" by machines in *The Principles and Development of the Calculator* [4] have nothing of interest to the computer scientist? Are we so confident, in the rush to solve current and ever-changing problems, that no insight or understanding has been lost in the chain of textbook learning which underlies engineering education?

We will probably never know, since today such questions are left to the historians of science and technology, who are the last ones to whom the engineers would ever listen. The technological community itself must regain a scholarly attitude to the accumulation of knowledge and understanding relevant to the advance of our mastery over nature. No one will or can do it for us.

There is yet another implication of the contention that technological innovation is part of the growth of civilization. We are concerned again with the process of innovation itself.

The analysis and design of technological systems employs engineering theories. Some are broad physical theories, like elasticity or thermodynamics. Some are general analytical tools like theories for optimization or control. Others are more specific physical models like linear fracture mechanics or tribological models of wear. Others are specific conceptual devices like least-squares estimation.

Innovation in scientific engineering is sometimes expressed as the development of a new model or theory. This was certainly true of the parallel development of modern powered flight together with the aerodynamic theory of airfoils. What are the characteristics of theories in applied engineering science? What patterns can be followed in developing new theories? How do we know when a new theory is needed? How do we compare and choose between alternative theories? How are engineering theories tested? How are they disseminated? Nurturing an awareness of these processes and questions, and of some plausible answers, is important in the training of engineering researchers.

One of the reasons for the historical perseverence of technology is that virtually any constellation of concepts and devices, no matter how primitive, can provide *some* answer to the challenges which worry us. Our textbook tradition makes the great strides in engineering science seem smooth and logical, but the reality at the cusp of innovation is much different. It is rarely obvious that the innovator must seek a fundamentally new concept, because the old tools worked in the past. Students study many theories in their course work, usually from the problem-solving perspective: use a theory first to understand a phenomenon, and then to avoid or exploit it. Studying the intellectual history of science and technology is essential for appreciating that models and theories must sometimes be abandoned, and for understanding how new models and theories emerge.

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So why should the best engineers study humanities? Because it will make them better engineers, more responsible, more creative and effective. I have said nothing about which engineers, at what stages of their education, should turn their attention to these matters, nor have I said anything about what exactly they should study. These are the hard questions, and they await our attention.

References

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