What's Happening to Engineering Education

by Frederick C. Lindvall

With the space age rapidly emerging from science fiction into reality a new dimension is being added to technology. No longer are we constrained to move and to think within the thin confines of our earth's atmosphere. Space has become the new frontier. Space ships and space islands intrigue the imagination and challenge our inventive genius. At the same time we find ourselves ignorant of much basic information on which to build ideas and to design their engineering embodiment. We lack materials, energy sources and guidance systems to carry us beyond the limited capabilities of current missile developments. We must expand the engineering system concept—and with it our techniques of analysis and synthesis—far beyond our present skills, because space is not merely a new dimension; it is a wholly new environment for man and his machines.

Progress into the wild blue yonder will be slow, frustrating and expensive. The utility of such enterprise is certain to be questioned at every turn, and every effort will be challenged on economic, moral and even religious grounds. Nonetheless, man with his insatiable curiosity and indomitable urge to conquer the unknown will ultimately break the technical bonds which tie him to earth and will project himself into outer space. Some rocket experts predict this dramatic moment as soon as fifteen years hence!

But before the first adventuresome spacemen batten the hatches of their ship and take off for a trial run, step by step explorations will be made. More and more elaborate satellites will be put in orbit to give us scientific data on the environment in increasing detail. Sounding rockets will probe to greater and greater distances beyond the point of no return, telemetering back results of physical and biological measurement and experiment.

Engineering problems of unique character and complexity will challenge the best of our abilities, and collaboration with scientists and specialists in aviation medicine will dramatically expand engineering interests and influence.

New knowledge, instrumentation and materials will flow from such work, and engineering imagination will quickly direct them into novel applications and devices useful for more mundane purposes. In short, the engineer has a key role to play in this dawning age of space.

An exciting field which challenges engineering education is that of computers and their application. Let us examine the implications of this challenge in some detail. As an example, we are being urged to offer courses in computer fundamentals, logic, design, components, applications and use—not to speak of complete curricula leading to degrees in computer engineering.

Some schools have strong research interests in modern computing and may be justified in offering such instruction. At the same time, other customers for our graduates give equally convincing arguments for more or less specialized instruction in, for example, control systems, instrumentation, automation, system engineering, operations research, nuclear engineering and information theory. Needless to say, we are somewhat confused and bothered beyond mere professorial petulance over these challenges to comfortable academic routines.

Formal instruction pertinent to computing can have specific as well as general aspects. Of general character are computer fundamentals, including logical design; applied mathematics that incorporates a new philosophy and approach to problem formulation for computer solution; related mathematics, such as Boolean algebra, probability and statistics, group theory, matrix algebra; and a mathematics "laboratory" for numerical methods, iteration procedures and relaxation methods.

Engineering education is being pulled into new and different directions. Shall we concentrate on fundamental education or go in the direction of specialized training?

More specific instruction could include computer circuitry, components, storage devices, input and output systems, programming and coding, laboratory experience, checking routines and trouble shooting. However, from the educational point of view, such instruction should be watched critically lest it be too specific to particular computers, devices, and those systems subject to a high rate of technological obsolescence. The significant generalizations can easily be obscured in such instruction by a horde of details which may be only of transient value in the hustling computer art.

The computer's challenge to engineering education is properly in the area of fundamentals. Fortunately, some of the significant basic factors implicit in modern computation underlie other developments in engineering science as well. Probability and statistics, general concepts of reliability and generalizations from information theory, for example, permeate modern engineering—particularly instrumentation and control.

Systems study, as contrasted with component study, is the coming approach to involved engineering problems. Computers or simulators of varying degrees of sophistication are likely to be parts of such systems. The science of decision-making may eventually become a recognized engineering science taught in the colleges, implemented by the power of high-speed computing, analysis and synthesis. Engineering cybernetics (the more generalized aspects of servos and control) also leans heavily on concepts that are basic in modern computation.

The implications of high-speed computing in our classical engineering science subjects are a bit frightening. For example, structural design, whether applied to bridges and buildings or to aircraft, could be completely different in approach if high-speed computing were generally available. Rapid iterative methods, optimization procedures, and even incorporation of nonlinear properties would give an engineer freedom to explore new design concepts.

Engineering economy could be greatly extended in scope by computers, in that alternative choices could be examined quickly and tested for the effect of many parameters. In short, the whole approach to a physical problem may be different if high-speed computing is available. The problem formulation would be derived directly from basic physics into machine terms, without necessarily going through a mathematical formulation. We would then be less inclined to warp the physical system into formal mathematics which we can solve. This would be particularly true if nonlinearities are involved—and most of nature is nonlinear!

Students will become aware of these new horizons in basic thinking which modern computing suggests. However, the great new day is only dawning and we will fumble along for quite a while with analyses and techniques that later may be displaced. Existing methods of engineering will apply indefinitely to thousands of unglamorous but essential problems, and these the students must be prepared to solve realistically. So our education in engineering won't suddenly be coded and programmed for the computer art, but it will eventually include the fundamental subjects that are pertinent and will develop those broader methods of analyses and thinking that computers will make possible. We welcome the computers with their challenges, but we are not quite ready to throw away our slide rules!

Reliability is another new factor which has come to represent an important quality of equipment and its performance. This quality is rapidly assuming an almost paramount importance in many systems. The simple and innocent-sounding reliability criterion presents some extremely difficult problems—first, of stating sensibly the expected reliability, and, second, the synthesis of the system to achieve it. Some of the methods of analysis and synthesis resemble those of information theory. Statistical methods have their place, also, in determining a degree of confidence that a given system will perform as desired.

Some engineers, whose work in weapons systems and missiles has made them acutely conscious of the importance of reliability, believe that there is a new field of analysis and synthesis to be developed under this term "reliability." This new field involves concepts and methods of thinking which are now only vaguely understood. Here, again, for its educational implications, "reliability" appears not as a likely subject for a course in itself, but rather as a pervading idea which threads through many aspects of our engineering analysis and design.

Reliability, of course, is not a new thought, but the problems of missile guidance and control give it a prominence of first magnitude. Similarly, other engineering features of design, production and performance are brought into sharper focus for space age vehicles than for less exotic devices and applications.

Technical sophistication

Nonetheless, these new problems are catching up with us in many other areas as we seek improved performance, greater efficiencies and extended applications at higher levels of technical sophistication. We must design uncomfortably close to ultimate limits in many instances, but we can do so with more assurance because of better instrumentation, more knowledge of material properties and refined design methods.

Nuclear energy is another vital subject of great engineering significance which can pull engineering education into still different directions, with exciting new details to stimulate the student. The fact of radiation itself introduces unique problems which complicate the application of older principles of analysis, design, materials and heat transfer. Some schools have responded with nuclear reactor engineering curricula, but others have taken the position that, because nuclear reactors are specialized devices which involve so many engineering fundamentals common to other applications, only a few substitutes are required rather than a separate curriculum.

In the colleges we cannot, and, I believe, should not attempt to meet these challenges by detailed specialization in all the areas of current interest and importance. We must, instead, do the more difficult job of examining each new development for those features that are truly basic, extracting the concepts that are new and fundamental, and synthesizing the important generalizations that have lasting value. This exercise of self-discipline, of sticking to fundamentals, is not easy. The other way—that of following avidly in the classroom the exciting new developments, the intriguing applications, and the fascinating new details—is more fun, has high entertainment value for the student, and is an easy, pleasant way to teach. But it has the elements of a phony gold brick—the superficial appeal and the form, but little substance—and the values in such instruction are apt to be transient.

Thus engineering colleges must evaluate critically the fundamental character of these new advances so that curricula and course content of the basic sciences and engineering sciences may be improved to serve better as fundamental education for future professional application. We must always be critical of that instruction which is specialized training rather than comprehensive education.

On this point Alfred North Whitehead, the mathematician and philosopher, has some apt remarks. "A well-planned University course," he says in *The Aims of Education*, "is a study of the wide sweep of generality. I do not mean that it should be abstract in the sense of divorce from concrete fact, but that concrete fact should be studied as illustrating the scope of general ideas.

"This is the aspect of University training in which theoretical interest and practical utility coincide. Whatsoever be the detail with which you cram your student, the chance of his meeting in after-life exactly that detail is almost infinitesimal; and if he does meet it, he will probably have forgotten what you taught him about it. The really useful training yields a comprehension of a few general principles with a thorough grounding in the way they apply to a variety of concrete details. In subsequent practice the men will have forgotten your particular details; but they will remember by an unconscious common sense how to apply principles to immediate circumstances."

Key to success

To these remarks of Whitehead, I should like to add that, from an engineering point of view, the ability to apply fundamentals to new situations is the key to successful professional practice. As a corollary, versatility, or the skill in moving from one field of technology to another, marks the outstanding practitioner, and, in fact, such ability is virtually a test of understanding of the fundamentals.

These ideas should sound familiar to alumni of Caltech, where fundamental education rather than specialized training has been the objective for many years. Caltech can also take pride in its leadership in recognizing early the importance of the humanities as a vital part of science and engineering education. Now all engineering schools include some, and seek to add more of history, English and social science by displacing so-called professional subject matter. But this change is not coming easily and as someone has said wisely, "Reorganizing an academic curriculum is like trying to move a graveyard."

This trend toward breadth is now well accepted and moving ahead. At the same time (even before our recent dramatic satellites) engineering has been challenged in many areas—some military, some civilian—to new achievement in research, design, and production. Many of these areas involve materials, techniques and methods not presented in text books or even in public discussion.

A sampling of the advertising in professional journals, alumni magazines and college publications gives a feeling for this climate of modern engineering in phrases such as, "A career that requires creative thinking, utilizes all your skills and talents, offers the chance to learn the latest techniques" . . . "Want to grab the atom by the tail and put it to useful work?" . . . "Want to dig in and really get down to the basics?" . . . "Start today and plan tomorrow" . . . "Up to two years of theoretical and practical training are offered" . . . "You will push beyond existing limitations into new concepts and new products" . . . "Today more and more new ideas come from men trained to an awareness of that which is yet to be accomplished" . . . "The door to electronic wonders is only slightly ajar. The greatest discoveries lie ahead."

The emphasis is on the new, the undiscovered ideas, devices and systems. Creative thinking is an ideal eagerly sought and carefully nourished. Advanced ideas and methods intensify the need for a basic engineering education which has extensive scope and depth in the fundamental sciences and the engineering sciences. This basic education is a foundation for professional work to be learned in practice, and for graduate study which is becoming increasingly a necessity.

An initial degree

Admittedly, a four year curriculum with this orientation must omit some of the engineering details which we have all been accustomed to present in our teaching, and which have some immediate value to the young graduate if he happens to fall into work in the general area he has studied. But if our engineers of the future are to be identified with the highest levels of effort in technology, the advanced designs and the new materials and processes, we must accept the fact that a Bachelor's degree program is insufficient for the highest level of professional engineering practice. In the same way, our colleagues in physics and chemistry expect the Bachelor's degree to be an initial rather than a terminal degree.

We are all well aware of the fact that during the war many scientists distinguished themselves in work which was quite foreign to their professional experience, and which they regarded as essentially engineering in character—but a type of engineering which had never been studied before. In fact this experience has led to a certain arrogance among some scientists with respect to the competence of engineers. However, this invidious comparison overlooks the fact that at the time of World War II very few engineers had had graduate education, and even fewer held the Doctorate degree—whereas these useful scientists were, for the most part, exceptionally able people who were also PhD's. Their additional education, together with maturity and research experience, was of great value, but most important of all, it was sufficiently fundamental and general to be applicable to new situations and new developments.

Such strength should also mark the education of our best engineers so that they may function truly as engineers in advanced development, synthesis and design, with no handicap of a shallow base of fundamentals or weakness in analysis. Obviously, not all engineers will work at this high level, but their basic education should not exclude them from the opportunity. Indeed, the opportunities and challenges are unlimited in all areas of technology. The space age with its "new dimensions" clearly dramatizes the future for us and for the public, and establishes a favorable climate and receptive attitude which will be of enormous help in our efforts to strengthen engineering education.

Teacher shortage

It is in the achievement of this improvement that we are in most serious difficulty. We have not enough competent teachers in our engineering colleges to meet the needs of increased enrollment and higher quality of instruction. Evidently, with more graduate work there will be a greater demand for more teachers with advanced degrees.

The Caltech staff in engineering, with its very high proportion of Doctorates, is far from typical, and throughout the country a large number of advanced degree men ought to enter the teaching profession. A special study for the American Society for Engineering Education by its Committee for the Development of Engineering Faculties reveals that during the next ten years, due to the normal growth of engineering student enrollment, faculty retirements, loss to industry and for other reasons, about 9500 new teachers of engineering will be needed, or some 1000 per year.

Last year a national total of 590 PhD degrees in engineering was reported. A few of these new PhD's entered teaching, but if all of them had done so the number would still have been too small. Next year will not be significantly better.

Thus our problem is, first, to encourage more of the best students to enter graduate school to prepare for careers in engineering teaching and research; second, to make a teaching career as attractive as possible, with reasonable pay and good basic research opportunities; and third, to do everything possible to assist existing engineering faculties to develop professionally in new technological directions and improve in effectiveness in their teaching. For it is only from superior teachers that we can expect to obtain superior graduates. There is no substitute for quality, and it is the improvement of quality that is now pertinent in engineering education.

I earnestly hope that Caltech can make a conspicuous national contribution to this strengthening of engineering education—not only by example, but as an important source of teachers of high quality.