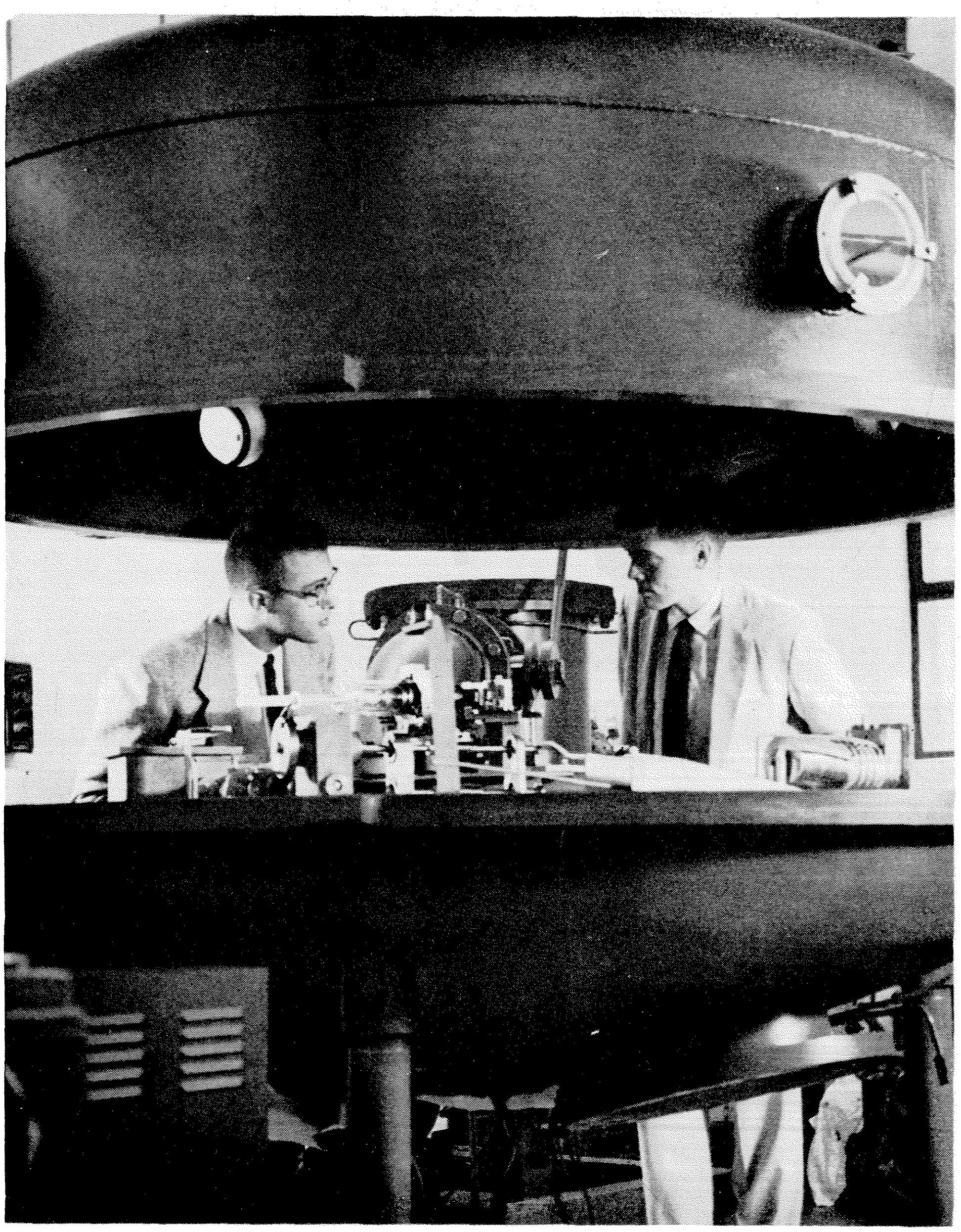

"We need public understanding of the role of the engineer and the place of the engineering function as a part of the technological process."

by
Frederick C. Lindvall

The Vanishing Engineer

The engineer, although he has been with us as a useful and productive member of society for 2,000 years, now suddenly seems to be vanishing from current popular literature.

In the Pasadena *Star-News* of February 24, 1960, a story begins: "Pasadena's foremost space scientist told a Washington committee . . ." After identifying the scientist as Dr. William H. Pickering, director of Caltech's Jet Propulsion Laboratory, the story quotes him as saying that the new NASA space program "represents bold and imaginative thinking based on solid engineering analysis." Dr. Pickering, for over 20 years a member of the electrical engineering faculty at Caltech, can and does identify that which is clearly engineering in the program. This example is typical of the loose public identification of technical developments as science. Indeed, so broadly have the terms "science" and "scientists" been applied to current developments that even the public relations staffs of some of our major engineering firms speak glowingly of the latest hot developments of the "scientists" in their laboratories.

Dr. James Killian, about a year ago, stated in a talk he gave in Detroit: "We need to bring more clearly into focus the image of the engineer in the minds of our citizens. Despite all the efforts of our engineering societies and councils, this image is not sharp nor accurate. For example, the lack of any clear distinction between the scientist and engineer has been manifest in all the recent public discussions of our national strength in science and technology. Some of the great engineering accomplishments of our time have come to be loosely tagged, in the public mind, under the generic title of science. This confusion is not in the interest either of science or engineering, and the scientists are as unhappy about the confusion as the engineers. I do not advocate any less emphasis on science and its importance. I do urge a comparable emphasis on the role and importance of the engineer."

Let me also summarize the statement of another engineering college administrator, who expressed a general reaction: He feels strongly that one of the serious problems in getting qualified young people to go into engineering schools is the great stress today on science – "with the almost total omission of painting the role of the engineer in society for the general public. The development of nuclear power, the development of the atomic submarine, the development of satellites are always spoken of as scientific achievements, when, of course, they are major engineering feats." Over the long run, if we are to "draw into engineering education those students who are eminently fitted and who can make major contributions, we have a major educational job to do. This requires a well-conceived and well-executed continuing plan of painting an accurate picture of what the engineer does and the kind of liberal training for a modern technological society which our very best engineering schools provide."

In this last statement lies the serious aspect of the problem of the vanishing engineer. If failure to receive due credit for engineering achievements were the sole reason for concern, this could be put in the "don't-give-it-a-second-thought department." But there is a very real effect of this emphasis on science which reflects itself in the college enrollment in engineering and science.

Shrinkage in engineering interest

At Caltech, where we have a fixed number of students (180) enrolled in the freshman class, the student choice of engineering and of science shows very dramatically the growth in science interest and a rapid shrinkage in engineering interest. In fact, a projection of the engineering enrollment figures leads quickly to the impression of the vanishing undergraduate engineer.

Our freshman class is not segregated as to option. This selection occurs at the end of the freshman year. So let us take a look at the percentage of the sophomore class electing engineering for the past few years. In 1953 and 1954 approximately one-half of the sophomore class chose engineering options. In 1955 the figure was 35%, in 1956 it was 38%, in 1957 it was 27%, and in 1958 it was 21%. At the same time, of course, because of the fixed enrollment, the percentages for science choice have gone up, to maintain a constant total of 100%.

Further examination of the student choices shows some interesting facts. Caltech's freshman class is selected from a much larger number of applicants, usually ranging from 1,200 to 1,500. On the application blank, each student states a career choice which, however, is not a factor in his admission. In 1953, 55% of all of the applicants declared for engineering as a career choice. This percentage held about constant until 1957, which marked a steady decline until, of the 1959 applicants, only 41% declared for engineering.

Engineering choices

This is really a much smaller decline than the actual engineering choices made by those students who were admitted to the Institute. The engineering interest shown by all of the applicants has fallen off a little faster than the national average, but not markedly so. For example, in 1957, engineering freshmen constituted 17.8% of all male freshmen in the nation. In 1958 the figure was 15% and in 1959 it was 13.6%. While freshmen college enrollment of all colleges has been going up, engineering enrollment has been going down in terms of absolute numbers and, of course, in terms of percentage.

Enrollment in other engineering undergraduate classes has also declined, but the full effect of the present shrinkage will not be felt in terms of graduating seniors until 1962 and 1963. At this time the number of engineering graduates per year will be substantially below the figures for 1959 and 1960. During this same period the USSR expects to nearly double the 1958-59 graduation rate of engineers. By all of the estimates made by the Engineering Manpower Commission, the future demand for engineers will increase, while at the same time the rate at which engineering graduates will be entering into the profession will be shrinking. This is a serious professional gap.

If engineering enrollment is dropping because of current glamor attached to the word "science"– is this bad? Can't the science graduates do engineering work? The answer is, of course, that some scientists can do engineering work if they have the interest and motivation for it. And what about the total numbers of scientists as compared with engineers, and the current interests of students who are studying science?

At a number of schools where engineering enrollment has been dropping and science enrollment has been increasing, most of the increase in science has been in physics and mathematics. But even if there are substantial increases in numbers of graduates in science, the contribution to the needs of technology will not be sufficient.

It is interesting to look at some overall figures. We have in the United States, at the present time, approximately 200,000 scientists; about 1/2 are chemists, 1/4 are biologists, 1/8 are in the earth sciences, 1/10 are physicists, and about 1/30 are mathematicians. (These and subsequent figures are from National Science Foundation sources.) Of these 200,000 scientists, approximately 45% or nearly one-half are in educational institutions. In the country we have approximately 600,000 engineers. This figure includes those who are graduated from engineering curricula or who practice engineering in the sense in which I have been using it; it does not include large numbers of people who have adopted the name "Engineer"--as, for example, the Brotherhood of Locomotive Engineers.

Educational background

It is interesting to make a comparison of the educational background of scientists and engineers. Consider the chemists, who represent about one-half of the total scientists. For 5%, formal education stopped before the Bachelor's degree; for 54%, formal education stopped at the Bachelor's degree; 17% earned the Master's degree; and 24% earned the Doctorate. Of the 20,000 physicists, 3% have no degree, 25% have the Bachelor's only, 27% the Master's only, and 45% have the Doctorate degree.

Among the 600,000 engineers, 27% had four years of high school or less, 17% had some college, 40% had four years of college, 14% had five years of college or more. Of this total number of 600,000 engineers, about 12,000, or only 2%, are in academic institutions. Hence, nearly all of the country's engineers are in industry or other professional practice; while, among the much smaller number of scientists, only about one-half are involved in direct contributions to technology. In this context, engineers outnumber scientists about 5 to 1, and outnumber physicists in industry about 50 to 1. So when we read of a new satellite as a great achievement of science, it is reasonable to suppose that a few engineers had something to do with it. Physicists can be useful but there aren't enough of them!

In the broad scope of science and technology which ranges from research through development, test, evaluation, production engineering, manufacturing, application, and marketing, on to ultimate use, some aspect of the engineering function may appear with greater or less emphasis. The role of the scientist working in science is normally in the research area where new discoveries are made, new physical principles identified and generalized, theories evolved, and new physical facts established. When a scientist works beyond this area, toward application or end use, he is not doing science in the normally accepted sense; he is performing functions better described as engineering or applied science. The engineer, in turn, frequently needs basic data or information which does not exist, and works in the laboratory to add to knowledge in precisely the way a scientist would. So it is not what he is called but what he does that is really the distinguishing feature.

And now let's get down to the difficult job of indicating what engineers do. I made some remarks at a symposium at Marquette University last spring entitled "On the Nature of the Engineer." Some of these thoughts may be helpful in this context.

The engineer is known by his works and his objectives. Long before the word "engineer" came into the language, certain men designed and built the structures of the ancient world, the palaces, the temples, fortifications, roads, and bridges. Fertile but arid lands were transformed by the miracle of irrigation into gardens for produce and for pleasure. Cities were made possible by water supplies brought from great distances in primitive aqueducts, and were made livable by development of systems of waste disposal. The early engineer exploited water transport through canals, locks, and stream improvement, and sought to control floods.

Gradually the ingenuity of man devised machines to replace human labor. The early engineer found new materials and new ways of improving old materials. His objective was to adapt nature to the needs and wants of mankind. But as he devised new schemes and new machines, he was also asking the question, "Why?" He was curious and sought to understand the workings of nature not solely for projection to new applications, but as new knowledge itself.

The beginnings of science

In his efforts to understand, we recognize the beginnings of science. Indeed, many of these early investigators whom we now call "scientists" were first of all pragmatic, practical fellows with specific objectives no different from those of engineers. And experimental science, beginning as early as the thirteenth century and flowering in the seventeenth, adopted empirical experimental methods then used by engineers and artisans. Engineering helped to stimulate the rise of modern science in the seventeenth century, and was in turn changed in character by the birth of applied science in the nineteenth.

Now mid-twentieth-century technology is again working at the frontiers of knowledge. Engineers and scientists jointly are seeking new information and as a team are developing new applications. A new engineering development or new instrumentation brings to light unexpected facts which extend our knowledge in corroboration of existing history, or force re-examination of popular hypotheses.

As Francis Bello aptly stated in *Fortune* ("The 1960's: A Forecast of the Technology," January 1959): "The point where technology leaves off and science begins – the distinction between applied and basic research — has become increasingly fuzzy. In the 60's it will become fuzzier yet, for the great research tools that will dominate physical science in the years ahead will be engineering marvels first and research tools second."

The teamwork is so close that a clear identification of the engineering and science functions is difficult, if indeed such identification is significant. Similarly, the nature of the engineer becomes less clear in our most advanced technological developments. He is not the boots-and-breeches engineer of hoary tradition; neither is he the white-coated scientist of Madison Avenue fiction. Is he, in fact, becoming an applied scientist, or does he have distinctive attributes as an engineer? The answer has more than casual significance for engineering as a profession, and profound implications for engineering education.

Education for the age of science

Several years ago the President's Science Advisory Board created a panel to consider problems in science and engineering education. This panel prepared a paper ("Education for the Age of Science") which attempted to define problem areas and propose some recommendations. The scientist, as defined in this paper, is one who seeks to extend the boundaries of knowledge in his chosen field. The engineer has the task of combining the knowledge of science with his knowledge and awareness of the needs and limitations of human beings and of a human society to develop and create new "things" for human use. These things may vary from a tiny transistor to a huge dam, from a hearing aid to a super-highway, an automobile, an airplane, or a space vehicle. While the scientists have uncovered the basic knowledge, it is the engineers who have created the tangible tools, materials, and products that have revolutionized our daily lives, our community living, and our national defense.

The scientist and the engineer form the team that paces today's technology. In science lie the foundations upon which the engineer builds toward a goal of the utility, comfort, and advancement of man. He is concerned with machines, the environment in which they operate, and with the men who work with them and effect their control. He is further distinguished from his colleagues in science in his constant concern to achieve an optimum design to meet the many and frequently conflicting criteria of performance, reliability, efficiency, cost, and productibility. The associated synthesis, analysis and design of an element or a system are unique characteristics of engineering.

The profession of engineering has thus become one of the most important in modern society. Our civilization would deteriorate, would become too weak to survive in modern world competition without the work of the hundreds of thousands of trained men (and the too-few women) who keep the wheels of industry turning, who create new and useful products, who envisage, design, and build great factories, intricate communication, power and transportation systems, and vast irrigation, navigation, and flood-control projects. The scientist and engineer have created for the first time in history a society potentially free from want — one more concerned, in fact, with surplus than with scarcity of many material products, as well as a society in which freedom from back-breaking toil has been largely achieved. Finally, in today's great international competition, America's ability or inability to help others in their engineering progress may be crucial.

In this definition of the engineer I stress the design function, the creative effort, and the objective weighing of alternatives which mark the good engineer and always have. Some 60 years ago A. M. Wellington, an engineer, wrote a book in which he discussed the problems of railway location. To paraphrase Wellington, no matter how forbidding a region, nor how many feasible routes there may be, one route exists which will be superior to all others in overall long-range cost, and it is the essence of good engineering to find that optimum solution. This statement could easily apply to present-day engineering systems, but the details are much more complex and cover a wider range of the physical sciences.

A lively motivation

The engineer has the lively motivation of finding the best solution to a problem, and as time goes on he has at his disposal new tools which allow him to analyze larger problems with more assurance. Analog and digital computers are rapidly becoming important design tools, and it is possible to make synthetic solutions to problems and discover the effects of varying any of the parameters which can affect the end result.

Civil engineering structures, for example, lend themselves well to computer techniques and give the engineer an opportunity to run quickly through several alternative designs to give the one which most nearly meets all of his design objectives. For example, an analysis of a concrete arch dam has recently been made electronically, and the engineers had the satisfaction of varying several important boundary conditions and constraints — a change in any one of which would have required several days more of desk-type calculation.

Computers, of course, are no substitute for the creative effort required in engineering synthesis and design. The engineer must first create a system or a device which he expects to be a reasonable solution to his problem. The engineer can then proceed to analyze this proposed solution for its feasibility and possible performance. Depending upon circumstances, this analysis may be simple or complex. It may be that the analysis can be done through the medium of a mathematical model and can be handled on a modern computer. But this basic design calls for creative effort of a high order. Then, as the analysis proceeds, modifications develop and a final configuration emerges. It may become apparent that essential information is lacking. Basic science has failed to give necessary information in ranges of temperature or stress or corrosive conditions which are inherent factors in the new design. Then the engineer must undertake to develop this new information for himself. He will then be working as a scientist and his work may be indistinguishable from that of the scientist as to technique or information sought. But he has a definite engineering objective. He knows why he needs the information, where he is going, and when he is expected to arrive with the finished design.

The engineer has always had to work without complete knowledge of his materials. One of our commonest materials, mild steel, has some peculiar properties which other steels and non-ferrous materials do not have. Among other properties, mild steel has the annoying one of fracturing in a brittle manner at moderately low temperatures. The temperature at which the nature of failure changes from plastic to brittle is called the "transition temperature," which describes but does not explain the effect. Certain recent work promises to yield an explanation, but in the meantime hundreds of annoying brittle failures have occurred because we do not know how to eliminate the transition or how to push the transition temperature far below normal environmental temperatures.

Engineer and medical practitioner

In some ways the engineer functions in the service of mankind the way the medical practitioner does. The recent development of polio vaccine is a good example. Basic research on the nature and behavior of the polio virus has been underway for some time, but, rather than wait until everything is known about the polio virus, Dr. Salk undertook the development of the vaccine which has had such dramatic and effective results in removing most of the curse of polio.

But engineering of today is clearly in a state of transition. New developments in science which have claimed the attention of scientists have left the engineer with large areas of what are called classical physics and chemistry which he must explore for himself if he wishes to develop the new knowledge he needs for application. Much of physics has become the domain of the engineer — including the physical properties of materials at extended temperature, solid state physics, electricity and magnetism, physical electronics, theoretical mechanics, thermodynamics, spectroscopy, and thermodynamic properties.

The engineer has also become increasingly concerned with problems of chemistry, particularly reaction kinetics and combustion processes. And the engineer today is perhaps the most important contributor to applied mathematics and to computer logic and design.

We can look ahead and see many problem areas which will require engineering solutions. For example, energy conversion is assuming greater and greater importance. Considering electrical power systems alone, we have in the United States a total generating capacity of nearly one kilowatt per person — and this is a point on a curve which has shown a doubling approximately every ten years. But, in addition to conventional energy conversion, ideas are beginning to emerge which are based on nuclear reaction (fission now and fusion a little later), on fuel cells which make direct chemical conversion, with energy release not limited by thermodynamic temperature considerations, and on solar or other radiation. Fuel cells of efficiency comparable to that of a modern thermoelectric station could change radically the complexion of our public utility systems in terms of generation and distribution. It is not fanciful to think of automobiles powered by fuel cells and electric motors. Indeed, one of the automotive research laboratories has mentioned this dream car.

Materials are both a handicap and a challenge for the engineer. "If," as one writer maintains, "any one factor were to be singled out as holding back progress in atomic power and other advanced technologies, it would be lack of suitable engineering materials — particularly metals and alloys. The materials situation is regarded as so serious that a number of worried scientists are urging that the government establish a major new research institute wholly devoted to the problem . . . The problem in metallurgy is easy to state: There has as yet been no major breakthrough in metals comparable to the transistor in electronics, nylon in high polymers, or nuclear fission in energy creation."

The engineer of the future

Clearly, the engineer of the future has opportunities and responsibilities beyond those which we know today. His capabilities in science, in analysis, and in design call for continuing professional development. Furthermore, the sophistication of the components and the complexity of the systems with which the engineer must work will call for educational effort which goes beyond the present, if he is to function as a truly professional man.

Then, in addition to the greater understanding of modern science, and the synthesis of knowledge into engineering systems, a third function of the engineer is growing in importance. This is his management and technical leadership function. His education must include substantial work in the humanities and the social sciences, in addition to facility in communicating his ideas and understanding those of others.

The repeated plea from industry that engineers

continued on page 30

should have such breadth leaves no doubt concerning the importance of the humanities. Furthermore, we are urged as educators to omit practical training such as labor relations, personnel management, and similar things which have little meaning for the young graduate, and which industry can supply more effectively later on. In short, industry believes it can do a better job than colleges can in giving supervisory or management training, but that the colleges can function better in their traditional role of education in the broad social-humanistic areas. Also, in the broader sense, engineers have come to value the humanities as fundamental to understanding man in his social environment. The engineer thus recognizes his growing professional responsibility.

Now comes the important question: Can the necessary basic science, the engineering sciences, synthesis and design, and the humanities be fitted into a four-year program? In a superficial way, yes – but not with the level of comprehension needed for tomorrow's work. Everything points to the necessity for more extensive education than is possible in a four-year BS program. More graduate work will be essential for the engineering leaders of the future; and the pressure for it is evident now. The objective must be an education which will have the breadth to permit broad-scale systems thinking, and at the same time have sufficient depth to permit the necessary specialization.

Who designs the hardware?

Mr. Luke Noggle of the Westinghouse Company has written: "This science education is fine, but who is going to design the hardware? There is emerging a new type of educational institution which expects to train personnel to handle this type of work. These schools are engineering-oriented technical institutes and feature a two-year terminal program. Such programs comprise specialized courses which prepare the student for a particular technology. Since these programs are for only two years' duration, naturally much of the instruction is directed toward a particular field such as industrial control, electronics, power and radio engineering.

"The student's preparation is up-to-date in these technologies and the course content in the applied sciences approaches an equivalent of a BE degree earned ten to fifteen years ago. It is possible to find some of these schools teaching the application of differential equations in circuit analysis, the use of vector analysis in field theory and the use of LaPlace Transformations in transients. These are exceptions, but most of the accredited technical institutes offer course work using the applications of differential and integral calculus. The graduates from these schools could easily, with practical training and experience, be placed in many positions which are normally reserved for the college graduates in engineering."

Our colleagues in science have never regarded the Bachelor's degree as anything but a good start. Real professional education comes in graduate work. Engineering is rapidly approaching this state. It is also clear that engineering art and practice does not belong in college instruction, but is knowledge which industry should expect to provide. The college responsibility, in turn, should be for more intensive education, extending beyond our conventional four years, including greater emphasis on creative design and the synthesis of more comprehensive systems.

New areas, new problems

Going back to total engineering figures (600,000), we must conclude that not all of these engineers are capable of modern technological advances. A relatively small number have the education and background to apply modern science to the new needs and wants of mankind. What is needed is more engineers who have the basic education and the flexibility to move into new areas, attack new problems, conceive new applications. In other words, we need engineers who can work with scientists, but who are motivated toward new applications and new uses of scientific information, who can see the device or system to meet a need and who can, if necessary, work *as* scientists to develop new knowledge and new information to supply basic ideas, principles, and facts which may not now exist.

This kind of engineer does not rely solely on the "state of the art," nor on handbook information. He is a pioneer in advanced technology, as his colleague in science is a worker on the frontiers of knowledge. This engineer needs the same type of basic education and research experience as the scientist does if their partnership is to be effective.

It follows, then, that the engineer shall have an education similar to that of the scientist in fundamentals, methods, and extent – but distinct and different in objective and motivation.

All of this points to more and better education for engineers; to higher professional standards for engineering practice; to better support for engineers in the less exciting details of their work. We need public understanding of the role of the engineer and the place of the engineering function as a part of the technological process. Science provides support but not end objectives. The engineer must be recognized as a man of action with a high order of versatility in application of new knowledge to practical problems. He is a new kind of engineer. He is not vanishing; he is changing.