Physics and Engineering in a Free Society

I. EDUCATION

By J. A. Stratton

I HAVE been uncertain about the position I should take in our discussion this afternoon. The American Institute of Physics has sponsored this gathering. My persuasive friends, Dr. Suits and Dr. Hutchisson, who induced me to take part, have long been articulate spokesmen for the role of physics in modern engineering. In the light of my own interests, they might reasonably anticipate that I would support that cause. However, I have felt increasingly of late that the need to interpret the engineer to the physicist is even more pressing. This meeting today with our Corporate Associates seems an appropriate occasion to begin. The central theme of our conference is, in fact, the question as to how physics and engineering each may contribute best to the advancement of a free society. At one time or another, I have had a serious professional interest in both fields. But I shall speak to you today from the vantage point of one whose deepest concern for a number of years has been with education.

One of the most distinguished novelists of our generation, Sir Charles P. Snow, who by training was a physicist, has been a recent visitor to the United States, and we had rather hoped he might be with us today. His paper on "The Two Cultures" that appeared first in the *New Statesman* and his Rede Lecture, delivered at Cambridge University a year ago, have made an immense impression in his country and ours, because he describes so well a problem that has been a matter of concern to many of us. His subject, you will remember, is the deepening gulf between the literary intellectuals and the scientific community. It is a gulf of mutual misunderstanding accentuated by a breakdown in the means of communicating ideas, by the development of special vocabularies, and, worse, by the use of identical words with utterly different meanings. The rift between science and the arts is acute, although possibly less so in America than in Britain.

But unhappily, as Sir Charles goes on to point out in his Rede Lecture, there are signs of cleavages appearing in our society other than that which separates the scientist from the humanist. The stupendous accumulation of knowledge and techniques that marks the twentieth century has led inevitably to a growing specialization in the professions. The consequence is a fragmentation of learning and the intellectual isolation of scholars, each on his own little professional island. Of course, this sort of thing is by no means wholly new. I imagine that the medieval guildsmen felt much the same way about each other and about the clerical philosophers of their day as Rutherford may have felt about T. S. Eliot in ours. But the

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consequences of misunderstanding may be more serious to us.

One of these consequences is the failure of the American public to understand the respective roles of the scientist and the engineer and the nature of their contributions to productive industry. And directly related to this matter of public comprehension is the crucial problem of technically trained manpower. What measures must we take as a nation to insure that an adequate number of young men and women enter upon careers in science and engineering? Are the present and foreseeable economic and military goals of the country so endangered by potential shortages that we should adopt a plan of partial mobilization or a system of special inducements as in time of war?

Surely the answer is no. Ours is a technological society, but our highest aim is to preserve it as a free society. Authoritarian states such as China and the Soviet Union appear, at least for the short term, to enjoy an enormous advantage in the planning of their economic development. They can regiment their human resources almost as freely as they can make allocations of minerals or consumer goods. For us, the question of adequate technological manpower is part of a larger issue of whether democracy can survive in competition with a dictatorship. That is a matter upon which we really have no choice. We are inalterably dedicated to the democratic idea; consequently, we must have faith in the power of the democratic process. We believe in the concept of free enterprise, and therefore we must likewise support a free market in the professions.

In this free market, all who represent science and industry—such as we here today—have not only a right, but also a responsibility to guide and encourage students in school and college in the choice of careers. We must demonstrate to the very best of our ability the intellectual challenge and excitement of engineering and science, as well as their urgent importance to the national interest. The decisions that these young people in high school or college make about their future professions no doubt will be affected in some degree by the prospect of material rewards—of starting salaries and stock participation. But don't ever underestimate the idealism of youth even in this materialistic age. I am convinced that judgments on the importance, the interest, the intrinsic worth of prospective careers are still the crucial factors that determine each year how many from each fresh graduating class enter the several professions.

The answer to the manpower problem is a deep-seated and intelligent interest in engineering and science aroused early in primary school and continued through high school into college. And how do we stir this interest? By excellence in teaching, and by constant revision and improvement in the content, the techniques, and the methods of presentation.

On this score I take anything but a pessimistic view. Never in American history has there been a more concentrated and enlightened effort to strengthen and advance education in science than at present. The contributions of the Physical Science Study Committee will prove to be a landmark in secondary-school teaching, and I can hardly pay too high a tribute to my colleague Professor Zacharias for his vision and imagination and for his success in joining in a common enterprise the energies and range of experience of high-school teachers and some of the most eminent physicists from our universities. And the greatest contribution of the Physical Science Study Committee, it seems to me, has been the stimulation it has given to others to do likewise. The time was ripe, and the way was shown. All over the country there is interest and movement. Independent groups in fields other than physics have formed spontaneously and are planning and working. This is a movement that has sprung out of the profession of teaching itself, and we may hope that it will grow in power and range. I am confident that we are on the threshold of revolutionary changes in the teaching of science.

Happily, these developments will not be confined to the high-school level. There are studies in progress that relate to the primary school. Even more significant is the college problem. Not so very long ago professors in our major universities were disposed only to disparage the state of physics in the lower schools. Now they have recognized that we in the colleges must look to our own fences. Here, too, there is a widespread need for revision and modernization. There should be increased emphasis on the aims and evolution of science and on its relevance to our culture. In most institutions, elementary laboratory instruction in physics and chemistry has been notoriously sterile. New experiments must be devised to bring modern physics into the realm of the undergraduate, to excite his interest, and to strengthen his understanding. And finally, there is an opportunity to extend the use of films, modern lecture demonstrations, experimental kits—all the new techniques of teaching that are beginning to show such bright promise at more elementary levels. It is highly satisfying to observe that the American Institute of Physics recognizes its responsibilities in furthering these efforts, and no doubt many of you have read in the September issue of the *American Journal of Physics* the report of a Conference on the Improvement of College Physics Courses which presented a series of recommendations and plans for immediate action.

WITH these comments on the place of science in contemporary society and with these examples of how education is moving to meet its broader responsibilities, I come now to the principal subject of my remarks—the relation of physics to engineering, and some implications for the education of the engineer.

Just what has happened to the interest in engineering on the part of undergraduates in technical schools and universities all over the country? Everywhere one finds a remarkable shift in enrollment from engineering departments to physics and mathematics.

Let me cite some figures from MIT by way of example. Throughout the five-year period 1956–1960, we have maintained our freshman enrollment essentially constant according to plan. Freshmen indicate their preference upon admission, although they are not asked to commit themselves to any particular professional field until much later. Within the stated period, the preferences expressed for engineering dropped by 30 percent. In all fields of science, there was a corresponding increase, and in physics, in particular, the indicated growth of interest was 60 percent.

Local conditions, of course, always influence such figures, but I think no one will contest the fact that they reflect a condition affecting schools of engineering everywhere, a condition that is critically serious in its implications for our industrial development.

What is the cause? To what extent has the undergraduate been captivated by the glamor of recent developments attributed, often improperly, to "science"? Many engineers have protested rather bitterly, and with some justification, the practice of our news reporters of crediting to science a number of great accomplishments that are, in fact, triumphs of engineering. Nonetheless, I think it quite clear that the profession as a whole has been rather ineffective in presenting to the public a lucid and compelling view of the true nature of engineering, of the challenge and excitement it can hold out to the brightest minds, of its important and indispensable contributions to society. If we could dig down to the roots of the current shifts in interest among our students, I think we would discover that they stem often from sincere and thoughtful convictions that modern science has become intellectually more stimulating and socially more important than engineering.

For my own part, I think this view, should it continue to prevail, could be disastrous for the country. I also think it completely unfounded in fact. But also, in keeping with my earlier remarks, I believe that we must seek our remedy by building upon the inherent strength and appeal of the great engineering professions rather than in resorting to a containment of the current interest in physics through artificial limitations upon enrollment.

We must begin with engineering education itself. We must ask ourselves, more candidly than has been our practice in the past, whether in its traditional forms it does indeed offer a challenge to the very brightest young minds. And does it indeed meet the needs of the contemporary industrial revolution? I think the answer will be no, or at least rarely. But here too, as in the teaching of science, there are signs of great developments in progress.

Let me comment, therefore, upon the conditions that seem to me to underlie the current crisis in engineering education.*

Although one looks normally to the academic institutions to provide the innovating forces of education, it is now industry itself, on many fronts, that is already showing the way. But neither in industry nor within the schools of engineering has there been full agreement on the most urgent needs of the profession, nor consequently any unanimity of opinion as to how and to what extent our curricula should be revised.

The grounds for this division of judgment are easy to discover. The great bulk of American industry still draws upon well-established, relatively stable technologies. Steel, oil, motors, construction, to name but a few, are the backbone of our national economy. And in these industries, the effectiveness of each method or process has been tested by experience. Because of the inherent nature of the operations involved, research has influenced rather slowly the character and volume of production.

To this basic industrial core we must now add the extraordinary and expanding array of new companies whose very lifeblood is research and development. Their field of operations lies along the furthest frontiers of scientific discovery. Their business is to exploit the advances of science, to translate them rapidly and

* The comments that follow have been adapted from a statement in the author's Annual Report to the Corporation of MIT.

economically into useful products and services. Relatively few of these new enterprises yet bulk large on the industrial horizon. But their role in the current technological revolution, their significance for the future economic strength of this country in the face of rising international competition, is wholly out of proportion to their individual size.

As we go about the task of preparing our engineering students to meet the responsibilities of *their own generation*, we must consider in fair perspective the whole range of future needs and opportunities. Since the middle of the nineteenth century, American engineers, educated in what is now a classical pattern, have taken a leading part in the prodigious growth and achievements of our industries. Any alteration in this proved plan of education must clearly be designed to increase the prospects of further contributions on the part of our engineering graduates.

The argument for revision rests largely on the fact that today's scientific revolution is no mere extension of the industrial revolution. No experienced observer of the contemporary scene can easily escape the conclusion that research and development *are in fact* powerful agents for growth and change. The impact of this innovating force of research bears increasingly upon every segment of our industrial activity—upon our basic industries as well as upon our more novel enterprises. Popular interest in the spectacular success of electronic devices or the prospects of "exotic power packages" should not obscure the greater significance of far-reaching advances on many other fronts. Recent applications of solid-state physics to materials—both metals and nonmetals—and progress in the chemistry and thermodynamics of combustion, in the theory of communications and control, in biochemistry, in the mechanics of fluid flow, to suggest only a few, will in due course affect the operations, the competitive position, and the profits of industry of every size and category.

Industry in the decades ahead will exploit increasingly the progress of basic science. The time lag between scientific discovery and practical application will diminish and the boundary between pure and applied will often be confused. But the achievements of industry, the reduction of ideas and principles to useful products, will remain the work of the engineer. And, as I remarked earlier, one of the important responsibilities falling upon our professional societies, on industry, and our academic institutions, is that of conveying to students a clear understanding of the character of the engineering profession, of the challenge and excitement of its opportunities.

The pace of technological change is accelerating. We cannot possibly foresee the progress of discoveries of tomorrow. We ought, therefore, to concentrate our efforts in imparting to prospective engineers a thoroughly fundamental technical competence, together with the versatility and the intellectual self-reliance to keep pace with the advancing frontiers. This means a greater emphasis on basic science, and every conference on engineering education of late has concurred in the need for a higher level of achievement in mathematics, physics, and chemistry.

Until recently our engineering schools had lagged in this regard. This accounts in part, I think, for the rise in physicists in industry. We find them increasingly employed in areas of application and development. One reason surely is that it is they, rather than the engineers, who have comprehended the possibilities for change and innovation. Now I think all of us are quite clear that research and development represent in fact a continuous spectrum of activity. And none of us would overcompartmentalize the work of the physicist and of the engineer. It matters not a whit whether a man doing a particular piece of work calls himself a physicist or an electrical engineer. But comprehension of the fact that physics and engineering are indeed different, with different professional missions, is essential.

The pure scientist and the true engineer differ fundamentally in their aims, their motivation, their methods of attack, and the kind of reasoning which leads them to their decisions. In our new emphasis upon fundamentals in engineering education, we must avoid the danger of downgrading other essential attributes of the engineer. There is a need for something more than advanced mathematics, more than an understanding of the systems concept, or the use of operations analysis, or optimization techniques. The student ought to have more than a passing acquaintance with a laboratory. He must acquire a deeply ingrained feeling for experiment, for scale and orders of magnitude, and what it means to measure. He needs to appreciate the professional engineer's concern with cost, with reliability, with public responsibility.

Earlier I spoke of the great changes taking place in the teaching of science. The engineering field, by and large, has been slower to take stock of its needs. But I can report to you that there is new life and movement in our engineering schools all across the country, and we can now look forward to a vigorous and imaginative attack on the basic problems.

Let me conclude then with the final observation that these comments on engineering education obviously leave much unsaid. Engineering encompasses a broad spectrum of activities, and there is no single route to useful service in the profession. Whatever the bias of a particular academic institution or industry, we must recognize that there are many valid points of view—views that are complementary, not competitive. And one of the strengths of our free and pluralistic society is that we can and do support a great variety of educational institutions with differing roles and missions. We need technically trained manpower in quantity and quality at all levels. But we urgently need also a creative breed of engineers who will combine a deep knowledge of science and mathematics with the special attributes of the engineering profession itself.