factors concerning

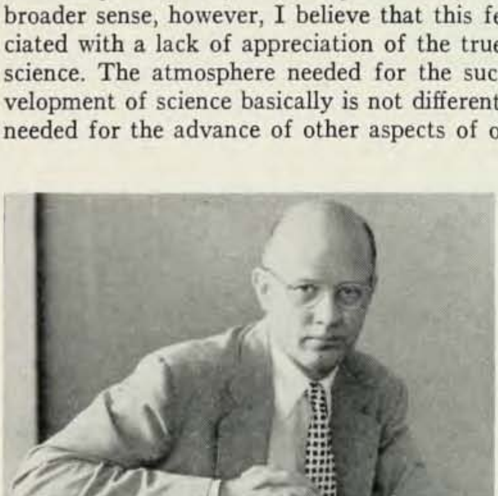
Education for Science and Engineering

By Frederick Seitz

OUR nation is now passing through one of the gravest periods in its history. The fate of many of the most precious things in the heritage of modern man will depend upon our ability to surmount the present crisis. Apart from the physical well-being of those now living, many matters of profound cultural value which we have inherited through the intellectual enlightenment of the Greeks and the religious genius of the peoples of Asia Minor are at stake.

Survival requires that we retain leadership in many things. The areas of science and engineering come to mind at once because of their relation to military strength. Although these disciplines are absolutely essential to our strength, one cannot focus attention upon them to the exclusion of other factors. Indeed, outstanding individuals with a deep sense of public conscience occasionally express fear that far too much emphasis will be placed upon science and technology in the years ahead. To the extent that these individuals are fearful that we shall ape the Russians too closely and suffer as a consequence, they are unquestionably right. In a broader sense, however, I believe that this fear is associated with a lack of appreciation of the true nature of science. The atmosphere needed for the successful development of science basically is not different from that needed for the advance of other aspects of our culture. The great generalizations of science are primarily of humanistic value. They occupy positions along with the great generalizations of other fields such as art, history, literature, philosophy, and religion. If we achieve an environment in which the most basic science thrives in a self-sustaining way, the other areas of cultural importance will benefit no less.

It is true that certain phases of engineering can prosper in an atmsophere in which science is either not active or receives indifferent treatment. The technological successes of the Germans in the period just prior to and during World War II provide examples of this situation. Actually, I believe that such a pattern can be succesful only on a short-range basis. It is a simple truth that German technology suffered from the damage to the supporting science well before 1945. It paid this price for the systematic repression of scholarship, through which science suffered, in the period after 1933. I suspect that the one-sided development of scholarship in Soviet Russia which focuses so much attention on relatively short-range technical developments will eventually prove to be far more of a hindrance than a help through the loss of versatility. It is quite probable that Soviet technology has been successful thus far only because of the free access to the productive scholarship of the noncommunist world. In spite of systematic propaganda to the contrary, it is probable that the greatest disaster which could overtake Soviet technology would be the destruction of the cultural institutions of the free world which still represent the greatest sources of basic knowledge. Conversely, routine duplication of Soviet practices concerning science and engineering would probably undermine the solid virtues of our own system.



Frederick Seitz is head of the Department of Physics at the University of Illinois and chairman of the American Institute of Physics. He presented this paper before an audience of high-school principals at a conference on science education in elementary and high schools in the state of Illinois held April 11–12 on the campus of the University of Illinois.
(*Photo by Laura Gilpin*)

Scientific and Engineering Manpower

IN discussing manpower in science and engineering one is faced immediately with consideration of two factors, namely, quantity and quality. The two features cannot be discussed independently. This circumstance arises not because quality can be used as a substitute for quantity and vice versa but from the paradoxical fact that quantity becomes significant and effective only when the appropriate distribution of quality is assured.

Let me illustrate the nature of this paradox by considering one of the most brilliant and creative scientists of our time, namely, John von Neumann, the member of the Atomic Energy Commission who died of cancer last year at the age of 53. Von Neumann was not known very well in the popular sense since he shunned publicity. He was instead what has been termed a scientist's scientist, greatly revered by a distinguished group of scientists and engineers in a number of fields.

He was the son of a prosperous Hungarian banker and normally would have fallen heir to the family business. He was formally educated as a chemical engineer but possessed such genius for mathematics that he became a professional mathematician. He migrated to the United States in 1930, when he foresaw with characteristic insight the convulsions to which Europe would be exposed. While in his mid-twenties he established the mathematical foundations on which the rigorous treatment of quantum mechanics, or atomic mechanics, rests. Prior to 1940 he devoted attention to that subject and to the following fields of pure mathematics: mathematical logic, operator theory, continuous geometry, measure theory, and the theory of games. During the war he turned to matters of applied military interest and made a number of critical contributions to military technology. For example, he proposed the implosion technique for detonating fission weapons; he made significant advances in the theory of shock waves, developed much of the basic theory of high-speed electronic computers, and applied them to numerous practical problems. Following the war, he played a leading role in the development of hydrogen weapons and was the prominent scientific figure in promoting the present national program in ballistic missiles. He initiated the study of the theory of the weather with computing machines. His interests were universal and ranged over wide areas of subjects outside physical science, including such matters as economics and history. He had a clear realization, even during World War II, that the dangers arising from Soviet ambitions were at least the equal of those presented by the fascist countries. He did all in his power to sustain our military strength after 1945. At the age of 50 he decided to enter public service in a more direct way and accepted a Presidential appointment as commissioner in the Atomic Energy Commission. This brought him to the public eye for the first time.

Quite apart from the fact that he was a notable genius, von Neumann's career focuses attention upon a number of matters concerned with science and engineering. For example, his productivity emphasizes again that one individual with appropriate ability, training, and orientation may have the creative output of a very large number of distinguished, but less able, individuals. This observation, although true, is obviously not novel. What is more to the point for this discussion, von Neumann's creative powers made it possible for many individuals of lesser creative genius to be vastly more effective than would otherwise have been the case. Conversely, the existence of a large number of well-trained individuals of lesser genius made it possible to realize the benefits which could be derived from von Neumann's creativity more rapidly. Perhaps it is a feature almost unique to science that the absolute value of the work of the minor figure increases with the value of the major figures in the fields of endeavor. The contrary is true in many other areas, such as art and philosophy, in which the great figures obscure the minor ones.

One principle that may be drawn from these observations is that it is not useful to promote the production of the *quantity* of scientists and engineers, unless one is certain that the major individuals are of sufficient stature to make the remainder employable in a profitable sense. Thus, the all-important question of quality must be given the dominant attention. The quantity of scientists and engineers required in our nation will be determined automatically by a demand generated jointly by the creativity of the leading figures and the requirements of circumstances. It is of primary importance to foster the most unusual and gifted talent before the question of numbers becomes appropriate. Our educational program in science and engineering is still at a stage where quality demands the over-riding attention. This does not mean that numbers are unimportant, but rather that both the numbers of individuals inspired to accept education and their effectiveness will increase if further emphasis is placed on quality.

A second major principle may be gleaned from an analysis of von Neumann's educational background. His early education through the university level was obtained in Hungary. He then moved to Switzerland and Germany. It is interesting to note that he received PhD degrees in the same year at the University of Budapest and the Technical University of Zurich at the age of 23. His talent and the flexibility of the academic system permitted this. In brief, he was a product of the European academic circle in which very great emphasis was placed upon the development of the scholastic attainments of the individual and upon early specialization. His education was closely matched to his aptitude at each step. Although he was the heir to the family enterprise, he was left free for an academic career when the family appreciated his uniquely outstanding talents. In other words, he developed in an atmosphere in which dedication to scholarship was regarded as both natural and desirable for the unusual individual. In taking the academic path instead of pursuing material wealth, he was made to feel that the prestige of his family was

John von Neumann "... a scientist's scientist"
(Photo by Alan W. Richards)

strengthened, not weakened. Thus, in following a scientific career, he occupied a position of equilibrium with his environment in spite of his rare genius.

Quite apart from the matter of the quality of scientific training he would have received in a typical secondary school in the United States at the present time, von Neumann would have found much more difficulty in developing his genius during the formative years had he been raised in our nation at the present time and moved through the conventional channels of public education. His unusual qualities would have set him apart. He would have been subject to countless pressures to conform to a pattern which could only have diluted his achievements by thwarting him from the development of his specialized talents. It is certain he would have survived these pressures and achieved a form of greatness, but it is doubtful if his development would have been nearly as complete and if he would have been of comparable service to our nation.

Perhaps it should be added that as a social being, von Neumann maintained excellent relations with a very broad circle of professional colleagues through periods of very difficult enterprise. One was never able to detect any weakness in relationships with others that might have stemmed from the fact that his education did not stress group participation in an explicit way—a factor on which so much emphasis is placed in secondary-school education in our country.

Means of Strengthening our Education

THE center of strength of education in science and technology now lies in the graduate schools of the great universities. These schools are oriented toward an international ideal of scholarship which places primary emphasis on the development of the individual through specialization which is matched to his personal characteristics. The scholarly ideals of the graduate schools are closely related to those found in the entire academic environment in which von Neumann developed. In fact, in a broad sense it is safe to say that von Neumann would have found an educational pattern appropriate for his abilities only at the graduate level in the United States at the present time.

The high schools stand at the other end of our educational spectrum. They cater to a popular ideal which is not strongly sympathetic to accomplishment through specialization. According to this ideal, one should strive to achieve material prosperity by participation in group endeavors in which individual characteristics are subordinated to those of the group. In a sense, the high schools, like the graduate college, have achieved a type of internal consistency. The principal difficulty is that the two are oriented in very different directions. Perhaps I should add that even though the public attitude, with its emphasis on material things, has dominated the pattern of high-school education, the public has not been quite so willing to share the material wealth of the nation with the high-school faculty.

The colleges, which obviously have important goals in addition to training scientists and engineers, are caught in a compromising position by the need to conform to the contradictory ideals of the secondary schools and the graduate schools. The ensuing conflict has not permitted the colleges to develop a strong consistent character. They suffer from obvious schizoid tendencies. View them as you will, the colleges of the United States as constituted at present have pathological attributes. I believe it is highly necessary that this illness be cured in the next generation, if our educational system is to sustain the free world during the difficult years to come.

Perhaps it may be emphasized at this point that the difficulties in our own educational system are not necessarily inherent in republican democracy. They are not found in the republican democracies of Western Europe, nor did they exist in our own country prior to World War I. Apparently they are associated with attitudes developed during the period of easy prosperity of the 1920's.

It is my personal opinion that only one major direction of change is practical: the secondary schools must become reoriented while retaining their capacity to provide appropriate education for all. This will happen only as a result of the concerted action of the public and those in educational circles responsible for the policies of the secondary schools. The primary problem is that of altering the attitudes of the general public and with it the attitudes developed in secondary schools. This change must accompany, if not actually precede, a change in the quality of education in science and engineering.

There are two general areas in which modification of the attitude is needed.

First is that concerning the general outlook toward history. To the extent possible we must cultivate a general awareness of the principle first appreciated by Polybius, that the successes and failures of societies do not just happen but have a variety of sources which are deeply imbedded in the societies. More explicitly, American wealth and strength is not a birthright of our population, but can be retained in the future only by doing the proper things. Our secondary schools must place more emphasis on world history and not merely on domestic or regional history. The history of Mesopotamia, Greece, Rome, or Europe is basically as important to the average American as the facts surrounding our own Revolution or Civil War. In fact, the importance of our national history becomes completely comprehensible only when viewed in the light of the former.

Second, it is time to return to the point of view that the individual renders his greatest service to the community when he or she develops inherent, special, and valuable talents without false constraints. This specialized training should begin as soon as the interests of the individual become clear, say at age 10 or 12. Secondary-school education should contain both enterprises which are undertaken collectively by the entire age group and enterprises which are undertaken in a more specialized way by the individual. It is time to emphasize again, as was true earlier in our national history, that the latter are not less important than the former.

With these reorientations in attitude it should be possible to provide a far more satisfactory basis for the development of any field of endeavor, including the areas devoted to science and engineering, in a national way. If asked to select the subjects of greatest value in secondary schools for the future scientist or engineer, I would choose the following four in the sequence given:

1. English, English Composition, and Literature. The ability to formulate one's ideas in clear concise English and to comprehend the ideas of others is still the most critical aspect of education for science and engineering, as for most other fields.
2. Mathematics, including Algebra, Geometry, and Trigonometry. The logical discipline of mathematics is still unexcelled. The work should include emphasis on both theory and manipulative drill. The student showing unusual mathematical aptitude should have access, through courses or special reading, to mathematics beyond trigonometry.
3. It is highly desirable to have other sciences presented in high school but only if given at a thoroughly professional level. The three which are most appropriate are Biology, Chemistry, and Physics. Under any circumstances, however, it is absolutely necessary that the teachers have professional standing in the subject they teach and be given an opportunity to remain in contact with the moving frontier through appropriate educational opportunities. The salaries for secondary-school teachers must be adjusted to retain and procure this level of professional quality.
4. Languages. The ineptness of the average American scientist or engineer in any language but his own is little short of a national disgrace. In fact he is often inept in his own as well. This pattern obviously stems from a form of provincialism which we can no longer afford if we desire to occupy a position of leadership among other nations. Every educated American ought to have reasonable mastery of at least one language other than English.

If the foregoing program sounds old-fashioned, I can only state that it has a notable record of success in our earlier history and in other lands which we no longer can afford to ignore.

Need for Literacy in Science

IT is evident that, next to the home, the high school occupies the most critical position in the education of the general public. If the attitudes developed in the secondary school can be altered in the way proposed above by placing further emphasis on world history and upon the virtues of specialization, the public attitude towards science will be more nearly in keeping with the value of science to society. A poll described in a recent issue of *Life* indicated that only ten percent of our population could name two living scientists. Those named most frequently by this fraction were Oppenheimer and Salk and for evident reasons. One-third of the population believes that the scientists are basically unreliable and cannot be trusted with the knowledge they generate. Still further, a survey of the high-school students at Oak Ridge recently indicated that the average student felt that the scientists as a group were only poorly linked to society.

An analysis of the actual facts shows that in most of their social behaviors scientists conform to the pattern of typical college graduates. They possess unusual domestic and economic stability and, in general, are motivated by a healthy sense of social responsibility.

It is clear that the popular opinion of scientists and their value will be altered only as a result of a reorientation of the attitudes developed both in the home and in secondary schools. Moreover, the foregoing summary of the popular opinions indicates that such a reorientation is long overdue.

Apart from this, it would seem to be of doubtful value to insist upon extensive public education in the quantitative details of science or engineering. For those who do not go on to college and for those who do but do not possess aptitude for the details of science, I would place primary emphasis on a continuing course in general science at the secondary-school level which gives familiarity with the history and accomplishments of science and its relation to the matters of everyday life. This should be descriptive and inspirational, placing emphasis upon the cultural roots and the goals of science and the countless ways in which it affects our understanding of the world about us.