SCIENCE and NATIONAL

The advancement of science, in both utilitarian and cultural terms, demands a fresh approach to the methods of science education in our schools.

By Nathaniel H. Frank

IT IS indeed an honor and a pleasure to have the opportunity of addressing you on the occasion of Science Day of the sesquicentennial celebration of the founding of Hebron Academy. It is perhaps somewhat rash of me to undertake the presentation of a topic as ramified and complex as the relations of science to national affairs, but the profound significance of this subject, both for the individual and for the country as a whole, has provided me with the courage for such an undertaking. I am deeply concerned about a number of rather widespread misunderstandings about these matters, and I hope to be able in the following remarks to clarify some of the subtler points which, when viewed superficially, lead to erroneous and even to potentially harmful conclusions. My remarks, I trust, will be applicable with equal validity both to the physical sciences—mathematics, chemistry, physics, geology, etc.—and to the life sciences—biology, botany, zoology, etc. —and you will forgive me if I draw most heavily on physics because of my own more intimate acquaintance with this science.

Traditionally, science has always played a dual role in the affairs of mankind. First, there has been the pursuit of pure or basic science to satisfy man's natural curiosity and his innate urge to speculate about and try to understand the world in which he lives; and secondly, there has been the application of scientific findings (applied science) to engineering, technology, industry, and indeed to almost every facet of our social and economic life. But there has been a continuous and increasingly rapid change in the magnitude of the relative activities in these two areas from the first to the second, until today we are overwhelmingly conscious of our dependence on our technological proficiency. Not only are our physical well-being and our standard of living involved, but because of the almost unbelievable changes in the weapons and the nature of warfare, the very existence of our nation and society as we know it depends only too critically on our staying well in the forefront of technological progress. This awareness has brought with it the curious state of mind which tends to deprecate the value of pure uninhibited scientific inquiry and regards pure scientists as somewhat starry-eyed impractical individuals of no great immediate importance in attaining solutions of the pressing problems of our times. Not only is this disturbing, but it represents a potentially dangerous situation, and if allowed to spread unchallenged can ultimately lead by default to the destruction of those very things which so desperately need strengthening. I hope to be successful in presenting to you the principal reasons for the validity of this statement, but a skillful and successful defense of the deeper values of pure science is not enough. This must be accompanied by a dynamic, constructive campaign waged within the realm of pure science, primarily in the field of science education. I will return to this later.

Let me turn now more specifically to the relation of science to our National Defense. The public is only too well aware of the terrifying technological changes in war as demonstrated in World War II, of the appalling increase in the destructiveness of weapons, and of the increasing necessity of reliance on complex technical gear for waging modern war with any reasonable chance of success. During that era of national emergency, all efforts were focussed on military needs and scientists turned wholeheartedly and without restraint to the application of their skills and knowledge to the military effort. Their outstanding achievements, for example, in connection with radar and the atom bomb, are common knowledge. Pure research as such and scientific education came practically to a standstill. Viewed in the light of the long-range requirements of the country, this was a large price to pay, and the present great shortage of scientists and engineers is ample evidence of this. However, it is not my intention to question the wisdom of such a course, since in times of danger to our very existence, extreme measures are called for and decisions cannot wait. We are now living in the aftermath of that conflict, in a world beset by international

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tension and mistrust. This continuing cold war brings us face to face with new and uncomfortable problems. On the one hand, there is the continuous and compelling pressure to acquire and to maintain an unmatched military position, requiring only too much in the way of national effort and expense, as evidenced by our present tax burden; on the other hand, there is the very natural and impatient desire to revert to a more comfortable peacetime economy with balanced budgets and reduced taxes. The Congress is under heavy pressure to reduce federal spending and will do this by reducing the appropriations for those activities which are judged not vitally essential to our national well-being, although they may be inherently useful. These activities then are somewhat like luxuries: pleasant, useful, somewhat uncomfortable to do without, but not critically important.

This all seems quite reasonable and sensible, as indeed it is, but now comes the crucial point. Which items are essential, which are desirable but can be curtailed partially without serious damage, and which are truly nonessential? It is just the answers which the public as a whole gives to these questions (and Congress *is* sensitive to public opinion) which present a grave danger to science and a consequent potential weakening of our internal strength. This assertion may seem paradoxical to many of you, since, as I have pointed out, the public is extremely aware of the vital role which science has played and is playing in our military effort. There are constant reminders of this when one reads the advertisements for "help wanted" by firms engaged in defense work, that is, in guided missiles, radar, etc., pleading for physicists, engineers, and scientists in general. This brings me to the crux of the situation. *The public has become aware of the impact of science on the nation almost solely and overwhelmingly in terms of applied science, not pure science.* Scientific research has been identified with applied scientific research and even with the development of new products. A pure scientist is often regarded as occupied with matters somewhat remote from the urgent practical demands of our national life. One has only to look at the relatively small budget of the National Science Foundation, to the fact that the basic research budget of the Atomic Energy Commission was cut from about 43 to 33 million dollars last year, and to the small fraction of the total research and development expenditures of the Armed Services devoted to basic scientific research, in order to find convincing evidence in this regard. I should point out, however, that it is only fitting and proper that practically all of this Armed Services budget should be expended in applied military research and development, and pure science owes a great debt to those in the Armed Services who see to it that basic research is supported as well as it is. Unfortunately it is only too likely that the support of pure science will be reduced even more as further economies come into being in federal spending.

I submit, ladies and gentlemen, that we face an unfortunate and dangerous situation which must be rectified lest we weaken the very strength in defense which we must attain. Let me point out first that, in the last analysis, our military superiority must lie in keeping ahead of our potential enemies in the creation of really new technological weapons and in their skillful employment. Military security surely cannot lie *solely* in the refinement of weapons based on well-established scientific principles and facts—and this is what applied science accomplishes. No amount of refinement of this sort can hope to compete with the introduction of truly new devices. The discovery of nuclear fission and the subsequent events leading to the production of the atomic and the hydrogen bomb illustrate this point. These new devices stem from progress made in pure science and, in the long run, lack of proper support and encouragement of basic research and of education in the sciences can rob us of the very stockpile from which we are to draw our future strength. One more remark in this connection—the length of time which elapses between a new discovery in pure science and its application to practical ends, military or otherwise, has been decreasing at an unbelievable rate. This fact gives added weight to the proposition that we as a nation cannot afford to lag behind in our basic scientific strength.

THIS now brings me to the next topic, the relation of science to our industrial and economic strength. It is a truism to state that our national economy and productivity depend sharply and in increasing measure on technology and engineering. During the past several decades there has been a marked change in the character of engineering, namely, an evolution from a largely empirical to a largely scientific subject. The extent to which this change has taken place varies from one engineering profession to another and in general is greater in newer fields of engineering where tradition is not so deep-rooted. Thus we find an increasing proportion of applied science in fundamental engineering research. At this point it might be well to point out the differences among engineering, applied science, and pure science. The broad problem of engineering is that of carrying out effectively a relatively large and complex operation with the objective of fulfilling some needed economic or public function. An engineering operation today leans very heavily but not exclusively on technological methods. It encompasses problems of human limitations, personnel, economics, psychology, politics, and many others, as well as those of a technical nature. A proper analysis of the desired operation as a rule then leads to a set of technical requirements, among others, and one can then draw on the vast stockpile of technical "know-how." More often than not, the precise technical tools and knowledge which are called for are not available and compromise must be resorted to in practice, but just here lies the role of applied science. Not only does applied science supply most of the technical devices needed for engineering, but the requirements of engineering operations feed back, so to speak, a host of technical problems requiring solution. Thus, there is a closed-cycle type of feedback which constantly provides the aims and objectives of applied scientific endeavor. It is, of course, to be understood that this does not imply any relaxation of the rigor and fundamental character of the scientific research involved. Pure or basic scientific research differs from applied science primarily in its goals and objectives. It is an "open-ended" process which is self-regenerating, in which the curiosity of the scientist dictates the lines of endeavor which are pursued without regard for practical application. From this come adventures into realms of experience which are partly or imperfectly understood, the evolution of new scientific principles and the growth of science as a whole.

Of course the applied scientist must have a sound background of fundamental scientific principles at his command and this very essential requirement has long made necessary the inclusion of pure science in the basic education of the applied scientist and of the engineer. Thus the pure scientist has always played a vital part in the education of these people and so indirectly contributes to the strength of our engineering skill and industrial productivity. Today, however, there have emerged two new factors which have increased enormously the educational demands on pure science.

First, there is the extraordinary rate of growth of pure science. One can assert with reasonable assurance, at least in physics, that since the turn of the century more progress has been achieved scientifically than in the whole previous history of man. In this twentieth century period have come into being epochal upheavals in basic modes of thinking, as exemplified by the quantum theory and the theory of relativity. These are by no means simply erudite intellectual pastimes for the few, but they lie at the very core of our understanding of the nature of matter in bulk, e.g., the solid state, and of the structure of atoms and atomic nuclei. I hardly need emphasize the practical implications of these facts. Secondly, as I have already indicated, the time interval between discovery in pure science and application to engineering has grown astonishingly short. Let me illustrate this as follows: Somewhat over a hundred years ago Michael Faraday discovered the laws of magnetic induction and it took something over fifty years before the industrial manufacture of electrical generators and motors came into being. There was a period of roughly thirty years between the discovery of thermionic emission and the commercial sale of vacuum tubes, about the same interval between Hertz's discovery of electromagnetic waves and the establishment of the first commercial broadcasting station, and some eighteen years between the discovery of x-rays by Roentgen and the production of the first Coolidge tube. In the present century we find an interval of some eleven years between the discovery of neutrons by Chadwick and the building of the first nuclear reactor. Then, during the period of World War II, a span of about five or six years represents the interval between the discovery of microwave principles and the creation of airborne radar and also between the discovery of nuclear fission and the use of the first atomic bomb. In the postwar era, we find the commercial transistor appearing on the market a little over three years after the discovery of the underlying scientific knowledge concerning semiconductors.[1] Thus we see a rapidly shrinking time scale during which discovery in pure science turns into a commercial product. It is even more significant that we are now confronted with a situation in which a student may enter college to obtain an engineering or scientific education, and even before he attains his bachelor's degree a whole new industry comes into being. As a consequence of the foregoing, no longer are the traditionally basic courses in science adequate for the modern engineer (or layman) and very large pressures are growing for more advanced and modern science subjects as a necessary base for today's technology. Due to the rapidity of change and of growth, these demands are made long before a new generation of engineers can be educated adequately, so that they themselves may become teachers of future engineers in these broader fields, and thus we find the burden placed squarely on the shoulders of science teachers. This complex of events has brought a far closer tie between the industrial and the pure science effort—as opposed to engineering and applied science—than has ever existed before, and the demand for men educated in the basic sciences both by industry and by government has grown to vast proportions. There is good evidence that we are entering an era of increasing support of pure science by industry in this country, and this is most encouraging. Thus science faces a whole host of educational problems, the successful solution of which can do much to strengthen our country's economy and security. Before turning to these, however, let me point out that the developments of which I have been speaking emphasize the dangers of narrow specialization, and indeed are leading to a wave of "anti-specialization". This trend to broader and more basic requirements in education is of importance in helping us plot the course of our future educational effort.

[1] These estimates are given by Dr. Daniel Alpert in an article entitled "Physicists in Industry," Westinghouse Engineer, May (1953).

THUS FAR, I have been speaking of science purely in terms of its practical, utilitarian importance. Let me hasten to assure you that I do not underestimate the purely cultural values of the sciences—indeed quite the contrary—and in fact I would place these subjects well in the forefront of the liberal arts. To my way of thinking, the sciences, especially mathematics and physics, represent the greatest intellectual achievements of the human race, and their evolution has set the pattern for much of modern civilization. I submit that one of the educational "musts" is the teaching of the sciences in depth as an integral part of the educational scheme for all students. The importance of attaining some reasonable measure of judgment about things scientific can hardly be overstated, and the dual role of the practicality and the sheer intellectual and esthetic value of science emphasizes this need. Proper understanding, not only of the principles and methods in science, but of the sharply defined limits of experience within which it functions, is of immeasurable help in resolving many of the so-called conflicts between science and the spiritual affairs of man. Clarity and precision of thought and of written and verbal expression, are an integral part of the intellectual discipline provided by science, and it is evident that the attainment of these skills is of paramount importance for all.

Now to the challenge which faces educators in science. They must tackle a really difficult and subtle task. We are confronted on the one hand by a situation which brings us face to face with a rapidly expanding body of scientific knowledge and an increased tempo of scientific activity, along with the growth of a more difficult, subtle, and abstract theoretical structure, and on the other hand by the hard fact that essentially no more time is available for the scientific education of a student than in the past. We are already at a stage where a truly adequate base in science calls for a doctor's degree, and certainly much more of a young person's life than the seven or eight years needed to attain this can hardly be expected. What then can be done to satisfy the mutually exclusive requirements of a larger and more difficult body of scientific knowledge and the impossibility of making available a sufficiently long period of time in which to teach it? The mere addition of material covering modern scientific findings to the traditional content of science subjects will lead to dilution and superficiality, which can damage severely the educational value of scientific teaching. There is a growing and compelling need for an active and objective program to determine what part of the traditional subject matter in such courses may be omitted to make room for modern topics. It is further imperative to teach science in depth, and, if necessary, coverage of a wide range of topics should be curtailed to make time available for a deeper and more fundamental approach. One must be concerned more with the student's understanding of the spirit and methods of scientific investigation than with his exposure to a wide range of factual matter. I do not pretend to know in detail just how to accomplish these ends. The problem is difficult but it must be faced squarely and tackled in a true scientific experimental manner. It may well turn out that more than one satisfactory solution exists, and I suspect that this is true. So much the better, for then it will become possible for an individual teacher to choose those areas of scientific experience which he finds interesting and challenging as the vehicles which he may use to impart an understanding of the basic principles and logical coherence of his subject. Undoubtedly there will arise difficult problems of learning just how much of the applications of science must be included to stimulate adequately the interest of students without too much sacrifice of time for fundamentals, and I suspect strongly that each teacher of science will find that the proper answer will depend significantly on the particular group of students with whom he has to deal. From a somewhat broader point of view, the most difficult problem of all is that of getting a student to feel at home, so to speak, with abstract concepts and reasoning, for this is one of the principal signs of the growing maturity of our scientific effort. No longer can we appeal safely to the simple everyday experiences of man to attain proper understanding of the basic concepts of modern science. Let me illustrate by a very simple example. As you well know, the concept of mass in physics has evolved in somewhat the following manner. If one considers the weight or pull of the earth on a body such as a piece of metal which one may hold in one's hand, one recognizes in the most primitive way, because of the muscular exertion required, that there is a force with which the earth pulls on this body, and that this force depends both on the earth and on the particular body under consideration. One then proceeds to describe this experience by a separation into two factors: one relating to the earth, and one to the body. The latter attribute we designate as mass (in contrast to weight), and this concept of mass has grown from the very crude initial idea of "quantity of matter" to an extraordinarily abstract concept in modern-day physics—the tangible character of mass, so to speak, has disappeared completely. One talks nowadays of the mass of an atom or of an electron, and let us consider briefly how such a quantity is determined. We look into a laboratory containing a mass spectrograph used for such a measurement and find an array of electrical equipment, magnets, batteries, electrical meters, and so on. The measurement of mass consists essentially of the readings of electrical instruments, and from these readings one then must perform a theoretical calculation, out of which emerges a number which denotes the mass of the atom under investigation. This is a far cry from the relatively direct method of hanging a piece of metal on a spring balance to determine its mass. But just this process of indirect reasoning, of deducing the fundamental properties of matter from observation with the help of a complex theoretical structure, is typical of the methods of modern science.

The educational problem which I have just outlined constitutes a real challenge by itself, but unfortunately is only part of the whole picture. Essential to the success of any educational program in science must be adequate and skillful laboratory instruction; for the sciences, with the exception of mathematics, are fundamentally experimental sciences, and derive their meaning and significance in the last analysis only from observation. In this problem those schools which handle large numbers of students are at a serious disadvantage, since it is just in the experimental approach to a science that nothing can really replace individual experience. We at the Massachusetts Institute of Technology are confronted with such a problem, since at present some 1700 students study basic physics, and I can assure you that the problem of supplying adequate and meaningful laboratory instruction for all these students is by no means trivial. One of the great dangers of teaching the experimental sciences without laboratory experience is that of unwittingly creating in a student's mind the notion that science is essentially deductive in nature. A law or principle is stated either by the teacher or by the book and everything is then to be deduced from these authoritative starting points. Nothing could be more harmful to a proper understanding of the very essential inductive methods of reasoning, the generalizations from experimental experience, the probings and assumptions, and the speculations which characterize a true scientific approach to a problem. It is perhaps even more important to enable a student in the sciences to gain an insight into the manner in which the great principles have come into being, starting from experimental observations, than to acquire mechanical facility in applying well-established principles to specific problems. Just as there is a dual aspect to science, viz., pure and applied, so are there dual objectives in the teaching of science in caring for those who intend to go on professionally in the sciences and their application, and for those who will not require further education in these areas. It is my opinion that the same broad principles which I have already presented are valid for both types of students but there may well be a somewhat greater emphasis on the applications of science to technology and industry for nonscience majors than for the science majors in any given student body. In fact, a student who intends to embark on a scientific career would benefit by learning science at the secondary school level almost exclusively as a cultural subject, designed to enhance his intellectual breadth, and the applied aspect should be minimized. Since the secondary schools operate at that stage of education where interest in science essentially starts, and students begin to feel the direction in which they wish to move in later life, these schools can be looked upon properly as the primary source of the scientific manpower of the nation.

If what I have been telling you this afternoon is significant, then the extraordinary importance of science education in the secondary schools becomes evident. All of us who are concerned with scientific education look to schools such as Hebron Academy to lead the way in attaining effective solutions to these great problems which we all face.

Books

Library Organization and Management of Technical Reports Literature. By Bernard M. Fry. 140 pp. The Catholic University of America Press, Washington 17, D. C., 1953. $2.25.

Parallel with the growth of the published literature there has developed in recent years a new medium—the technical report. This book by the deputy chief of the Technical Information Service, United States Atomic Energy Commission, brings together in one volume interesting, and in some instances valuable, information on the documentation activities of the various federal agencies.

The book consists of six chapters and numerous tables, charts, exhibits and appendices. Chapters II and IV concern themselves with library practices such as administration of reports libraries, reference service, processing and cataloging. Chapter V contains a discussion of the handling of "security classified" documents.

Perhaps the most informative parts for both the scientist and the reports librarian are Chapters III, on producers and sources of technical reports, and IV, on the technical information service of the Atomic Energy Commission. In these chapters is found a concise and informative guide to the sources of scientific data, both published and unpublished, available from the various federal agencies. Included in Chapter III and its appendices are: a list of research and development organizations in the federal government, their principal fields of work, the location of main and field stations, and instructions concerning availability and source of reports issued; a list of AEC depository libraries; and a description of the abstracting journals issued by the Navy Research Section (now Armed Services Technical Information Agency), Atomic Energy Commission, National Advisory Committee for Aeronautics, and the Office of Technical Services, Department of Commerce.

The book also contains such incidental information as: Federal expenditures for research and development for the fiscal years 1940–50; total expenditures for research and development in the United States, 1941–52; distribution of the 137 000 scientists and research engineers in the United States, 1947; sources of annual production of technical reports in the United States in 1949; and the size, character, and annual growth of the technical report collections of some 29 research and development organizations in the country.

Fry's compilation provides a convenient source of information on governmental activity in the documenta-