Science and Humanity

Detlev W. Bronk

Johns Hopkins University, Baltimore

TO COMPREHEND THE ROLE OF SCIENCE in American civilization, we must look beyond the scientist's desire for practical accomplishments. It is especially important that we understand this at a time when every man's life is profoundly affected by the scientist's actions and at a time when the national government has assumed a direct responsibility for training scientists with tax-contributed money.

The most powerful motive in science is curiosity. Few may doubt this, because curiosity is common to all men; it may seem unnecessary to comment further. I do so because, even in this age of science, curiosity is often considered a bothersome trait which has got us into a great deal of trouble from the days of the Garden of Eden to those of Hiroshima.

There is opposition to curiosity first in childhood. Only the most patient parent encourages its free development at the expense of his personal peace. Only the wisest of teachers discard the easy methods of didactic instruction to follow as counselors at the heels of students who freely satisfy their curiosity. Even in the scientific laboratory the student's curiosity is suppressed and the laboratory becomes a training ground for technical manipulation rather than a place for intellectual exploration. The present tendency to create an educational system which thus suppresses curiosity for the sake of "efficient" education robs modern civilization of the true scientists it needs.

Nor will the scientists' research flourish unless they have freedom to follow their curiosity. Against this there is now strong opposition. When science seemed rather unimportant, scientists were left pretty much alone to do as they wished—provided they were able to live. Nowadays science is recognized as necessary for human welfare and national survival. Because of this there are many who are willing to support science provided they can organize and direct the scientists' activities—about which they know but little. And there are those who believe that the usefulness of scientific research can be increased and its practical yield multiplied by putting many scientists to work under the controlled direction of a few.

There are problems and there are times which require that the individual freedom of the scientist be submerged in a common effort for the public good. But there is a grave danger that the present demand by publicists, industrialists, and public administrators for large scale scientific organizations may impede progress.

The most important discoveries of scientific research have come from the intellectual adventures of individual scientists. No one directed Newton to discover the laws of gravitation. No one organized Faraday's discoveries in electricity for the benefit of the modern electrical age. No one suggested to Roentgen that he discover X-rays for the diagnosis of human ills. No one instructed Niels Bohr to pave the way for atomic energy. Great scientific discoveries will usually elude direction and organization as surely as would the creation of great music or poetry, or sculpture or art. Much of scientific research is exploration of the unknown and I, for one, do not believe it is possible to direct the course of an explorer through unexplored territory.

Scientists have a second purpose, no weaker than curiosity, but more difficult to achieve. It is the desire to bring order out of chaos. Those who suddenly grasp the relation of previously unrelated facts, and thus see their relevance, experience a deep esthetic satisfaction. It is in that phase of scientific endeavor that facts and observations are formed into the structure of knowledge, which is the foundation for further discoveries. This is the role of the scientist's creative imagination. Without freedom and leisure for the play of his imagination, a scientist becomes only a fact-gatherer, dealing with the bare bones of science, unarticulated and unclothed with the flesh of meaning. As we plan our new age of science we shall do well to preserve an environment in which this freedom will be nurtured, despite the urgency of present needs. For it is unlikely that the scientists' imagination will often leap to a specified goal. A chaos of facts will seldom fall into an ordered, predetermined pattern, useful for a certain end.

Modern scientific endeavor must certainly be organized to provide the instruments for research and the combination of human skills necessary for diverse experimental tasks. But society will gain most from scientists if they are given freedom to observe, to experiment and think. Science is playing an important role in America's world-wide struggle for the freedom

of the individual. In order that science may play that role well, the freedom of the scientists must be preserved against the regimentation of overstuffed organizations here at home. Despite the fantasies of scientific planners in and out of Russia, I should be surer of the social value of a mere score of scientists who are free to investigate and explain the facts of nature than of a thousand who are organized for the solution of a directed end.

In a democracy, however, it is not easy to justify such personal leisure and freedom, when most of the population must labor at routine tasks. "Why," asked a member of a Congressional appropriations committee recently, "should so few be supported to learn so much when so many know so little?" It is well to admit to such skeptics that some of the most important contributions of science to human welfare have no obvious practical usefulness. But let them consider how in a few generations we have been freed from the fear of natural forces that were mysterious and malevolent; how we have been freed from slavery to ignorance and superstition. At a time when science is prized for its contributions of instruments and weapons, of food and health and physical power and comfort, I would remind you that the pleasure which comes from an understanding of the beauties and forces of nature is a subtle value of science which extends the horizons of our intellect and enriches our lives.

Scientists are largely to blame for the fact that these intangible rewards of scientific investigation are not generally understood. One never hears musicians or sculptors or poets justify their role in society with the claim that they increase the physical well-being of their fellow men. Society values them, insofar as it values them at all, for the pleasure they give to life. Scientists, however, emphasize the material benefits of science because these are readily comprehended and accepted. In doing so, they misrepresent and belittle some of their major contributions to human welfare. Scientific research is one of the great adventures of the human mind. When the spirit of that adventure is generally understood, it will quicken the life and raise the hopes of people everywhere.

This is sufficient justification for the support of science as a major activity in society. But the effects of science do not end there. There is scarcely an aspect of American civilization which has not been shaped by scientific research and the applications of research. Our supply of materials comes from the laboratory as well as from nature. Industry depends upon power, scientifically created and controlled. Commerce requires swift transportation. Men live in cities heated and lighted and kept sanitary by scientific methods. Accordingly, the maintenance of American society requires a great army of scientifically trained men and women.

The characteristics of a continually developing American civilization are such that there is also an ever-increasing need for scientific investigation. The discovery of new metals makes possible the design of new machines, but that may require the development of new mathematical procedures. Atomic energy has created new elements which have made possible the discovery of new treatments for disease. In turn, such treatments require new methods for human protection against radiation. Each new scientific development creates further problems which require more study and research.

The demands for the fruits of science are further augmented by the recent war and by the present international hazards. This is an old story in the modern tempo, for the practical importance of science to warfare has long been recognized. Galileo and Leonardo were employed by their governments to improve artillery and the art of fortification. From that time onward, science has shaped the pattern of warfare until today science is recognized as one of the first lines of national defense. Scientists are required by the thousands for the training and operation of our armed forces. New weapons of aggression, forged by science, require of scientists new means for counteraction and defense.

The New Status of Science

Our culture, shaped by science and dependent upon science for its preservation, is now changing the pattern and status of science in America. Of that new status there are four aspects worthy of consideration.

The support of research. The first is a great increase in the money spent for research. During the year 1930, 166 million dollars were expended for scientific investigation and for its development towards practical purposes. By the year 1947 this amount had been increased to more than one billion dollars, which does not include expenditures in the field of atomic energy. Looking into the future, the President's Scientific Research Board has recommended that the amount should be two and a quarter billion dollars by 1957.

It is significant to recite additional figures. In 1930 the United States Government expended 23 millions for science, or 14 percent of the total. In 1947 the federal sum was 625 millions, more than 50 percent of the total national expenditure for scientific research. Obviously, those who are responsible for determining our national policies believe that the support of science is a governmental function.

But it is not surprising that they should meet strong opposition. On the one hand, federal support of science is opposed because of fear that science and scientists will be deprived of their freedom, and that the fruits of science will wither. On the other hand, there is also fear that the central government may gain from its vassal scientists too much power over the American people. To shrink from such dangers, however, is to doubt the virtues of American democracy.

If there be any field of activity which is the proper province of the national government, it is the encouragement of research. It is from scientific research that our citizens have the greatest promise of higher standards of living, better health, and security against the dangers of foreign aggression. Individuals, unaided, cannot reap the full benefits of science.

It would be unfortunate if the full responsibility for the support of science were relegated to the government. The integration of science into American culture requires that many individuals have the status of participating stockholders in the advancement of science. That this is increasingly so is a healthy characteristic of our social customs. University departments of teaching and research are supported by great numbers of individuals who are conscious of their responsible part in society. Countless industries are this year expending half a billion dollars on the discovery and development of new knowledge. Foundations for the furtherance of research now receive the benefactions of millions who, to the limits of their resources, follow the generous example of the wealthy few. Such are the National Foundation for Infantile Paralysis and the American Cancer Society.

The need for more scientists. The wise use of these increased financial resources requires a great increase in the number of scientists. This is the second characteristic of the new status of science.

It is not long since scientific research was an avocation of teachers and exclusive occupation of but a few isolated workers. Today universities, industries, and the government compete to fill needs for many thousands of scientific investigators. The number of scientists, technicians, and engineers has increased only one-tenth as fast since 1940 as has the expenditure for research and development. While the budget was increasing 335 percent, the supply of trained manpower expanded only 35 percent.

The technological and scientific progress of the nation and its operation depend upon less than one-half of one percent of our population; one-tenth of one percent of our population are actually engaged in scientific research and development; less than twenty-five thousand among our population of 150 million have had the advanced training for scientific research and teaching represented by the doctorate.

To meet these needs, the universities are straining every available facility. Private and public foundations and industries are contributing large sums for the education of scientists, and the government is initiating fellowship programs for the training of young men and women. The Atomic Energy Commission alone has appropriated two and one-half million dollars for such fellowships during the coming year or two. This is the development of a national resource of great importance.

No individual is endowed with all the qualities required for the pursuit of science, but there are vast, untouched reservoirs of human talent. For the advancement of science, as for the advancement of every phase of our civilization, we must learn to identify and to train those who are best qualified for a given social function, without regard for family fortune. Only thus are we likely to meet the specialized needs of a complex culture.

The spread of science. For several centuries the universities have been the nurseries and the homes of science. Now, as the number of scientists trained in the universities increases, more and more of the scientists migrate elsewhere.

The university began to lose its place as the only home of research about 1900, when the laboratories of the General Electric Company and of the Bell Telephone system were first established. Such industrial laboratories have grown and multiplied without a stop in sight, and now they have their numerous federal counterparts. This spread of science outside the universities is a third characteristic of its modern pattern.

It is well for the universities that this is so. A university is the ideal environment for thought and investigation and the spread of knowledge. The application of that knowledge to the practical problems of today is the function of other institutions which are being created for that purpose. The university scientists who withstand the pressure to solve practical problems of the present are the scientists who are free to pave the way for useful applications of the future.

The social responsibility of the scientist. Many of those who are devoted to the discovery of new knowledge have developed a concern for its social effects. I would name this uneasy sense of responsibility as a fourth characteristic of modern American science. It is natural that this should be so in troubled times of great change, for which science is in no small part the cause.

The critical needs for national survival marshaled our science to an extraordinary degree during this recent war. But the scientists' satisfaction in their

achievements, which armed human courage, has been sobered by the realization that new forces of destruction were thus unleashed. Nor has the end of conflict been reassuring. The accomplishments of ages lie in ruins, and the hardly gained knowledge of nature is used by both, in the conflict between the good and the evil.

Science itself is neither good nor evil. It is "neither a benign nor a malignant activity of man." Science is a quest for knowledge and understanding, to be applied for human use as men desire. It is with such thoughts in mind that scientists feel an increasing obligation to participate in decisions as to how their discoveries and technical developments shall be used. But the fulfillment of this obligation will require scientists to acquire a knowledge of human affairs and of the motives which shape public policy. Even then scientists will most effectively participate in the wise use of science in public affairs by disseminating and understanding of science to those in public authority and to those who shape popular opinion.

Certainly it is desirable in a democracy that every citizen take an active part in the direction of government, to the limits of his abilities. Accordingly the growing social conscience of scientists is desirable. So, too, is the slowly increasing participation of scientists in the affairs of government. But our complex social structure requires that each citizen have a primary responsibility for some special task. Thus I return to the point that our future welfare requires that a goodly number of scientists be free to study nature without regard for the practical needs of the moment.

The Place of Basic Research

The encouragement of scientific exploration or research—in contrast with the application of science—has not always been a characteristic of American culture. Commenting upon this a century ago, Alexis de Tocqueville attributed the emphasis upon immediate, practical values to the traits of a democracy, where, said he, "men . . . seldom indulge in meditation . . . and require nothing of science but its special applications to the useful arts and the means of rendering life comfortable." The observations of this distinguished observer of democracy in America were not far wrong, for fundamental research has flourished less here than in Europe. But his assumptions as to the reason for our emphasis on the practical aspects of science have been disproved by the recent development of basic science within our democracy. There are significant causes for this increased emphasis on fundamental research.

One of these causes is the spread of college education and the inclusion of science in the academic curriculum. To this I would add adult education in science by the radio and by scientific journalism which has reached high standards here in the United States. But as President Conant has emphasized in his book *On Understanding Science,* much of our education still deals with the results of science; there is little discussion of the methods and sequence of science. Until this defect is corrected we face a popular demand that scientists mortgage their future usefulness by concentrating their efforts on the practical application of past discoveries.

Despite the inadequacies of scientific education for the layman, many recognize that Michael Faraday's discovery of electromagnetic induction was necessary for the subsequent development of electric power and light and traction; that the botanical research of Gregor Mendel in the garden of a monastery paved the way for increased production by modern agriculture; that the theories of Willard Gibbs laid the foundations for much of our chemical industry.

Realizing this dependence of the practical upon that which is at first impractical, many intelligent citizens have supported basic research in universities, whence the discoveries flow into the stream of knowledge. The universities have thus assumed responsibility for exploring the endless frontiers of the nation.

In a democracy, it is appropriate that this national service should have been initiated by individuals. It is desirable that they should continue to accept that obligation. But it is also a proper responsibility of the national government which previously has been charged with the development, and protection for the future, of basic natural resources such as forests, water power, soil, and fisheries. Basic research, in contrast to applied research and technology, is not unlike such resources, for it provides new scientific knowledge of future value for our national welfare. This is the reason for support of university research by the Public Health Service and the armed forces and the proposed National Science Foundation.

In accepting such a partnership with the federal government the universities have assumed an obligation to preserve the freedom of scientists to seek "new trails to knowledge." Despite the present vigor of science, many who determine public policies see the desirability of applying a new discovery in the development of materials, machines, or weapons, in the treatment of disease or in the improvement of agriculture. Few have the faith to support abstract research, in the exploration of the unknown, for the benefit of future generations.

"If the Americans had been alone in the world," said De Tocqueville, "with the freedom and knowledge acquired by their forefathers and with the passions

which are their own, they would not have been slow to discover that progress cannot long be made in the application of the sciences without cultivating the theory of them." We are not alone in the world, but we now occupy a position of preeminent power in world science. In our present position is it appropriate that we should benefit from the discoveries of scientists in other nations without contributing in return some discoveries to their benefit?

Science Is International

There can be no consideration of modern American science without regard to the international status of America. Our position in the world and the condition of the world depend upon science. If you suspect me of exaggeration, I suggest that you recall the influence of the atomic bomb on world thought and action.

The genesis of new ideas is catalyzed by the work and thought of others. Recognizing this, scientists have been among the first to realize the dependence of their work upon the efforts of those in other lands. Together with the traders for rare goods they have sought intellectual products and new discoveries wherever they were to be found. This desire for international cooperation derives from no unique nobility of spirit, but comes, rather, from the simple realization of the personal advantages that derive from a free exchange of ideas. If scientists are better prepared than others for the acceptance of the principles of world unity, it is because they have longer realized the benefits that come from such cooperation.

American scientists roam the free world for ideas and knowledge, and gladly receive their foreign colleagues who are free to come. Scientific missions to foreign capitals have been established for the exchange of information, and large sums have been allotted under the Fulbright Act for the interchange of scholars. Most significant, perhaps, is the role of the American government and American scientists in rebuilding the physical facilities for scientific research and teaching in foreign countries. Our nation is but one of the nations in a civilization that is based upon science. Lasting benefits of the unprecedented European Recovery Program will depend in large measure on the degree to which European science recovers its ability to meet the needs of a modern society.

Science increased in any free country will be "increased to the benefit of mankind in general." The observations of Galileo and Copernicus extended the intellectual horizons of no one national group; the discoveries of Faraday, the Englishman, have eased the labors of the citizens of many countries; a cure for disease discovered in Holland will be as beneficial to a sufferer in New York as it would be if it were made in Philadelphia. The future of American science and the welfare of the American people depend upon the rehabilitation of science throughout the world. Without such a scientific recovery, the civilization of other nations will become very different from the American culture.

Even now we delude ourselves when we talk of living in an age of science. The cultures of America and Western Europe are very different from those of other areas. If science expands in America without a corresponding development everywhere, there will be a further imbalance of cultures. There lies a grave danger to peace and stability.

The use of modern science gives a nation tremendous power and material advantages. Accordingly, it is natural in these days of international tension that those countries in which the practical aspects of science are developed to a high degree should be feared and suspected, and envied for the benefits they reap. This leads me to inject a comparison of American and Russian science. Excepting a few isolated, practical developments which would surely be used against us by an enemy, the discoveries of American scientists are free for all to hear and read. American scientists are encouraged to visit their colleagues overseas and to teach in foreign lands. Our laboratories and universities have been opened to foreign visitors coming by the thousands. Untold millions have been contributed to equip laboratories abroad. American science has done its part in rebuilding the international highways of science. This Russia has not done except in one week of self-gratifying celebration.

American science—in common with all phases of our culture—has accepted the responsibility to share its knowledge and its methods with all peoples, and especially with victims of poverty and disease and ignorance. Western science has an important role in shaping world cultures appropriate for these times.

Science Can Build A Better World

Modern cities with sanitation and communication and transportation are the products of science—but slums and noise and polluted air are symbols of our too great regard for the material aspects of civilization, and of too little regard for human life; the machine worker of mass production has not yet achieved a noble life of creation. Certainly the solution is not to abandon science, for even those who deplore most loudly the evils of our machine age would reluctantly return to a life of ceaseless labor, hardship, and disease. The same machines that build the slums can recreate the cities for human welfare. The planes that carried bombs on their missions of destruction

are also available for the swift transportation of sick and wounded.

If I were to name another and one of the most admirable characteristics of American culture, it would be the gradual union of the physical and the human sciences, and more especially the union of the natural sciences with the social sciences and the humanities. In these troubled days the scientists can take little satisfaction in the social consequence of their discoveries. The material contributions of science alone do not create a rich and satisfying life. Nor do the intellectual values of science alone provide the spiritual satisfaction which men crave. Scientists are merely partners of many others in mankind's great endeavor. Science liberates men from the fear of unknown natural forces, frees men from grinding toil for mere survival, subdues pain, and cures sickness. Thus, science frees men to enjoy art and music and literature and the beauties of nature and religious faith. Science makes possible the enjoyment of much that science alone cannot give. Scientists are partners of those in other walks of life who seek to improve man's estate.

I should be blind to the status of modern American science if I did not recognize its critics and opponents. Many are torn between *fear* of new horrors science may add and *hope* that science will build a better world. Without science, which created the atomic bomb, we would still be defenseless against natural forces and disease. Would we rather be the *certain* victims of natural forces or *possible* victims of atomic energy misused by man? The question is: Do we have courage to understand the facts of nature and educate our fellowmen to use them for human welfare?

Science provides the building stones of a better world—but the world will be as we choose to make it.

This article was condensed from a chapter in the forthcoming book Changing patterns in American civilization (*the inaugural series of Benjamin Franklin Lectures delivered at the University of Pennsylvania during the spring of 1948*). *The volume is to be published May 20 by the University of Pennsylvania Press.*

The Enzymatic Reduction of the Retinenes to the Vitamins A

George Wald[1]
Biological Laboratories, Harvard University

THE RETINENE$_1$, formed by the bleaching of rhodopsin, is converted to vitamin A_1 by a reaction for which reduced cozymase (DPN—H_2) serves as coenzyme (*10*). Retinene$_1$ is vitamin A_1 aldehyde (*2*); and the essential process is the transfer of two hydrogen atoms from DPN—H_2 to this molecule, reducing its carbonyl group to the primary alcohol group of vitamin A_1:

$$\underset{\text{retinene}_1}{C_{19}H_{27}CHO} + \text{DPN—}H_2 \xrightarrow{\text{retinene reductase}} \underset{\text{vitamin } A_1}{C_{19}H_{27}CH_2OH} + \text{DPN}$$

In the outer segments of the retinal rods this system is coupled with a second one which reduces DPN (*10*).

The reduction of retinene$_1$ has been followed in cell-free bries of whole retinas, in suspensions of isolated outer segments of rods (*10*), and in freshly prepared solutions of rhodopsin in aqueous digitonin (*3, 10*). Such fresh rhodopsin solutions lose the capacity to reduce retinene$_1$ within 3–4 hrs after preparation. This is because they lose their DPN—H_2 by the action of an enzyme widespread in animal tissues and particularly active in brain, to which retina is closely related (*4*). Rhodopsin solutions left at room temperature for 18 hrs, which have entirely lost the ability to reduce retinene$_1$, are reactivated by addition of new DPN—H_2. The apoenzyme, retinene reductase, is therefore relatively stable; the inactivation of fresh rhodopsin solutions is due to the loss of the coenzyme.

The retinene reductase system has now been fractionated into its components, all in true solution. Two components are in a satisfactory state of purity and chemical definition: the coenzyme, DPN—H_2, prepared by Ohlmeyer's method (*5*); and the substrate, synthetic retinene$_1$, prepared by the chromatographic oxidation of crystalline vitamin A_1 on manganese dioxide (*2, 8*).

The apoenzyme has not yet been isolated as a pure substance, but it has been prepared free of the other components. It is extracted with dilute salt solutions from homogenized frog or cattle retinas, forming a

[1] This investigation has been supported in part by a grant from the Medical Sciences Division of the Office of Naval Research. I should like to acknowledge the expert and devoted assistance of Mr. Paul K. Brown in many of the experiments.