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Science and Public Understanding

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As a setting for this paper, I would like to go back almost 400 years to a rebellion started by a 14-year-old schoolboy. The boy was Francis Bacon; the year, 1575; the setting, Cambridge University. The rebellion turned out to be one of the most important revolutions in the whole history of thought, for the schoolboy Francis Bacon became the first prophet of the scientific age, and to do that he had to overthrow the whole system of scientific thought of the philosophers and learned men of his day.

Before going any farther, let me explain that although I start almost 400 years ago, I will get up to date very quickly, for after saying a little about the revolution that Francis Bacon started, I want to discuss for a little longer another revolution that some of us ought to start.

Bacon was born in 1561. Henry VIII had been dead only a few years, and his daughter, Queen Elizabeth, occupied the English throne. England was beginning to become a powerful nation, but the Spanish Armada was not destroyed until Bacon was well along in his twenties. It was an age of exploration. Among Bacon's contemporaries, Henry Hudson explored territory familiar to all of us; Francis Drake explored other parts of the globe; and William Harvey explored the blood stream. Bacon was undoubtedly influenced by these discoveries, but another type of discovery influenced him even more. He was impressed by the invention of the printing press, and saw that the easy production of books would become a powerful influence in educating man and changing his thinking. The invention of the compass made it possible for Hudson, Drake, and others to explore the whole world. The work of smelters and potters and glass makers was producing new materials and products of wide usefulness. Bacon foresaw that such inventions would have a profound influence on the conditions of human life.

Bacon also saw the philosophers and learned men of his day and was not impressed—at least not favorably impressed—by what he saw. Science in Bacon's time was the possession and privilege of a few learned men, philosophers who followed the tradition of Aristotle and Plato. Bacon found their theories sterile. He counted their failure to observe natural phenomena and to conduct experiments a lack so great as to doom their work to everlasting uselessness.

Social Utility of Inventions

Contrasting the social utility of inventions with the sterility of the theory-spinning of philosophers, Bacon started his rebellion. Clearly it was no minor tyranny he sought to overthrow. On the contrary, he set out to be a giant-killer, to overthrow the whole system of scientific thought of the philosophers and to remake the world in order that all men might live fuller, happier, and healthier lives. Prevailing thought before Bacon's time did not conceive of the possibility of a drastic improvement in the conditions of human life. Bacon did conceive of such an improvement. He foresaw, and was perhaps the first to foresee, that this goal could be achieved by a great scientific revolution. To the grand design of that revolution he devoted his life. The science that Bacon sought to establish was to be grounded in experiment and natural history, was to be productive of new inventions, was to provide the foundation for an expanding industry, and was to serve to better the lot of individual men.

Profound and sweeping as these proposals were, they have been realized. We who live in the age of science and technology see the evidence on every hand. It would be fun to bring Bacon back to life and to serve as his guide while he discovered the changes that have taken place. Imagine his excitement in purchasing shirts that need no ironing, socks that do not wear out, a stove that lights its own fire and extinguishes that fire when the meal is cooked, a shiny box for the kitchen in which food can be kept fresh for long periods, spectacles with a hearing aid concealed in the temple. In the array of available goods, Bacon might be particularly pleased to find the many articles made of stainless steel, for one of the specific projects he proposed was the development of rust-proof steel. He even predicted that stainless steel would find its first use in the kitchen.

It would be fun indeed to show Bacon a house full of gadgets, a big department store, a busy airport, or a modern hospital, but the sight-seeing trip should not stop with such exhibits. For Bacon knew that pure empiricism—experiments of fruit, as he called such practice—was only part of the task ahead, and that more fundamental research—or what he called experiments of light—was also necessary. Bacon believed that as long as one restricted himself to empirical and technological work, inventions could come only one or two at a time, but advances in basic knowledge and understanding of nature's laws could result in whole clusters of useful inventions. It seems to me that this was one of Bacon's greatest insights. The dependence of technology on basic science is now generally recognized. For Bacon to recognize this relationship during the comparative infancy of both experimental science and industry shows how remarkably sound his judgment was.

Bacon would certainly want to see our modern scientific research laboratories. To the prophet who advocated the collection of great storehouses of the factual knowledge of nature it would be an exciting experience to visit the Smith-

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sonian Institution, the Library of Congress, and some of our magnificent zoological and botanical parks. To the prophet who foresaw that the scientific revolution was too great a task for any private individual, and who called upon King James for government support, it would be a revelation to visit the National Science Foundation and the National Institutes of Health and to read an account of the federal appropriations in support of research and development. The philosopher who berated philosophers for spinning elaborate theories without observing the phenomena they were discussing would be an ardent supporter of the close and continuous interplay between experiment and theory that characterizes the work of scientists in our universities and research laboratories.

In truth, many of the things that Bacon advocated have become common practice; many of the things he wanted to see come to pass have come to pass. His role as the first philosopher of the scientific age is completely and permanently established. To my mind, perhaps the best summary of his accomplishment is to say that he took science away from a little coterie of philosophical speculators who realized neither its nature nor its potentialities and gave science to the whole world with instructions for making it the most powerful instrument man has known for improving the conditions of human life.

Social Decisions Required

We have come a long way on the road that Bacon charted. Unquestionably, he would be enthusiastic over the progress that has been made. But he could not be complacent, for the very success of science has created a new problem in its relationship to the welfare of society. The new problem is this: science has become so abstract and complex, and is changing so rapidly, that it has become extremely difficult for the nonscientist to understand. At the same time, science has assumed such a fundamentally important role in our industrial and technological society that it becomes extremely important for the nonscientist to understand its nature and the role it plays in our culture and our economy.

Some aspects of this problem are widely recognized, but the basic nature of the problem is not generally understood. As a concrete illustration, we have the case of the atomic bomb. The bomb is a frightening object, and the peril that comes from its destructive force is generally known. The more profound peril, however, is not well recognized. It is the fact that society simply cannot digest the bomb, and in this respect the bomb is symptomatic of the fact that science is gaining greater and greater power, and in so doing is posing more and more urgent problems for society. As scientists gain greater and greater understanding and control of the forces of nature, it becomes of mounting importance for society to make the right decisions concerning the support of science and the control and utilization of scientific developments.

Already we know the nature of some of the developments that will require difficult social decisions. What will society do with the ability to develop power in any amount, anywhere on the globe, free from dependence on water power or fossil fuels? What will society do with the ability to launch a missile capable of destroying a city thousands of miles away? What will we do with the ability to construct a factory that requires no human operators but only maintenance personnel to keep in repair the machines that convert raw materials into finished products? What will we do with the ability to send explorers to the moon?

These questions arise from the work of scientists and engineers, but the questions affect all mankind, and the answers that are arrived at should result from the thinking of other men, and not of scientists alone.

Popular Attitudes

The intelligent cooperation of scientists and nonscientists in arriving at answers is made difficult by the progress of science itself. For as science progresses, other men find it more and more difficult to appreciate what science is about and to understand the scientists' language, problems, and intentions. As scientists have moved farther and farther from processes and problems that are open to the inspection of other men, they have dealt more and more in abstractions, have developed specialized vocabularies and a technical jargon, and frequently have concluded that their subject matter is too esoteric for general understanding. In truth, it is difficult for the nonscientist to know what modern science is about. When the scientist speaks of megaton bombs, of distances a billion and more light years away, of space that is negatively curved, the nonscientist looks puzzled. Even if he recognizes the individual words, the magnitudes are beyond his comprehension, and he lacks a framework of experience and understanding into which to fit such strange concepts.

The absence of understanding leads to confusion and to a public attitude toward science and scientists that is muddled instead of being clear and coherent. On the one hand, a considerable amount of anti-intellectualism exists. The scientist or scholar is frequently an object of suspicion and mistrust. His loyalty is more likely to be questioned than is that of other men. He is considered strange, unusual, not altogether honest, and sometimes antisocial. The teacher is a "square," and rigorous intellectual scholarship is out of date. These disquieting attitudes show up in many forms and places. On the other hand, however, the public is not opposed to science; it welcomes and enjoys those fruits of science that it can assimilate. There is no serious opposition to radar, television, antibiotics, or electronic computers, and we know that the individual who perfects a cure for cancer will be a public hero. Thus, while the fruits of science and scholarship are honored, the scientist is not. This is what I mean by saying that popular attitudes are muddled.

It is, I think, a truism that a society that does not appreciate the problems and the promise of science, the things it can do and the things it cannot do, cannot derive maximum benefit from the potentialities of science. A society that eagerly grabs the fruits of science but does not accept the scientists who produce those fruits cannot make full use of the scientific talent that exists in its midst. A society that does not understand science cannot make the wisest decisions on how to use the new powers that science gives it.

On this point I would like to quote from an address given by J. Bronowski at the 1955 meeting of the British Association for the Advancement of Science ["The educated man in 1984," *Advancement of Science* **12**, 301 (1955); *Science* **123**, 710 (1956)]. Bronowski said: "When a society is penetrated, as ours is, by technical skills and engines, the decisions of state cannot be taken out of the context of science. . . .

"The fate of a nation may hang on an error of judgment here. Let me give you a slightly mischievous example. In 1945, the British Government published. . . . a White Paper on the wartime development of atomic energy. Among the documents in this White Paper is the directive by which Mr. Winston Churchill . . . set up the project to make an atomic bomb. This directive begins with the words: 'Although personally I am quite content with the existing explosives. . . .'

"This bland phrase is a monument to a nonscientific education. Think what it would have implied in a dictatorship—in which, as the example of Germany shows, the dictator is surrounded by specialist advisors who are yes-men, and who are therefore bigoted and ignorant even in their specialty. In a dictatorship, Mr. Churchill's satisfaction with existing explosives would have been the end, not the beginning, of serious research toward an atomic bomb. . . . I do not much care for atomic bombs myself, but still less do I care to have them judged in phrases like Mr. Churchill's. In 1941, they might have weighed life and death between this country and Germany; and what brought down the scales was not the wisdom of statesmen, but the democratic tradition which caused Mr. Churchill to waive his own unwisdom.

"This example shows us succinctly what voters and statesmen do not know. I have called Mr. Churchill's astonishing phrase a monument to a nonscientific education. For it could have been written only by a man, an intelligent man, who simply does not understand how big a million is. The difference between atomic explosives and ordinary explosives is the difference between the length of a nuclear bond and a molecular bond; and this is a factor of more than a million. To suppose somehow that, in multiplying the energy of an explosive by a million, you are doing nothing very different from multiplying it by two, or five, or ten—that is simply not to grasp the scale of the world. . . .

"Here we reach the nub of what we mean by a culture. Of course, we do not want members of Parliament to be atomic physicists or experts in virus diseases. . . . Why should they be? They are not literary critics or historians. Yet, without being specialists, they know the difference between Milton and Kipling, and what sentiments each of these minds stand for. They know that Pitt and Napoleon were contemporaries and that, in the nature of things, the Industrial Revolution in England came before and not after the American Civil War. But in the field of science, the voters and those whom they elect have absorbed no such implicit knowledge. They have no framework into which to fit new information, no standards to test it by, and no vocabulary with which to handle it. If I were to say with enough solemnity that the stars must be very young because they are made of neurons and enzymes, no statesman would wink at me. . . ."

In this quotation and earlier, I have tried to demonstrate the importance to the world of having statesmen and voters with an intelligent and discriminating understanding of science. Let me discuss the steps necessary to attain such understanding. Those steps fall under the two familiar headings of education and public relations.

Education

Education in science needs much improvement. I am not here talking about the education of scientists, but about a more difficult problem—the education of nonscientists. This is not the place to go into details of educational reform, but it is pertinent to point out that there is a shortage of science teachers; that far too many science teachers are inadequately educated in their subject matter; that these conditions are likely to continue so long as prospective teachers can receive higher salaries and enjoy greater prestige in industry; that many science courses are dry, dull, and crowded with inappropriate and sometimes incorrect subject matter; that most college courses are designed almost exclusively for the future scientist; and that at all levels science is too frequently taught as a collection of facts instead of as a method of gaining knowledge. These are serious shortcomings, but I pass over them here in order to point out a more fundamental reform that is necessary.

When the traditional curricula of our schools and colleges were established, science was not included because it was not a necessary part of a good general education. For general cultural purposes, students had to master their mother tongue; they had to learn something of history and the arts; they had to acquire a modicum of arithmetic; they needed an introduction to ethics and morals and forms of government; and they needed some knowledge of the language and cultural traditions of other peoples. But students did not need science because adults could get along quite well without knowing science.

Later, as science came into greater prominence, American schools and colleges offered courses in science, but usually as electives rather than as an integrated part of a general curriculum. Much science is taught, and we have excellent technical schools. If a student wishes, he can go through college taking science or engineering courses and very little else. On the same campus his classmates with other interests can graduate with practically no science at all. Such specialism results in the nonscientist learning too little science, and the scientist, too little else. In England and the European countries, the separation has been even sharper. Special schools and colleges have been developed for students who want to study science, but these schools are intended for the training of future artisans, engineers, scientists, and technicians. The future lawyers, civil servants, statesmen, and men and women of general education continue to attend schools that follow the classical tradition. Neither in Europe nor in the United States has science become a generally accepted part of a liberal education.

The reasons that were valid in keeping science out of the traditional curricula are no longer valid. It is no longer true that most educated people can get along quite well without an understanding of science. It is as important for a Congressman to understand the impact of science on society as to understand the impact of nationalistic strivings on the stability of government. It is as important to understand the language of mathematics as the language of Ancient Rome. It is as important for a citizen to understand the influence of scientific and technological developments on the economy of his country as to understand the historical influences that shaped that country. Science has become an instrument of such power in changing society—whether the change be good or bad—that no nation that pretends to have an educated citizenry can neglect it. To do so is not only to remain ignorant, but to imperil the whole future of the nation.

Public Information

As a second point of attack, there is a public relations or public information aspect, as well as a formal educational aspect, to the problem of bridging the gulf between scientist and nonscientist. It is important to give a better understanding of science to students who are now in school. But it is also important to give such an understanding to the voters and policy makers of today. This is a huge undertaking, but fortunately there already exists a considerable effort to inform the public about science. Industry, scientific associations, and universities are engaged in a variety of adult education and public information programs. We have an able group of science writers whose professional competence is devoted to the task of teaching science to the lay public. It is true that too much of the popular information about science deals with discoveries and not with the processes by which they were achieved; too much attention is given to getting an earth satellite into its orbit before the Russians succeed in a similar effort, and not enough attention to the scientific meaning of having an instrumented basketball circling the globe a few hundred miles out in space; too much of science writing deals with black boxes, magic cures, and so-called modern miracles, and too little with a greater understanding of the processes of nature. These disproportions exist, but we know they exist, and scientists, science writers, radio and television producers, and others who contribute to public education can work together to bring about better balance and better general understanding.

Scientists must take the initiative for improving science education, for making science part of liberal education, and for giving the public a better understanding of science. They see the problem most clearly, and they have taken some of the steps that led to the present gulf of misunderstanding. They must take the first steps to close that gulf.

It seems to me a matter of utmost importance that the gulf be closed, that we secure a better general understanding of science and a better integration of science into the culture of our time. It seems necessary first because a growing gulf of lack of understanding endangers the continued support of scientific work. Second, it seems necessary because science and engineering have become and must continue to be a fundamental support of the way of life and the type of society we wish to continue. The future of science depends largely upon public understanding and acceptance; the welfare of the world depends largely upon the future of science and the wisdom with which society handles the problems that are raised by scientific and engineering developments.

Perhaps we need another revolution in thought, a revolution led by another enthusiastic and devoted rebel who will make it his life's work to bring about the better integration of science into the complex web of modern life and culture.

Postglacial Hypsithermal Interval

Edward S. Deevey and Richard Foster Flint

It is generally agreed (*1*) that some time after about 11,000 years ago, when continental ice sheets disappeared from the more temperate parts of northwestern Europe and northeastern North America, most of the world entered a period when mean annual temperatures exceeded those of the present. We have objected (*2*) to the term *postglacial climatic optimum,* which is in widespread use for this warm climatic phase, but our suggested term, *thermal maximum* (*2*), is likewise open to objection (*3*). In both nomenclature and stratigraphy, the definition of the interval has seemed inseparable from the problem of the "Little Ice Age" (*4*), but a recent interpretation (*5*) of glacial events in the Glacier Bay district of Alaska has been helpful in clarifying our thinking.

We propose to recognize the *hypsithermal* interval, adopting the term applied by Chiarugi (*6*), but changing its spelling and redefining it as the time represented by four pollen zones, V through VIII in the Danish system. More precisely, it was the time of abundant hazel (*Corylus*) pollen in lake and bog sediments in Germany, from the first rise of hazel at the bottom of zone V to its decline (and that of *Quercus* + *Tilia* + *Ulmus* pollen) to values below 10 percent of total arboreal pollen at the bottom of zone IX (*7*). In effect, this redefinition calls for a return to the stratigraphic scheme of Rutger Sernander as modified by von Post (*8*); the interval is the equivalent of von Post's *postarktisk värmetid.*

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Stratigraphy

For the stratigraphy of the time represented by the last 12,000 years, northwestern Europe is the best-known region, and it is there that we look for a point of departure. Although the designation of a type section is customary in stratigraphic practice, we omit it through inability to choose, among several thousand published pollen sequences, a single one more suitable than a hundred others. Instead, we give in Table 1 summaries of the postglacial pollen stratigraphy of Denmark and northern Germany. The numerical system of zonation is the Danish one (*9*). The dating of the zonal boundaries is approximate, but it incorporates radiocarbon evidence (*2, 10*) as well as other data (*11*). The table also gives the dates of recurrence horizons in Swedish bogs (*12*), the radiocarbon-dated glacial maxima in the Glacier Bay district (*5*), and a generalized pollen stratigraphy of eastern North America that incorporates the recent work of Leopold (*13*).

The climatic character of the European phases is broadly but convincingly shown by the estimated displacement of the alpine timberline in Switzerland (*14*), which is also included in Table 1. With this information, as with other phytogeographic evidence, it is difficult to separate the effects of temperature from those of precipitation, but if temperature variation was primary—as much other evidence suggests (*15*), it is reasonable to apply the lapse rate in calculating the temperature anomalies. This leads to the inference that the thermal maximum of 2° to 3°C above the present occurred in sub-Boreal time in Switzerland, and that temperatures higher than today's prevailed from Boreal through sub-Boreal time.

Nomenclature

The long, warm interval spanned by Danish pollen zones V through VIII, which has been dated from approximately 7000 B.C. to approximately 600 B.C., we propose to call the *hypsithermal* interval. We have changed the spelling of Chiarugi's *ipsotermico* (*6*) to conform with the English style of Greek adjectives and to express the customary distinction between *hypsi-*, high, and *hypso-*, a height. Chiarugi's original definition was explicitly based on rock-stratigraphic units, but it included his pollen zones III through IVb, thus excluding zone Va, sub-Boreal. The exclusion seemed reasonable in the light of the pollen stratigraphy of maritime Etruria and of other facts known in 1936, but it can now be seen that it makes the hypsithermal interval too short.

Apart from its priority, we prefer this term to others because (i) *optimum* is subjective and, when it is applied interchangeably in arid and humid countries, ambiguous; (ii) *thermal maximum,* as Antevs (*3*) has stated, applies to a stratigraphic horizon or to a point in time, not to a zone or its time equivalent; (iii) *xerothermic* usually implies too much that is unknown and is at best of local application; (iv) *altithermal* (*16*) is an etymologic hybrid and its stratigraphic basis has never been defined—as it is dated, it applies to only part of the zone in question; (v) *megathermal* (*17*), although correctly formed, is uninformative as to how "big" or "mega-" was the temperature; was the interval, for instance, more megathermal than the