determined by the role of such a mission in the larger framework of planetary, particularly martian, exploration. Among the data of fundamental scientific interest are those concerning the chemical composition and its variation over the asteroid. From these data it should be possible to establish the chemical uniqueness of the asteroids or their kinship with other bodies in the solar system. The successful remote-measurement techniques employed in the unmanned Surveyor experiments on the lunar surface should be useful on the asteroid, particularly for the light major elements. Recent technological advances in the field of energy-dispersion x-ray spectrometry make this a promising complementary technique for elements above atomic number 11, including critical minor elements.

The crystal structure of the material would provide information on temperature, pressure, and other variables during and after the formation of the asteroid; remote measurement of these properties is also within the capability of the Surveyor system, although it has not as yet been tested in space.

One of the fundamental questions concerns the competing rates of accretion and breakup. The temperature-pressure record in minerals would provide a basis for estimating the maximum size achieved during the past history of the asteroid. The extent of shock damage, evident from conventional x-ray and optical diagnostic investigations, should also throw light on the breakup question. For such investigations we need samples returned to the earth. Also of value would be manned or unmanned seismic experiments which would indicate to what extent the originally loose material has been compacted, and if the compaction has reached such magnitude as to suggest that the asteroid is a fragment from the interior of a planetary-sized body.

As in the lunar and martian exploration, determination of the age of the major events in the history of the asteroid is of fundamental importance; the necessary measurements can be achieved only on returned samples.

In general we see that the scientific problems associated with an asteroid mission are similar to those of the lunar missions and can be approached with instrumentation now existing and tested. By comparison with the moon and planets, the asteroids are even more promising sources of scientific information bearing on the history of the inner part of the solar system. From the point of view of space travel, journeys to the asteroids appear useful in providing the experience necessary for the more demanding voyages to the nearest planets. But there are also a number of other technological advantages to be explored, including the ease with which an underground shelter or an observatory can be constructed on an asteroid. If the asteroid is a result mainly of accretion, compaction by impact and gravitation would be low and the surface material loose. This, together with the low gravitational field, would make it simple to excavate and move soil for shielding against penetrating radiation and meteorite impact.

In Defense of Science

Alvin M. Weinberg

It is incredible, but true, that science and its technologies are today on the defensive. The attack, which is most noticeable in the United States, has been launched on four fronts. First, there are the scientific muckrakers, mostly journalists, who picture the scientific enterprise as being corrupted by political maneuvering among competing claimants for the scientific dollar. Second, there are thoughtful legislators and administrators who see a waning in the relevance of science to the public interest, especially as we address ourselves to grave social questions that are hardly illuminated by science. To deny connection between science and public affairs weakens one of the main arguments for public support of basic science: that out of basic science comes technology, which in turn improves our human condition. Third, there are the many technological critics who urge a slowdown, or at any rate a redirection, of technology because of its detrimental side effects. And finally, there are the scientific abolitionists: the very noisy, usually young, critics who consider the whole scientific-technological, if not rationalistic, mode of the past 100 years a catastrophe. To them technology is the opiate of the intellectuals (*1*); some of the more extreme would demolish human reason as the ultimate tool for achieving human well-being. The consequence, or perhaps a further symptom, of all this harassment is a reduction in society's support for science. The U.S. budget for science has fallen from 2.5 percent of the gross national product in 1965 to 2 percent in 1969.

It is appropriate at this 10th anniversary meeting of the Association of German Scientists to examine these attacks against science and its technologies. We who have devoted our lives to the use of science for human betterment cannot allow our underlying belief in the rational use of science to be undermined without reacting sharply and positively.

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The Scientific "Muckrakers"

"Muckraking" is a word used by the American President Theodore Roosevelt, to describe a group of journalists who, at the turn of the century, found corruption in American society and exposed it. The scientific muckrakers, such as Daniel S. Greenberg, Spencer Klaw, and others, see corruption in the scientific-political system. Perhaps it would be more accurate to say their sensibilities are hurt by the existence of a scientific politics.

By scientific politics I mean the process, essentially political, by which priorities in science are established. The political process—that is, the give-and-take, the dealing and wheeling, between different aspirants—is the only way priorities can be set in a system not governed by the marketplace. Where there is a marketplace, priorities are set automatically by the feedback of the market. Where there is no market, priorities must be set by politics.

To the extent that the scientific enterprise operates in a *non*-market economy, its priorities are finally set by politics. To be sure, there is Harvey Brooks's intellectual marketplace in the working of science—the Republic of Science as Polanyi calls it (*2*). The better ideas survive; the poorer ones disappear simply because of the interactions among the scientists, all of whom subject each other to sharp and unending scrutiny. But the intellectual marketplace is imperfect. It works well on the microscopic scale: within each field of science, canons and standards are well understood and are applied effectively. Nonsense in a given field is weeded out; the good receives encouragement; the bad is ignored. But, because science is so fragmented, it is difficult for the intellectual marketplace in one field to feed back onto another field. The standards of rigor, of excellence, and of taste in the different fields of science differ. For example, I would guess that some of modern quantum chemistry appears to be uninteresting to some of the founders of quantum mechanics who have remained in physics; and perhaps modern field theory doesn't appear to be getting very far as viewed by the quantum chemists.

Politics must therefore be an essential element in setting the big priorities in science: the major strategies, the decision to back a large accelerator or a big space adventure. The large question is the character of this politics. Is the give-and-take that constitutes scientific politics conducted in an atmosphere of self-service, if not venality (as is almost implied by the scientific muckrakers), or is it conducted in a sober, intellectually enlightened atmosphere?

It would be hard to prove that the politics of science is conducted on a peculiarly high moral plane. Nevertheless, two things can be said. First, the intellectual marketplace, imperfect as it is, does operate, and second, the philosophic debate on scientific priorities has to a considerable extent influenced the political debate by which priorities are actually set. To this extent at least, the politics of science is intellectually elevated.

Let me review very briefly the philosophic debate on scientific priorities. Philosophers of science have traditionally concerned themselves with questions of epistemology: what is scientific knowledge or scientific truth? But the debate on scientific priorities raises a new question in the philosophy of science: what is scientific value? The practical ordering of priorities within science has forced us to attempt to construct an axiology of science.

An axiology of science—that is, a relative ordering of worthwhileness in science—is to some scientists a contradiction. Every science is as good as every other science; the only criterion by which scientific activity is to be judged is the criterion of truth. As Peter Medawar puts it, "Science is the art of the soluble" (*3*). Yet, as Medawar himself realizes, this is hardly the whole story: Science is not only the art of the soluble; it is the art of the soluble and the important. Every scientist, implicitly if not explicitly, orders his scientific ideas and hunches according to some scale of value, some scale of importance. The new element that has been injected by the debate on scientific priorities is that for the first time we are trying to make such scales of values explicit.

I shall not try to review all the attempts at establishing an axiology of science. Suffice it to say that the phrase, "criteria for scientific choice," is now heard often, whereas 10 years ago none would have thought it useful even to discuss such a priori criteria. Of the various criteria that have been suggested, for example, by Victor Weisskopf (*4*) or by me (*5*), I still think that the so-called "external" criteria remain most relevant to the conduct of scientific politics. These external criteria ask of a science that it be relevant—either to technology, or to society in general, or to other branches and parts of science. The latter criterion can be stated: "The scientific merit of a field of science is to be measured by the degree to which it illuminates and contributes to the neighboring fields in which it is imbedded."

These rather philosophical attempts to create an axiology for science have provided a language, if not a framework, for the political debate that establishes scientific choices, at least in the United States. Much of the visible part of the confrontation between fields takes the form of reports, usually sponsored by the National Academy of Sciences, each summarizing the state of a large field of science: its promise, its problems, and its requirements. To date there have been about a dozen such reports covering, among others, physics, chemistry, mathematics, ground-based astronomy, and behavioral sciences (*6*). Many of these reports, especially the more recent ones, seek to justify their claims for support on grounds that were delineated in the philosophical debate on scientific priorities. For example, the relevance of the field to other fields of science, as well as to technology and to society in general, is stressed. Thus, we read in a recent report on high-energy physics, "At the present there are a number of important instances which show the influence of high-energy physics on the rest of science. . . . Thus, we find high-energy physicists making many of the most important contributions to theoretical techniques in handling many-body problems; to computer technology; to the techniques of dealing with ultrashort time intervals; and to superconductivity technology. Not only the methods but also the discoveries themselves begin to have their impact on other sciences" (*7*).

My point in describing the situation is not to claim that the attempts to create an axiology for science have been necessarily successful; rather it is to demonstrate that the scientific-political process is significantly influenced by these philosophic discussions. In the process, the politics of science is itself elevated. The scientific muckrakers properly point to the existence of politics in science. They have neglected to recognize the degree to which the politics of science is sanitized and legitimated both by the intellectual marketplace and by the budding axiology of science.

Relevance of Science

I have already referred to relevance as one criterion by which society judges the support that it is ready to heap upon science. The argument as to relevance—meaning relevance to the achievement of ends that lie outside science—is an ancient one. On the one hand, there is the Newtonian view that science is simply an intellectual exercise, a part of high culture. On the other hand, there is the Baconian view that science is justified because from science "we learn how to make two blades of grass grow where one grew before." All of us, to some degree, are both Baconians and Newtonians in our attitude toward the role, and hence the basis for support, of science. In recent years, especially as the connection between science and technology has undergone attack, many scientists and scientific philosophers, notably Stephen Toulmin, have taken, or perhaps have retreated to, a strongly Newtonian view of science.

This Newtonian view hardly explains why science deserves more support than any other part of culture does. I have therefore tended toward the Baconian view: that science is a necessary overhead activity that creates the reservoir of knowledge upon which our new technologies draw. And, judging by the way we support science, one must conclude that our society takes a largely Baconian, rather than Newtonian, view of science. Most basic science is supported in the United States by agencies that have missions other than basic science: the Department of Defense, the Atomic Energy Commission, the National Institutes of Health, and the National Aeronautics and Space Administration, to name the largest. The National Science Foundation, the one agency specifically charged with the responsibility to conduct science for its own sake actually supports less basic science than these other agencies do. In the United States we have many "national science foundations," most of which are justified by the contribution they are supposed to make to the achievement of fairly specific nonscientific, possibly technological, missions.

The system up until now has worked rather well. But there are signs of strains and tensions developing that, if not corrected, could prove devastating to science. First of all, there is the obvious monetary squeeze: science tends to expand, but the federal budget does not. This takes a particularly painful turn in Senator Mansfield's proposal to prohibit the Department of Defense from supporting basic research. But, in addition, there seems presently to be a serious divergence between the aims, aspirations, and interests of the basic scientists and the aims, aspirations, and interests of the technologists whom the basic scientists are supposed to be helping. This divergence is of course nothing new. What this means is that parts of science are Newtonian, and there is little we ought or can do to change this. Nevertheless, since most of society's basis of support is Baconian, this divergence, ancient as it is, needs reexamination.

The most obvious and extreme divergence is caused by our society's newly recognized concern for the social problems: population, poverty, pollution, and peace. If there is any question as to the relevance of nuclear physics, say, to nuclear energy, then how much greater must be our concern as to the relevance of the physical sciences to these "social problems"? We are faced here with a hard dilemma. If we insist on the Baconian view that science is an overhead required to achieve society's ends, then, as society raises the priority of social problems, will not the hard sciences—physics, chemistry, even biology—suffer? Must the hard sciences ultimately be squeezed as society turns to matters to which these sciences are supposed to have little to contribute?

To an extent, this is surely the case. Isobaric analog states in nuclei won't resolve racial tension in Detroit or religious tension in Belfast. It would be dishonest of the nuclear physicist to claim the contrary.

Yet this is not the whole story. Today's social problems—like population, poverty, pollution, and peace—possess important technological components. How can we look at world population without at the same time examining the development of the remarkable new high-yielding strains of corn, wheat, and rice? How can one consider ways of stabilizing the world order, of achieving peace, without including possible developments in spy satellites and ABM's?

I have gone further and urged that in more cases than our traditional social thinkers are prepared to concede there may be "technological fixes" that could circumvent a seemingly impossible social problem, or at least to so alter its dimensions as to allow new social approaches. Let me illustrate with one "technological fix"—the Gangetic plain project of Perry Stout of the University of California at Davis (*8*). As all of us know, feeding the growing masses of India had, up until 3 years ago, been considered to be totally impossible. In their harrowing book, *Famine—1975!* (*9*), the Paddocks predicted that nothing could save India from bleak and devastating famine. A few years ago Stout pointed out that the whole Gangetic plain, extending from the Himalayas and including the entire state of Uttar Pradesh, is underlaid with groundwater. This groundwater is recharged each monsoon season. Couldn't this water be used to grow not one but two and possibly three crops of wheat each year? If the new high-yielding varieties that had been so successfully developed by the Rockefeller Foundation and the Mexican government were planted widely, then, according to Stout's estimates, the total yield of wheat in this area could be enhanced fourfold, and possibly eightfold! Stout visualized a vast irrigation project based, ultimately, on some million relatively shallow tube wells; 100,000 such wells already exist in India and in Pakistan.

The missing element in Stout's plan is energy, energy to pump water and energy to manufacture nitrogenous fertilizer. This latter is particularly important since the new varieties do less well than the old, low-yielding types, unless they are supplied with adequate nitrogen. Thus an essential part of Stout's plan is a network of large power plants, probably nuclear, to supply electricity for the pumps and for the electrolytic-ammonia plants. Before the central power plants are ready, gas turbines would be used. These are to be replaced gradually when sufficient electricity becomes available.

Here is a technological fix: a technologically based scheme, involving new discoveries in agricultural science and in nuclear energy, that could buy significant time in the face of an urgent social problem. This is not to say that this technological fix gets at the "heart" of India's social problem which is overpopulation. On the other hand, it seems to me to be a much more humane and practical approach than the one advocated by some social planners: to force India to control its population even if this means incredible famine. We technologists are not infallible, and Stout's scheme may not work; but neither are the social planners, such as the Paddocks, who only a few years ago were willing to write India off.

One can easily think of many other "technological fixes"—such as large tankers as a means of defusing the political sensitivity of the Suez Canal, or the intrauterine device as a means of reducing the social motivation required to achieve birth control. In every instance the fix achieves remedies rather than rooting out causes; and on this account this line of thought has been attacked as being insufficient or inhumane. Yet social problems are never really solved permanently—one only exchanges one social problem for another, hopefully less pressing, social problem. As Lawrence Durrell says ". . . nothing is ever solved finally. In every age . . . we are facing the same set of natural phenomena, moonlight, death, religion, laughter, fear. We make idolatrous attempts to enclose them in a conceptual frame, and all the time they change under our very noses" (*10*). *Any* resolution of a social problem basically buys time: I see nothing wrong with using technology to buy time.

If one accepts the technological fix as one means of alleviating social problems, then surely our reorientation toward social problems ought not to diminish our interest in certain technologies and their supporting sciences. Take the city, for example. Doxiadis, the city planner, has insisted that the arteries of communication and transportation in the city of the future ought to be placed underground, otherwise the city will be strangled, as well as disfigured, by its traffic (*11*). To make underground transport feasible, it will be necessary to improve our methods of tunneling through hard rock. New approaches to this old problem are now being tried: at the Massachusetts Institute of Technology lasers have been used to soften rock; at Oak Ridge we have used high-pressure water jets to cut through solid rock. Surprisingly we find that rock can be cut at water pressures considerably below the rock's unconfined compressive strength.

Thus our new concern with social questions will continue to place serious demands on technology; and, insofar as our science is relevant to these technologies, we shall continue to find a basis for the Baconian, commonsense rationale for society's support of basic science.

How relevant is our most modern science, the kind that excites and interests the leaders of a field, to the modern technologies? Some thoughtful philosophers, such as Derek Price (*12*), insist that for the most part science and technology are two separate threads that spin their courses rather independently of each other. Any stronger connection between them is largely a fiction invented by scientists who see in the Baconian view an easy justification for continued support.

There is some truth in Price's assessment. For example, when fission was first discovered and nuclear physicists became intensely interested in the phenomenon, their findings of fission resonances or of delayed neutrons were immensely important to the designers of nuclear reactors or nuclear weapons. Now, 30 years later, there is a great upsurge in fission physics occasioned by the discovery that the fission barrier is double-humped. This upwelling of interest in fission physics has hardly affected nuclear engineering.

Yet such divergence is temporary, and in a way misses the essence of the connection between modern science and modern technology. One cannot begin to do justice to this connection unless one considers how the two interact in the prime institution of modern technology—the large, multidisciplinary laboratory. Modern complex technology like communications or energy or space could hardly be developed outside big institutions such as Oak Ridge or General Electric or Bell Laboratories. In such institutions basic science is conducted not primarily for the breakthroughs that will lead to new technologies; these occur anywhere and are not confined to the laboratory. Rather, basic science, even very basic science, must be conducted there (aside from the kind that is obviously directly relevant) because basic science sets the tone and standard for all the rest. In a large, multidisciplinary, applied laboratory, basic scientists keep their technological colleagues honest. They are the eyes through which the institution keeps in touch with the rest of the world of science. In short, basic science, applied science, and technology, as practiced in the best of the big laboratories, form a continuum. To take any one of them away would weaken the institution and reduce its capacity to achieve its applied mission with sophistication and style.

I do not wish to overstress the role of the physical sciences in this new, social-problem-oriented world. The technological fix is certainly not a panacea. To resolve social questions will ordinarily require much social engineering, and much of this social engineering will surely need underpinning in the social sciences. Unfortunately our society has relatively little experience or tradition for large-scale support of social sciences; and possibly the social scientists have relatively little taste for, or commitment to, social engineering.

Perhaps what is missing is the counterpart in the social sciences of the large, multidisciplinary laboratory that has been so remarkably successful in the application of physical and engineering science to practical problems. And indeed, if technological components are to be assessed realistically, would not institutes dedicated to social engineering profit by active research in the hard sciences and technologies, as well as in the soft sciences? I have on this account proposed "national socio-technological institutes": perhaps a cross between Oak Ridge National Laboratory and a think-tank like RAND; or, in Germany, Karlsruhe might be expanded to include an institute of social problems. Such institutions would address themselves to large social questions with much the same style and techniques that the atomic energy laboratories have used in developing breeders. They would bring to bear on such matters as the city, or peace, or pollution, the entire armamentarium of science, from basic physics to applied engineering, from molecular biology to systems ecology. Not all disciplines would be equally relevant to every problem, yet all elements would interact, would create a scientific-intellectual atmosphere, and a style of work that might perform socio-technological engineering with a coherence and strength that now evade us.

Could socio-technological institutes of this sort—problem-oriented rather than discipline-oriented, interdisciplinary rather than disciplinary, relevant rather than irrelevant—eventually displace the university as the intellectual centers of this new age of social concern? Certainly the universities in the United States are increasingly preoccupied with their own relevance. These rumblings in the university might lead to the creation of such centers, either within the university framework or outside it.

At the Oak Ridge National Laboratory we have begun to add social scientists—economists, demographers, political scientists; and we have addressed ourselves to such social problems as urban decentralization, civil defense, and the Stout plan and its variants. Though it is too early to say just how successful these experiments have been, they may eventually lead to our becoming a socio-technological institute.

The Scientific Abolitionists

This approach to clarification, if not resolution, of our great social problems through socio-technological institutes calls for more, not less, science and technology. Yet to a very noisy and, I fear, influential group of younger intellectuals such attempts to inject more science into our social planning and thinking is anathema. To some extent this antiscientific fashion has infected much of our youth, as well as other parts of the society.

To an older member of the scientific establishment, like me, it is hard to understand exactly why so many of our young people have become disillusioned with science and its technologies. Some of their disillusionment began with the technological critics: Ralph Nader and Rachel Carson who have accurately and often painfully called attention to the detrimental side effects of technology. Nor would the effects long have remained unnoticed even without their voices. For example, the rain in some parts of Sweden is about as acid as Coca-Cola, $p\text{H} = 2.5$. This acidity is attributed to the oxides of sulfur that belch out of England's and northern Europe's industries and are carried to Sweden.

Some of the technological critics, particularly the conservationists, would reduce technology's assault on the environment by abandoning technology. The chlorinated hydrocarbon pesticides have been banned in several states in the United States as well as in some European countries. Curtis and Hogan (*13*) urge us to abandon nuclear reactors because in their view (which I believe is mistaken) nuclear reactors are unsafe. Some of these concerns—for example, pollution by pesticides—have merit. The pollution of lakes in Sweden by mercury-containing fungicides is a tragedy. To the extent that technology and its supporting sciences have been unable to foresee these ecological consequences, technology has been deficient and blameworthy. Yet, in accusing technology of being blindly insensitive to public risks and overly sensitive to private, or bureaucratic, benefits, some of the technological critics are being grossly unfair. The fundamental spur for nuclear energy is not the possible private gain of utility companies or reactor manufacturers. It is much more the new means of forestalling Malthus afforded by an inexhaustible source of energy. Chlorinated hydrocarbons enrich farmers; they also enable India to produce enough food to feed itself as well as controlling malaria.

How then is the scientific-technological community to respond to the technological critics? The answer is simple, in principle, and it has been urged by responsible technological critics such as Ralph Nader. The technologies that have sprung from our modern science are "tainted": the automobile is at once a convenient mode of transport and a death-dealing device as well as a pollutant of the atmosphere; the large tanker softens the political consequences of closing the Suez Canal, but it can ruin our beaches; persistent insecticides increase our food supply but still the robins. Is it not clear that the social responsibility of the technologist and his scientific supporter lies in removing the taints that now mar the modern technologies of abundance? Rather than ending technological development we must invent new technologies, or improve the old, so as to have both our food and our robins, our cars and our clean air.

Some of the directions in which we can make progress are already clear. For example, the tussock moth destroys millions of board-feet of fir timber each year in the Pacific Northwest. In the past few years entomologists have identified a virus that will kill tussock moths and tussock moths alone. Preparations of such a virus, properly cleansed of contaminating bacteria by zonal centrifugation, have already shown promise as a biologically safe way to deal with this wasteful pest. This is only an example of a biologically harmonious way of approaching control of insects; many others are now under study and development.

More generally, our science and technology shall have to concern itself more aggressively, more coherently with the environment. As Rene Dubos of Rockefeller University has said, we must understand man in relation to his technology and to his environment far more intimately than we now do. He asks our biomedical sciences, which have thus far been reductionist in approach and which have sought cures for human ailment by clever chemistry, to seek preventions and causes by enlarging our understanding of man's interactions with his environment (*14*).

Such studies will require new groupings of specialists—ecologists, analytical chemists, pathologists, epidemiologists, and demographers. It will require new institutions, somehow having the flavor of the socio-technological institutions I have already mentioned.

To me then, the job and the purpose of science and technology remain overwhelming: to create a more livable world, to restore man to a state of balance with his environment, to resolve the remaining elementary and primitive suffering of man—hunger, diasease, poverty, and war. These are not small tasks, nor are they new ones; that in science and technology we have the possibility of dealing with them is an article of faith of all who have committed themselves to the scientific way of life. It is the height of irrationality to turn our backs on all this, as is urged by the more radical of the scientific abolitionists. For rationality and science there is no simple or cheap substitute. Should science die under the onslaught of the nihilists, it could be only a temporary death. That human rationality and human good sense will prevail in the long run we take for granted. It is up to us, members of the older scientific-technological establishment, to persuade our younger impatient scientific nihilists that ours is the course of reason, and that in our arduously built scientific-technological tradition lies our best chance of ultimate survival.

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