many nocturnal, nonterritorial frogs. Even the bullfrog, however, uses at least some of its approximately six vocalizations in more than one context (*33*).

It is difficult to make an a priori evaluation of the extent to which these potential sources of exceptional messages are operative. Empirically, however, it appears that very precise messages are few in number and even totally lacking from the displays of many birds and mammals, and that even nocturnal species use many displays in more than one context. Assessment of the use of minor display variants is a fairly difficult problem, as is the detailed study of relatively asocial animals. Nonetheless, it does seem that the basic list of message classes given above, or some list that is similar to it in many respects, is likely to be very generally representative. If it is, then there are broad implications both for the evolution of patterns of communication (including at least the origins of language) and for the evolution of social systems.

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Science and Social Attitudes

Growing doubts require that science be put more recognizably at the service of man.

Robert S. Morison

Like all people with some scientific training, I suffer from feelings of unease when attempting to deal with the actions, and especially the attitudes, of people. For one thing, I do not have at my command the sampling and interview techniques wielded with so much aplomb by my colleagues in the social sciences. Fortunately for my own piece of mind, my scientific training was accompanied by enough exposure to the art of medicine so that I retain considerable respect for clinical intuition and judgment. This discussion relies much more on these elusive instruments than it does on quantitative scientific analysis.

As a matter of fact, it puts no great strain on one's clinical intuition to observe that large numbers of people in various parts of the world—including, perhaps most significantly, the advanced parts—are less happy about science and technology than they once were. The evidence is of various kinds. Perhaps the most quantitative is provided in the United States by the relative decline in students entering the sciences and the scientifically based professions. In some instances, such as engineering, the numbers have fallen absolutely in the face of a steady increase in the total number of potential students in each age class. Even more quantitative, and certainly more compelling to the individual scientist, is the evidence provided by the slowdown in appropriations for science. Third, one may cite the intuitions and reflections of thoughtful social clinicians like René Dubos (*1*), who has so courageously summarized the shortcomings of scientific approaches to human problems. True enough, he finally draws the con-

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clusion that what we need is not less science but more. Nevertheless, the argument depends on a careful demonstration that science raises new problems of increasing complexity as it continues to solve the older and simpler ones.

Earlier Attitudes toward Science

Before going on to a discussion of the possible reasons for a decline in public regard, we should pause to remind ourselves that the change may not be so large or so profound as we might suppose. It is not very clear that there ever was a time when a substantial part of the population really understood science, cared much about the kind of knowledge it produces, or thought much about its ultimate effects. Improvements in technology were welcomed because of the increased production of what were generally regarded as good things at less cost in human effort. On the other hand, the reduction in human labor was soon recognized to have a negative side. In the first place, as the Luddites saw very early, it tended to throw men out of work, at least temporarily. What was even worse from the psychological point of view, the machine tended to change the status of skills which had been acquired with much effort over long periods of years. Nevertheless, on balance, the industrialization of production both on the farm and in the factory has been regarded by most people as a net good; for, it must be remembered, even at the height of the Medieval and Renaissance periods, skilled craftsmen constituted only a very small portion of society. The great bulk of mankind labored in the most unimaginative and unrewarding way as farmhands with a status little better than that of serfs. Somewhat later than the general recognition of technological improvements in production came an even greater appreciation for the contributions of science to medicine and public health.

Most men probably never did take much interest in what might be called the philosophical aspects of science. Few really read Condorcet or the other Encyclopedists, and it is doubtful that any but a small handful of intellectuals ever thought that science would provide a way of life free of undue aggressions, anxiety, loneliness, and guilt. Perhaps the Communist Party is the only large social organization that has ever seriously believed that man himself may be improved through improving his material circumstances. Among Christians, as among adherents of many other religious faiths, there has always been a substantial body of opinion which holds that the reverse is true and that material prosperity has, in fact, an adverse effect on the human soul.

The progress of science undoubtedly has had some effect in reducing the grosser forms of superstition. One supposes, for example, that most men are in some sense grateful for being less afraid of thunder and lightning than man used to be. But, here again, it is doubtful that the scientific way of looking at the world has ever completely displaced older, more magical approaches to the deep questions. It does not appear that President Nixon, when making up his mind whether or not to deploy the ABM system, consulted an astrologer, but it is not unknown for heads of states in other parts of the world to do so, and most of our metropolitan daily newspapers maintain an astrology column as well as the more sophisticated services of Ann Landers. Indeed, it is estimated that there are 10,000 professional astrologers but only 2000 astronomers in the United States (*2*).

Putting aside the grosser forms of superstition and turning to better-developed and better-thought-out ways of looking at the world, I would hazard a guess that the metaphysical outlook of most people, even in the United States, is more influenced by Plato and Aristotle than by Galileo and Hume. Indeed, it might be interesting for a graduate student in intellectual history to survey this very question. For example, do you suppose the majority of Americans would consider the following statements to be true or false? "Other things being equal, heavy bodies fall faster than light ones." "Metals feel cold to the touch because that is their nature." "Justice and honesty are real things and part of the divine plan of the universe; men try to establish justice through the machinery of the law and the courts, but their efforts will always fall short of the higher ideal of justice as it exists in the divine plan."

Coming down out of the clouds, we might ask ourselves how many people ever really got much fun out of studying mathematics and physics in high school? How many felt pleased to discover that a suction pump doesn't really suck water, but merely creates a potential space into which the water is pushed by atmospheric pressure? If one looks back 40 or 50 years, one seems to remember that rather less than the majority of one's classmates really enjoyed physics and chemistry and the kind of picture they give of the world. Perhaps a somewhat larger number found satisfaction in biology, with its greater emphasis on immediate experience and the pleasure one gets from contemplating nature's wide variety rather than its unifying mechanics.

World War II called a great deal of attention to science and made many people grateful for its role in enabling England and its allies to maintain the integrity of the free world. Along with the extraordinary buildup of military technology came a very great increase in biological knowledge of a kind which could be applied to medicine and public health, and to agriculture.

The press showed increasing interest in reporting scientific events, and the quality of scientific reporting has greatly improved in the quarter century since the war. Most significantly, a grateful and more understanding public provided vastly increased financial support for what the scientist wanted to do.

On the scientist's side there was a burgeoning of interest in making science more accessible to the general public. Most noteworthy in this movement, at least in the United States, was the effort of outstanding university scientists to improve the presentation of science to students in elementary and secondary schools. There is little doubt that this effort has greatly improved preparation for college in all branches of science. The generous men who initiated the program hoped for something more, for they felt that, if the story could only be presented properly, anyone of average intelligence would share the pleasure of the most able scientist in discovering the orderly arrangement of the natural world. Nothing could be more admirable than the dedication and self-sacrifice of men like Zacharias and the late Francis Friedman, and nothing more charming in its humility than their apparent belief that almost everyone is potentially just as bright as they themselves. Unhappily, it has not turned out as they hoped. Elegant though the Physical Science Study Committee Physics Course undoubtedly is, it has not proved much more successful than any other method in making physics attractive to secondary school students.

Nevertheless, on balance, public interest in science became greater after the war than it had been before, and it was further stimulated by the orbiting of Sputnik. It is very difficult to say how much of this interest was due to competition for ever more sophisticated weapons, how much to a pure cultural

rivalry which puts the moon race into the same category as an Olympic track meet, and how much to the age-old wish to cast off the shackles which bind us to a single planet. However one apportions the credit among these three factors, it seems reasonably clear that an appreciation for basic science, as the scientists understand science, played a relatively small role.

Reasons for the Change of Mood

The decade of the 1960's has certainly seen a slackening in public approval of science. Is this change simply a return to the earlier, more or less normal state of ignorance and indifference, or are we witnessing an actively hostile movement? In either case it may do us all good to try to identify some of the more important reasons for the change of mood.

1) Science is identified in the public mind largely with the manipulation of the material world. It is becoming clearer and clearer that the mere capacity to manipulate the world does not insure that it will be manipulated for the net benefit of mankind. Nowhere is this more obvious, perhaps, than in the matter of national defense. As pointed out above, the generation that knew at least one of the great world wars is grateful to the scientist for having fashioned the means of victory over a grave threat to a free world. The oncoming generation views the situation in quite a different way. To them the obvious alliance between the scientific community and the military is an evil thing: far from making the world more secure, it has produced an uneasy balance of terror, with the weight so great on both sides that any slight shift may lead to unimaginable catastrophe.

It seems undeniable that those of us who have grown up with this situation have also grown somewhat callous to the fact that such a high percentage of support for university science comes from military sources. We tend to remember, for example, the marvelously enlightened policy of the Office of Naval Research, which did so much to foster pure science while the Congress continued to debate the desirability of a National Science Foundation. Those who come upon the situation for the first time, however, see almost nothing but a conspiracy between some of the best brains of the country and the unenlightened military. In any case, it must be admitted that science and technology appear to contribute disproportionately to the more fiendish aspects of an evil business—the defoliation of rice fields, the burning of children with napalm, and the invention of new and more devastating plagues.

2) Until fairly recently, the contributions of science and technology to increased production both in industry and in agriculture have been generally regarded as on the plus side. Even here, however, doubts are beginning to arise. Much of the increased production comes at the cost of a rapid exhaustion of natural resources and the increasing contamination of what is left of our natural environment. Nor is it clear that all of the goods and services produced really do a great deal to increase the sum total of human happiness. Indeed, it can be shown that the modern affluent consumer is, in a sense, a victim of synthetic desires which are created rather than satisfied by increased production (*3*). On the other hand, a substantial percentage of the population remains without even the bare essentials of life. Rapid increases in agricultural production have pretty well abolished famine in the advanced countries of the world, but the revolution in rural life has benefited only a few of the most successful farmers. The rest are clearly worse off than they were before; and, indeed, the large majority of them are hastening into the cities, where they create problems which have so far proved insoluble. Furthermore, the advanced technologies which make the increased production possible are now found to be doing as much harm to the environment as the more long-standing and better recognized industrial pollutions.

3) Surely everyone can agree that science has done wonderful things for the improvement of health. But, even here, uncomfortable questions are being asked. Have our best doctors become so preoccupied with the wonders of their technology that they have become indifferent to the plight of large numbers of people who suffer from conditions just as fatal but much less interesting? Even the most earnest advocates of increased research in heart disease, cancer, and stroke must be a little bit embarrassed by the fact that the United States, which used to be a world leader in reducing infant mortality rates, has now fallen to 15th place.

4) It is not only the maldistribution of resources that concerns the general public; they are becoming increasingly uneasy about the moral and ethical implications of advances in biological science. In many respects these advances seem to threaten the individual's command over his own life.

Actually, of course, the individual never did have as much control over his own life as he felt he had. Science may have simply made his own impotence clear to him by showing how human behavior is molded by genetic and environmental influences. Like everything else, it seems, human behavior is determined quite precisely by a long train of preceding events, and the concept of free will has become more difficult to defend than ever.

Perhaps more immediately threatening is the fact that science puts power to control one's behavior in the hands of other people. Intelligence and personality tests place a label on one's capacity which is used from then on by those who make decisions affecting one's educational and employment opportunities. New methods of conditioning and teaching threaten to shape one's behavior in ways which *someone else* decides are good. Drugs of many kinds are available for changing one's mood or outlook on life, for reducing or increasing aggressive behavior, and so on. So far, these drugs are usually given with the cooperation of the individual himself, except in cases where severely deviant behavior is involved, but the potential for mass control is there. Indeed, there is already serious discussion about the ineffectiveness of family planning as a means of controlling the world's population, and suggestions are made for introduction, into food or water supplies, of drugs that will reduce fertility on a mass basis.

As if these assaults on individuality were not enough, some biologists are proposing to reproduce standard human beings, not by the usual complicated and uncertain methods involving genetic recombination, but by vegetative cloning from stocks of somatic cells. In the face of all this, can we blame the great majority of ordinary men for feeling that science is not greatly interested in human individuality and freedom?

5) Science is not as much fun as it used to be, even for its most devoted practitioners. The point here is that science encounters more and more difficulty in providing a satisfyingly coherent and unified picture of the world. The flow of pure scientific data is now so prodigious that no one can keep up with more than a small fraction of it. Although most of us still retain some sort of faith that the universe, with all its infinite variety of detail, can in some way be reduced to a relatively simple set of differential equations, most of us

recognize that this goal is, in practice, receding from us with something like the speed of light. That simple set of physical and chemical principles on which the older generation grew up is now turning out to be not very simple at all, and the relation between these simple principles and the complex events of biology are not nearly so clear as they were when Starling enunciated his "law of the heart."

Although it is probably too easy to exaggerate the degree to which the progress of science results in the fragmentation of knowledge, the beginning student in the sciences finds a great deal of difficulty in relating his courses in chemistry, physics, and biology to one another. Even within a single discipline, he feels overwhelmed and frustrated by the number of apparently isolated facts that he has to learn.

6) Closely related to the foregoing thoughts on the growing complexity of science and the decline in the intellectual satisfaction generally derived from it is the question of student attitudes, for most of us make our first serious acquaintance with science as students.

My overall impression, in returning to a university after a lapse of 20 years, is one of disappointment that so few students seem to have very much fun either in their science courses specifically or in university life in general. This lack of pleasure is certainly more striking in the first 2 years, when the student is adjusting to a totally new social environment and devoting his attention to building the groundwork for later, more exciting studies. But I keep asking myself why these first 2 years of foundation-laying have to be so unsatisfying.

In the first place, I have come to believe that we discourage many students by expecting too much of them. We want them all to learn at a rate determined by the best. This can only mean that all *but* the best feel themselves to be dying of a surfeit rather than enjoying a marvelous meal. I am also coming sadly to the conclusion that, no matter how the subject is presented, a substantial number of college-level students have relatively little interest in the facts of science and lack the capacity to find pleasure in its generalizations. Whether the failure is primarily intellectual, in the sense that students simply have difficulty in understanding the nature of the generalization, or whether it is emotional and esthetic, in that they derive little pleasure from the generalization once it is understood, is not easy to determine. In either case, the prospect of unifying the community around a common understanding of science seems relatively remote.

An article by Richard N. Goodwin in the *New Yorker*, entitled "Reflections—sources of the public unhappiness" (*4*) puts some of the difficulties of science into a larger perspective. It provides a brilliant analysis of the unhappiness not only of our obviously dissident left-wing youth but of the many members of the forgotten middle class who, during the last election, swung rather wildly between George Wallace and Eugene McCarthy. Goodwin discusses this phenomenon in terms of the traditional Jefferson-Hamilton model and comes to the conclusion that a great many Americans feel that they have lost control of certain crucial factors in their life styles. Although I am far from being as convinced as Goodwin is that it will be possible to return a large portion of our decision-making to states and local communities, I agree with much of his analysis of the underlying problem. He is particularly convincing, for example, when he shows how Secretary McNamara, in his apparent efforts to rationalize the Department of Defense and bring the military more closely under civilian control, actually succeeded in constructing a Frankenstein monster which began to control him, as "when he was compelled against his own judgment to go ahead with an anti-ballistic missile system."

For our purposes, the key word here is "rationalize." Our rationalized systems do, indeed, seem to have developed the capacity to live lives of their own, so that mere men are compelled, against their will, to follow where the logical process leads. As we saw above, the medical profession is following in the footsteps of its dynamic research program and undertakes to perform heart transplants, at great expense, largely because it has found out how to do them. In the same way, we devote several billions of dollars each year in going to the moon, because it is *there* (and, again, because we know how to do it). Everyone who has done much science on his own knows that the next step he takes is determined in large part by the steps that have gone before. It follows that the progress of pure science, at least, is determined by the internal dynamics of the process and by the opening up of new leads rather than by public demand to meet new needs. The practical applications to human welfare, when looked at in this philosophical framework, become accidental bits of fallout, as the nuclear bomb itself "fell out" from the innocent effort of J. J. Thompson, Rutherford, Bohr, Fermi, and others to understand the nature of matter. No doubt all these men felt completely in command of their own research programs, but the public does not look at it this way, and, in a curious sense, the public may be more right than the scientists. This line of thought brings us to point 7 in our bill of indictment.

7) The continuing momentum of science toward goals of its own choosing appears to be coupled ever less closely to solving problems of clear and pressing consequence to human welfare. As we now see, enlightened congressmen and senators, well aware of the power of the scientific method but skeptical of its capacity to guide itself automatically to the points of greatest human concern, are making explicit legislative attempts to mobilize science to solve the problems of the pollution of our environment and the crime in our cities, if not, indeed, the unsatisfactory nature of our life in general. Realizing that nuclear physics is not very closely coupled to these matters, they are turning to social science in the hope that there is a group of scientists who can do for society what the physicists have done for the natural world.

Skepticism about Rational Systems

Skepticism about rational systems is, of course, not confined to science. Indeed, it well may be that the antipathy to science is merely a bit of fallout from the growing antipathy to rational systems in general (*5*). The movement has been a long time in the making. Lionel Trilling (*6*), for example, traces much of the despair, the irrationality, and the increasing devotion to the absurd of much modern literature to Dostoevski's *Letters from the Underworld*, in which, you will remember, the protagonist, in his violent diatribes against the existing order, concentrates his hatred on those "gentlemen" who believe that 2 and 2 make 4. What is even more frightening for our own time is the way the same anti-hero reassures himself of his own individual freedom by affirming his ability to choose the more evil of two options (*7*).

We, who have grown up rejoicing in science, were confident in our acceptance of Sir Francis Bacon's aphorism that we cannot command nature except by obeying her (*8*). We really did not mind obeying as long as we knew that we would ultimately command. But now the

empirical evidence may be turning to support those who feel that science is in some sense in the grip of natural forces which it does not command. Too often we conjure up genies who produce short-term benefits at the risk of much larger long-term losses. We develop marvelous individual transport systems which poison the air we breathe; learn how to make paper very cheaply at the cost of ruining our rivers; and fabricate weapons that determine our defense strategy and foreign policy rather than being determined by them. Above all, the applications of science have produced an unrestricted increase in the human population which we recognize as fatal to our welfare but have only the vaguest idea how to control. In a short time we will be able to design the genetic structure of a good man. There is some uncertainty about the exact date, but no doubt that it will come before we have defined what a good man is.

In the foregoing analysis, in an effort to obtain intellectual respectability I have painstakingly tried to break our problem down into a series of numbered subheadings. Actually, they all add up to the same thing: Although the general public is grateful to science for some of its more tangible benefits, it is increasingly skeptical and even frightened about its long-term results. The anxiety centers on the concept of science as the prototype—the most magnificent and most frightening example of the rational systems which men make to control their environment and which finally end by controlling *them*. It may be well to recall that the medieval structure of natural law was even more rational than science, in the sense that it depended on the mind alone without submitting its conclusions to empirical checks. It managed for a time to obtain even greater control than science has over both the bodies and (especially) the spirits of the people of the Western world. It, too, developed an interesting life of its own as it followed the paths of reason into ever more subtle areas. It failed, for a number of reasons, but primarily, perhaps, because neither the logic-chopping of the medieval philosophers nor the temporal power of the papacy which it was designed to support appeared to be sufficiently related to the longings of individual human beings. The Reformation, for all the complexity of its theology and, often, the brutality of its methods, was primarily an effort to assert the rights of the individual conscience over the medieval power structure.

A Watershed?

I am not really sure that we stand on the kind of watershed Luther stood on when he nailed his theses to the door of the cathedral, but we may make a serious mistake if we do not at least entertain that possibility. If we fail to recognize the average man's need to believe that he has some reasonable command over his own life, he is simply going to give up supporting those systematic elements in society which he sees as depriving him of this ability.

As I noted above, so perceptive a critic as Lionel Trilling traces much of modern literature and art to a long-standing revolt of sensitive and creative men against the systematic constraints of society. The New Left can be regarded as a politization of the same trend. Actually, of course, anarchy had a political as well as a purely intellectual existence when Dostoevski was writing, but the 19th-century political anarchists were effectively liquidated by the Marxists, who felt that they had a better idea. Now that Marxist communism has developed most of the ills of bourgeois industrial society plus its own especially repressive form of bureaucracy, anarchism is again put forward as an attractive alternative to organized, corrupt societies.

There is a difference, however, in the way 19- and 20th-century anarchists regard science. On the whole, the 19th-century ones were atheists and saw religion as the co-conspirator with government and business. Science tended to be favored, partly because of its contributions to man's material welfare, but perhaps even more because of its aid in debunking religion.

Two paragraphs from Mikhail Bakunin are worth quoting, partly because of the flavor of the rhetoric (*9*).

> [The churches] have never neglected to organize themselves into great corporations . . . the action of the good God . . . has ended at last always and everywhere in founding the prosperous materialism of the few over the fanatical and constantly famishing idealism of the masses.
>
> The liberty of man consists only in this: that he obeys natural laws because he has himself recognized them as such, and not because they have been externally imposed upon him by any extrinsic will whatever, human or divine, collective or individual.

The New Left certainly agrees with Bakunin about the need to destroy the existing order, but it tends to see God in a different light. In the United States, religion has been conscientiously separated from the State for so long that it is no longer regarded as part of the apparatus of repression. Indeed, many draft-card burners and other protestors against the immorality of the existing order are primarily religiously motivated. On the other hand, science as the interpreter of the laws of nature, which Bakunin set against the laws of the State, has lost its revolutionary character and is viewed as a dangerous collaborator of the industrial-military complex. One of the difficulties may be that science has become so complicated that the ordinary man no longer believes that "he himself has recognized them [natural laws] as such" but feels that "they have been externally imposed upon him."

Educating the Public

What, then, can we do to improve the image of science as something of human scale, understandable and controllable by ordinary men? In the first place, we will have to continue our efforts toward educating the public, both in school and outside it, through reporting in our newspapers and magazines. Although I have given some reasons for believing that there are limitations to the capacity of much of our population to understand and take pleasure in the way science understands the natural world, I still believe that much more can be done to improve matters than has been done so far. As for the formal part of education, I propose that we rather deliberately reduce the rate at which students must handle the material set before them, so that they can master it without feeling frustrated and overwhelmed. If we begin the process, as is now fashionable, in the early elementary years, continue it through college, and carefully design things so as to avoid redundancy, students might end up with a much more complete understanding than they do now. This effort is worth even more money and time than have been put into it so far.

As for less formal methods for presenting science to adults, we should devise some analogy that would do for the general public what agricultural extension courses have done for the farmer and his wife. The average successful farmer, although he is far from being a pure scientist, has an appreciation for the way science works. Certainly he understands it well enough to use it in his own business and to support agricultural colleges and the great state universities that grew out of them.

As one who has spent a considerable period of his life worrying about medicine and public health, I am much less happy about our efforts to instruct the average man in a rational or scientific attitude toward the conduct of his own life. It has proved ever so much easier to persuade the average farmer to plant hybrid corn than to persuade the average man to give up smoking cigarettes. We have been almost too successful in persuading farmers to put nitrogen on their fields, while we continue to fail in trying to persuade the average man to put minute amounts of fluorine in his water supply. Few individual doctors seize the opportunity to explain to their patients, in even quasi-scientific terms, what their illnesses are, and I am appalled by the bizarre notions of human physiology which are entertained by some of my best friends.

Granted that doctors do not have enough time to talk to their patients and that many doctors really are not very scientifically oriented themselves, we might think seriously of setting up in every city a kind of paramedical service designed to teach people about their own illnesses. A doctor with a patient who is developing coronary insufficiency, for example, could refer his patient not only for an electrocardiogram, a blood-cholesterol, and clotting-time determinations but for instruction, in a class of cardiacs, on just how the heart and circulation work. Such an enterprise might help individual patients adjust to their illness more suitably, but this is not the real point. The aim would be to take advantage of an unhappy accident in order to increase the individual's motivation to learn something about science. Therefore, such clinics should be paid for not only by the Public Health Service but by the Office of Education.

Second, we must make a major effort to bring the course of science, and especially its technological results, under better and more obvious control by individual human beings and their representatives. We are, it is true, slowly gearing ourselves to do something about pollution of the environment, but the overall guidance and control of this effort is largely in the hands of part-time experts who fly in and out of Washington to attend meetings which issue prophesies of doom or unsupported reassurances, as the composition of the particular panel may dictate. Somehow, thinking about the long-term results of technology, formulating the options in such a way that the public can understand them, and guiding the course of events along the chosen path must become as exciting and rewarding for the best minds as is the present pursuit of basic scientific knowledge. Above all, the options must be made clearly understandable to the people, and the people must feel that they are doing the choosing. The present method of announcing that such-and-such a corporation is about to erect a large atomic power plant on a certain body of water and then engaging in a debate, based on inadequate information, about the effects of the heat on the lake or river, the degree of radioactive contamination, and so on, is totally unsatisfactory.

The process of educating the public should begin much earlier, with discussion of the need for additional power plants and of the probable cost of putting them here or there, in terms of increased power rates on the one hand and increased contamination of the environment on the other. The public must slowly be brought to see that every such occasion involves a real choice between real alternatives, and that the alternatives must be balanced against one another. Similar considerations apply to the use of insecticides. Nobody, as far as I know, has seen fit to make any even approximate estimates of what our food might cost if we were to abandon the use of these agents. Similarly, nobody has told what it would cost to produce high-octane gasoline by means of some method other than the addition of tetraethyl lead.

We have been very negligent in devising ways and means of ensuring that the cost of introducing new technologies is borne by the people who immediately benefit from their use. If anything, the trend may be away from emphasis on this relationship. For example, the introduction of the cotton picker and of modern methods of weed and insect control, not to mention the enormous subsidies provided by the American taxpayer, have made the culture of cotton in a few counties in the South and Southwest extremely profitable, so that large landholders have become extremely wealthy. Presumably, the public at large has benefited by a slight reduction in the cost of cotton cloth. On the other hand, the social costs of this industrial revolution in agriculture have been incalculable; they have been borne primarily by the large number of Negro laborers who have been uprooted and transported into the cities, where they found themselves ill-prepared to benefit from the urban amenities enjoyed by their more prosperous fellow citizens. The economic costs of supporting them in an alien environment have been borne, not by the wealthy southern landowners and certainly not by the individuals who paid a bit less for the cotton cloth, but almost entirely by the displaced people themselves and by the people who pay real estate taxes in a handful of our larger cities.

All these problems are, however, subject to some kind of scientific analysis, and the options can be placed scientifically before the public. In preparation for this kind of decision making, we should probably overhaul our teaching of science, and especially of mathematics, so as to give the average man greater ability to evaluate evidence presented in modern scientific form. High school courses in statistics, probability, and systems analysis are clearly more relevant to modern living than Euclidean geometry, and might well replace this and other time-honored introductory courses in mathematics.

Role of Science in Military Affairs

Third, an effort should be made to clarify the role of science in military affairs. Although most of us who are acquainted with the facts know that much of the research supported by funds from the military services actually contributes as much to civilian life as to military matters, this fact is not known to the general public or to the student body. Cornell students, for example, are disturbed to learn that the largest single donor to research at their university is the Department of Defense, even though one of the university's two largest research enterprises is the observatory at Arecibo, whose contributions to pure science are of far more consequence than anything it has ever contributed to the Air Force. If the military uses of science occurred as fallout from scientific investigations undertaken for peaceful purposes, this would be far better for morale than continuation of our present course, in which pure science appears as the crumbs that fall from the rich Pentagon's table. The obvious and actually very easy way to accomplish this would be to reduce military appropriations by what, to the military, would be a tiny amount and substantially increase appropriations for the National Science Foundation and the National Institutes of Health. Certain civilian agencies, such as the Department of Commerce and the Department of the Interior,

should also be supporting far more basic and applied research than they are now.

Whether the civilian establishment for science should engage in any research of military consequence is a matter for debate, but such debate should be encouraged. Many universities of good will long ago decided that secret research has no place on a university campus, but this does not prevent them from doing unclassified work which has a clear military bearing, nor does the university ordinarily discourage its faculty from serving as consultants on classified projects carried out elsewhere.

There are obvious theoretical and practical difficulties confronting any other policy. Until now, for example, most scientists have felt that the importance of advancing knowledge overshadowed questions regarding the source of support. The control we now have of malaria is a net gain, regardless of the fact that, from the discovery of the malarial parasite in North Africa to the development of control methods by the American Army during World War II, research on malaria was often carried on by military personnel.

Furthermore, it is clearly important that we have, as consultants to the military, civilian scientists who learn the details of proposed weapons systems so that they can make an appropriate case against, as well as for, deployment of these systems.

Finally, as long as we feel ourselves threatened by the scientific and military establishments of other nations, it is with some difficulty that most of us who have special skills, gained largely through contributions from the American public, can refuse to use those skills for the defense of that same public. This last issue is becoming a rather knotty one, however, since we may have reached a point at which war is so disastrous for both sides that there is simply no point in undertaking the exercise at all.

Conclusion

The most important lesson for the scientific community would appear to be one that can be stated as follows. Science can no longer be content to present itself as an activity independent of the rest of society, governed by its own rules and directed by the inner dynamics of its own processes. Too many of these processes have effects which, though beneficial in many respects, often strike the average man as a threat to his individual autonomy. Too often science seems to be thrusting society as a whole in directions which it does not fully understand and which it has certainly not chosen.

The scientific community must redouble its efforts to present science—in the classroom, in the public press, and through education-extension activities of various kinds—as a fully understandable process, "justifiable to man," and controllable by him. Scientists should also take more responsibility for foreseeing and explaining the long-term effects of new applications of scientific knowledge. A promising procedure for planning the control of such effects is presentation of the probable outcomes of various available options so that choices can be made by the public and their representatives. Costs and benefits must be estimated not only in quantitative, dollar terms but, increasingly, in terms of qualitative and esthetic judgments. Thus ends the comfortable isolation of science from the ordinary concerns of men as a "value-free" activity.

References and Notes

1. R. J. Dubos, *The Dreams of Reason* (Columbia Univ. Press, New York, 1961), p. 167.
2. C. E. Sagen, personal communications.
3. J. K. Galbraith, *The Affluent Society* (Houghton Mifflin, Boston, 1958), chap. 3.
4. R. N. Goodwin, *New Yorker* **1969**, 38 (4 Jan. 1969).
5. C. E. Schorske, "Professional ethos and public crisis: a historian's reflections," *Mod. Language Ass. Amer. Publ. 83*, 979 (1968).
6. L. Trilling, *Beyond Culture* (Viking, New York, 1965).
7. F. Dostoevsky, *Letters from the Underworld*, C. J. Hogarth, Trans. (Dutton, New York, 1913). All of part 1 is relevant to this discussion, especially page 37: "Moreover, even if man were the keyboard of a piano, and could be convinced that the laws of nature and of mathematics had made him so, he would still decline to change. On the contrary, he would once more, out of sheer ingratitude, attempt the perpetration of something which would enable him to insist upon himself; and if he could not effect this, he would then proceed to introduce chaos and disruption into everything, and to devise enormities of all kinds, for the sole purpose, as before, of asserting his personality. . . . But if you were to tell me that all this could be set down in tables—I mean the chaos, and the confusion, and the curses, and all the rest of it—so that the possibility of computing everything might remain, and reason continue to rule the roost—well, in that case, I believe, man would purposely become a lunatic, in order to become devoid of reason, and therefore able to insist upon himself."
8. F. Bacon, *Novum Organum* (1620), aphorism 129.
9. M. Bakunin (Bakounine), *God and the State* (1893).