Corrected

THE GOALS OF SCIENCE*

(or possibly: SCIENCE IN SOCIETY?)

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The main topic of this paper is the relation between the scientific enterprise and the society in which that enterprise is carried out. This relation has become increasingly tense and complex in the last few decades. The problem arises, I believe, from the internal stresses and contradictions within both society and science.

Our society is fundamentally based on the premise of democracy. Modern democracy is the daughter of the rationalism of the 17th and 18th century and is therefore in a sense the twin sister of science. It is by its very origins committed to rationality, to optimism about the future of mankind, to faith in progress based on factual knowledge of the world. But, at the same time, western democracy is also committed to a utilinarian view of the world, a world of budgets and appropriations and cost-benefit accounting that puts a price on every item and on every activity within society. And, in addition, democracy is buffeted by irrational forces, which range from the irrationality of various counter-cultures to the irrational persistence of economic injustice, to the aberrations of war and nationalism, racism and to sectarian prejudices of all sorts.

The scientific enterprise itself also presents a multitude of faces. To its practitioners and to a certain number of initiated observers, science preserves the quality that made it, from Newton to Darwin and to Einstein, the most daring and most successful adventure of the human mind. For the enthusiastic scientist, the scientific enterprise is a monument to humanity's intellectual power and freedom -- a modern equivalent of the great cathedrals that the burghers of the middle ages raised as monuments to their newly found sense of economic power and political freedom.

But, if science is ~~the~~ a cathedral raised in praise of intellectual freedom, one must admit that too often, under the pressure of utilitarian society, the cathedral of science has come to look like one of those monasteries one sees in the French countryside, in which a modest church is almost hidden by a prosperous distillery ~~of liqueurs~~. The sale of products becomes the justification for being allowed to pray the Lord. It is a fact of life that science has become so expensive that its support can be justified only on the basis of the benefits that derive from it, which is to say that science has to be justified by the practical technologies that it generates.

Unfortunately, having to justify itself by the cost-benefit criterion, science inevitably also becomes involved in participation in many of the questionable activities of society -- a participation that in the long run is bound to undermine the rational heritage of science.

These multiple contradictions within both the enterprise of democracy and the enterprise of science are, I believe, at the root of the strains and misunderstandings that have arisen.

I shall single out some of these problems and comment upon them in the restricted field of the so called biomedical science (itself a misnomer, like science-and-technology and other binomials that please politicians and obscure reality). The three aspects I am going to discuss are, the cost-benefit reckoning of the fruits of research, the decision-making process in the selection of research programs, and the distrust of science and scientists that is manifested in our society at large and among certain elements of society in particular. Even though I cannot hope to come up with satisfactory practical solutions to these problems, I shall try to suggest possible steps toward a restoration of confidence.

The cost-benefit problem is the one that most directly affects the pursuit of science. It manifests itself, for example, in the form of congressional inquiries as to whether the American public is getting its dollars' worth from the investment in research, in terms of practical results, be these gadgets or vaccines or therapeutic advances. This is perfectly legitimate request. After all, public money is appropriated for building distilleries, not to raise cathedrals. And scientists, in order to carry out their work, have willingly accepted the practice of justifying the church by the distillery.

The main problem, however, is the misunderstanding that confuses basic research, out of which come rather indirectly whatever practical benefits may be expected from science, with targeted research, which is nothing but the application of existing knowledge to a specific target. To carry the metaphor a step further, basic research on herbs and essences may ultimately yield a new heavenly liquor. Targeted research may succeed in producing a cheaper variety of coca-cola.

The distinction between basic and targeted research is an extremely difficult one for the scientifically uneducated to grasp. There is an enormous difference between development research, which consists of applying existing knowledge to a new target, and basic research, which means the creation of new knowledge that may or may not ultimately be relevant to a given problem. Sending a man to the moon involved nothing but Newtonian mechanics plus lots of sophisticated gadgetry. But to control cancer we must first understand what cancer is and how cancer cells behave, and how they differ from normal cells, and how normal cells are put together. The Newton of cancer has not yet appeared on the scene, or maybe is just now getting his or her graduate degree.

Many kinds of answers have been given to the question of cost-benefits from basic science. Specifically dealing with biomedical science Mr. Benno Schmidt, former chairman of the National Cancer Board, has pointed out that any serious industry would invest at least 5% of its budget in research, whereas the US Goverment spends 110 billions for health activities and only about three billions for health-related research. This is but a pragmatic answer, that does not take into account the difference between targeted and basic research. After all, the total federal budget for research is about 25 billions, of which over 15 billions go into a variety of war-related activities, and nobody bothers or dares ask cost-benefits questions about those. All the fuss is about the three billions for biomedical science.

More convincingly, the Committee on the Impact of Biomedical Research has pointed out that most biomedical research deals with problems that are still unsolved at the basic level, that the benefits are indirect and sporadic, but that when the benefits come, they pay off handsomely for the investments that made them possible. The eradication of poliomyelitis, of death due to Rh incompatibility, and soon we hope of hepatitis, are given as examples of the benefits derived from ~~immunology alone.~~ one branch of biomedical science alone,

This is really the crux of the matter. New technologies seldom if ever arise from the demand of an applied field.

Discoveries that lead to practical applications are made, not because someone wanted to solve a given practical problem, but because many individuals were busy building their little corners of the cathedral.

Let me quote from an article by Victor Weisskopf,* himself quoting H. B. Casimir:

* "Science and Ethics," in: Physics in the Twentieth Century, MIT Press, Cambridge, Massachusetts, 1972.

"One might ask whether basic circuits in computer might have been found by people who wanted to build computers. As it happens, they were discovered by physicists dealing with the counting of nuclear particles because they were interested in nuclear physics."

...."One might ask whether induction coils in motor cars might have been made by enterprises which wanted to make motor transport and whether then they would have stumbled on the laws of induction. But the laws of induction had been found by Faraday many decades before that.

"Or whether, in an urge to provide better communication, one might have found electromagnetic waves. They weren't found that way. They were found by Hertz, who emphasized the beauty of physics and who based his work on the theoretical considerations of Maxwell. There is hardly any example of twentieth century innovation which is not indebted in this way to basic scientific thought."

In a more humble vein, I may cite my own experience ~~that~~ as it relates to the cancer problem. In 1946, I was interested in the effects of radiation on genetic material, and I asked myself the question whether a virus had just one gene or many. In the latter case, could two viruses be damaged by radiation in different genes, in such a way that they might come together to reconstruct a good virus? That curiosity led to the discovery that the genetic material, the DNA of bacteria and viruses, could repair radiation-induced damage. Later it was found that genes in all organisms are subject to damage and repair. It took twenty years before someone found that the human disease *Xeroderma pigmentosum*, which leads to skin cancer, is a genetic defect caused by an inability to repair DNA injured by radiation. And only recently it is becoming clear that the DNA-repair system present in every cell makes errors, which are mutations, and are likely to be the cause of many cancers including those produced by chemical carcinogens.

Let me suggest an analogy. The thousands of scientists working in their laboratories are like the uncountable numbers of coral polyps that are continously working under the waves, out of view, building immense coral reefs. The practical applications of science are like those rare sites where the coral reef emerges and forms an atoll, on which a complete new set of life activities can then develop -- birds, and insects, and plants, and mammals -- using the new land created by the submarine work of the coral polyps but bearing little resemblance to the coral itself. Let us not forget that on the atoll itself the coral polyps are usually dead.

I have referred to cancer. This brings me to the second area of public criticism, the decision-making machinery by which priorities in science are chosen. In the scientist's view the problem seems to lie with the politicians; in the popular view, with the scientists themselves. About six years ago Washington began to become interested in a National Cancer Plan. It was at first the pet project of Senator Yarborough, and when he failed to be re-elected, the Cancer Plan became Senator Kennedy's baby. Then President Nixon, presumably seeing some political mileage in it, swiped it away and adopted it as his own. After President and Congress had made the decision, several hundred scientists were then brought together to put some substance into it. Since 1972 the program has come along rather successfully in terms of scientific advances, although it has already begun to come under attack both by the cost-benefits advocates because in four years it has not yet solved the cancer problem, and by many scientists because of its crash program aspects.

Incidentally, it is one of the interesting features of democracy to have on the one hand a national cancer program, while at the same time the use of the most powerful carcinogen -- cigarettes -- has increased to 600 billions per year, producing 80,000 lung cancer deaths; no effort has been made to curb the advertisement of cigarettes in magazines and newspapers; and no cost-benefit study has yet been published by tabacco growers or cigarette manufacturers.

Among the criticisms leveled to the cancer program was that socially speaking, cancer is not the only or the most urgent area where efforts might be concentrated: nutrition, child care and many others seemed to social reformers more urgent subjects to tackle.

On the other hand, many scientists complained, not without reason, that the cancer program received disproportionate share of the available research funds and that basic research in other areas was suffering -- which was true. And yet the cancer program, scientifically speaking, has prospered reasonably well. The reason is that it turned out to be a field of biological research whose time had come, at least at the basic level.

In the past 25 years molecular biology had made its enormous advances -- discovering the nature of the gene, the genetic code, the nature of gene messages and their translation into the structure of proteins. All this had been done almost exclusively through work on bacteria and bacteriophage.

The next natural frontier was the cell of the complex organisms; but here a complete new set of problems confronted the biologist: whereas in bacteria each gene responds in a stereotyped way to changes in the extra-cellular environment, in the different types of cells of a complex organism, for example a human being, different sets of genes become programmed in development to function in specialized ways: cells with identical genes "differentiate." This is the central problem of development, and is also the central problem of cancer. What makes a liver cell or a nerve cell or a skin cell what it is? And why does the cancer cell behave the way it does?

It appears now that cancer cells and agents that cause cancers, including viruses, may be destined to play in the growth of molecular developmental biology the same role that bacteriophages, the viruses of bacteria, played in the growth of molecular biology. Just as the orderly functioning of the genetic material of a bacterium could be explored by introducing into the bacterium a disrupting virus, so also the orderly functioning of normal cells may be clarified by studying what goes astray when a cell becomes cancerous. And in turn, from the growth of the new developmental biology, there may then grow the knowledge from which cancer prevention and therapy may evolve.

The fact that cancer research turned out to be a field whose time had come does not in itself answers the criticism of the way it was chosen for priority. It is because of the fundamental soundness of the scientific research structure in our society that a reasonable balance was achieved, so that not much money was spent on trivial gadgetry or on crash programs following untested leads.

The questioning of choices and priorities is only one aspect of a more general phenomenon, which may be defined as a crisis of confidence in the decision-making machinery of our society. The crisis of confidence is related to the apparent inability of a successful society to manage large problems, from the ~~treath~~ threat of atomic war to the problems of economic injustice and unemployment -- what I referred to earlier as the irrationalities of our democratic society. More specifically, the crisis of confidence involves doubts as to the ability of society to handle intelligently and constructively the powerful technology that science has made possible. The contrast between the billion dollar spectaculars of NASA, the 100 billion dollars for so-called defense, and the 25% of unemployment among recent high school graduates (35% if black) does not increase public confidence in the effectiveness of our democracy to make rational choices and to provide for human needs. In the resulting frustration, the distrust of the public turns to the scientists. What is being questioned is usually the choice of priorities for research, as though scientists preferred to work on useless topics than on useful ones. For example, Senator Javits, who has been a steady supporter of science within Congress, had the following to say at a recent conference:

"The decisions with respect to the future of biomedical research, the determination of priorities, the weighing of the nonquantifiable social costs and benefits of medical technology -- these decisions are in fact political becuase they involve the entire body politic including, of course, the research community itself. A scientist is no more trained to decide finally the moral and political implications of his or her work than the public -- and its elected representatives -- is trained to decide finally on scientific methodologies."

This is a perfectly reasonable statement, which however fails to specify any useful machinery by which scientists and the public can effectively cooperate in setting priorities.

But the crisis of confidence goes beyond matters of priorities and choices. It begins to question the very integrity of scientists in the performance of their work. It casts scientists into the sinister light of the most lurid science fiction stories.

A typical and disturbing instance is the ongoing controversy about recombinant DNA experiments, a controversy that has been especially heated in Cambridge, Massachusetts. The experiments in question consist in joining together fragments of DNA from bacteria with fragments of DNA from cells of more complex organisms, plants or animals. The joint fragments can then be introduced into bacteria, grown in large amounts, and studied in a variety of ways to investigate the properties and function of specific genes and groups of genes. This technology makes available a powerful tool for the study of gene action and organization in complex organisms. It will be a key technology for the molecular understanding of cell differentiation during development.

The early developers of this technology observed a self-imposed moratorium and called for national regulation. The reason for this was to avoid the danger that genes from pathogenic organisms or cancer producing viruses would be manipulated in this way, creating a hazard that was clearly forseable.

Under prodding by these scientists, who were exerting a welcome sense of responsibility, the NIH formulated guidelines. Under the guidelines all potentially dangerous experiments, like those involving genes of pathogenic viruses or even the less dangerous ones involving any human genes, can be done only in a few special laboratories under high containment conditions. Other experiments, including any in which genes of bacteria and of animals other than man are brought together, can be performed in containment laboratories under strictly controlled conditions.

Even so, there has been strong criticism of all research involving recombinant DNA. The criticism falls into three categories, which I would classify as mystical, sanitary, and political. I have little patience for the first category, I believe the second is not justified, but I see some justification for the third category.

What I call the mystical criticism is the assertion that there is something intrinsically wrong in creating new organisms by mixing the heredity of bacteria and of complex organisms like plant and animals. The argument is that barriers that nature has set between organisms should not be crossed. There is not much point in arguing seriously against such an assertion. The argument of natural barriers to human knowledge and human use of knowledge has been put forward many times by the opponents of scientific progress, from the use of the telescope by Galileo to the use of steam engine to replace horsepower. It is interesting that one of the foremost advocates of the need to respect natural barriers also advocates abandoning the current efforts of cosmologists to detect intelligent life on other solar systems.

The second argument is that of safety: it is claimed that any organism carrying recombinant DNA may prove to be pathogenic and that therefore such experiments should not be done at all or only done in very special laboratories.

Apart from the fact that there is no reason to suspect that genes from a plant or an animal should render a bacterium pathogenic for man (it is generally extremely difficult to cause any non-pathogenic bacterium to acquire pathogenicity), the simple answer to the question of safety is that the proposed experiments, innocent as they probably are, would still be done under conditions of containment much stricter than those under which expert bacteriologists in hospitals and public health laboratories are accostumed to handle true pathogens.

The suggestion that such experiments should be done in remote laboratories where scientists could go occasionally to carry out their work indicates a profound misunderstanding of the significance of recombinant DNA research. I referred earlier in this paper to the fact that the molecular study of differentiation is the current frontier of biology. Within this area, the use of recombinant DNA techniques is not a peripheral technology, which a scientist might perform once a month or once a year in a remote laboratory in the Nevada desert. It is as central a methodology as the use of a microscope. Telling biologists today to forego recombinant DNA experiments is like telling a chemist not to use NMR or telling a physicist that he or she cannot use a laser. It may even be that the importance of recombinant DNA techniques for basic biology outsteps some of the practical applications that have been proposed, such as the mass production of insulin or of interferon.

At a more fundamental level, it seems to me that attempts to put limits to the use of powerful means of scientific exploration, provided such means are used responsibly, ignores the reality of today's world. We as human beings face problems that are not only technologically but biologically unique. To cope with the stresses and pressures that our own species will have to face in the next couple of centuries and to create a world fit for the new billions of human beings to live in, we shall have to understand as precisely as possible all interactions within our own body cells. We shall need to acquire a molecular understanding of the unique human brain, of human language, of human cognition. It is not through fear or distrust of experimental techniques that we shall acquire that knowledge. As Karl Popper stated in his Spencer Lecture: "Science or progress in science may be regarded as a means used by the human species to adapt itself to the environment."

And yet, while I disagree with many of the arguments put forward by opponents of recombinant DNA research, I must admit that I feel some sympathy for the political implications of their opposition.

Their criticism ultimately stems, not just from distrust in science, but from a political disaffection for what I called earlier the irrational side of our society. It also reflects a challenge to the will of scientists and scholars to stand up as defenders of rationality against those irrationalities.

Claims such as I have made, of the overriding human value of science, of its being a modern equivalent of the cathedrals of the middle ages, should be matched by evidence that scientists and other scholars are in fact selflessly dedicated to the cultural enterprise. Unfortunately, we know that too often this is not true. Scientists have lent their work and their prestige to some of the shabbiest enterprises of our society. To take only Vietnam as an example, scientists and scholars have collaborated in all sorts of ways, from the weaponeering of the automated battlefield, to the programming of the rain of fire over undefended villages, to the planned uprooting of millions of innocent people. And Vietnam is only one of the domains in which many scientists have gone along, passively or actively, with the irrationality of politics and the call of power. Is it surprising that our claims to innocence and purity sound somewhat hollow?

What can be done to change this situation?

In the first place, I think scientists should actively promote open discussion of the goals and limitations of science in order to generate that informed public opinion that alone can give legitimacy to any social undertaking, including science. In fact, I believe the work of the Cambridge Committee on the Impact of Recombinant DNA Research may ultimately prove to be a positive step in the right direction.

At a more fundamental level, what is needed to restore public confidence in the enterprise of science and in the intellectual enterprise in general is for intellectuals, including scientists, to exert an active leadership in the restoration of rationality to our democratic society. Scientists should take the initiative for a common front with the public, not just to direct the uses of science toward this or that goal of practical relevance, but to help redirect the priorities of society away from social inequality, racial injustice, wanton waste and absurd weaponeering.

We cannot call ourselves the builders of today's cathedrals if we close ourselves into the cult of a private chapel or if we are willing to worship in the temples of Mammon.

We cannot ignore or condone the irrational and inhuman uses to which the fruits of science are often put for reasons of power or of profit.

If we scientists refused to join the ventures of injustice; if we denied our know-how to the dehumanizing enterprises of society; if we insisted that the rationality of our work be matched by rationality in the use to which the products of our work are put, then we could again claim to be the builders of a cathedral, open to all for worship and wonder.

~~If we challenged selfishness and greed~~