THE ROLE OF SCIENCE IN OUR SOCIETY

Because the road from scientific discovery to new technology is a wayward one, lawmakers and officials intent on retuning Federal science policy must bear in mind that government support for long-term R&D is needed to complement industry’s short-term focus.

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Science, particularly physics, has been in a relatively privileged position in the United States since the end of World War II. Support by the government has been generous, and those of us whose careers have spanned the period since World War II have, until recently, seen research funding increasing in real terms. Our support rested on two assumptions: Science would improve the lives of the citizens, and science would make us secure in a world that seemed very dangerous because of the US-USSR confrontation.

The world situation has changed radically, both politically and economically. The USSR is no more, and economic concerns loom much larger as our deficit has grown and as economic rivals have become much stronger. With these changes there has come a reexamination of many of the assumptions about priorities for government activities. It should be no surprise that the rationale for the support of science is one of those things being reexamined. Being reexamined is not very comfortable for those under the microscope, for we are in effect being asked to rejustify our existence in terms of the relevance of our work to the problems that society perceives to be most immediate.

To the scientist this predicament is strange, for has not the scientific revolution that began about 400 years ago with the work of Galileo, and the technology spawned from this ongoing revolution, transformed the world? Indeed it has. A person brought somehow to today from only a hundred years ago would find the world very different and even bewildering. Back then the average life span was shorter, infant mortality was much higher, and disease carried off more people than did old age. Communications were primitive, only crude telephones existed, and there was no radio or television. The average person knew little of the rest of the world. Transportation was slow, and there were no automobiles or airplanes. There was no knowledge of the subatomic world, no computers and so on. Indeed, most of the work that people do today is in areas that did not exist back then and is based on the technologies derived from the scientific revolution begun by Galileo.

One of the principal present concerns of our society, and therefore of the Washington policymakers, is economic security. That issue is discussed in terms of such things as the deficit, technology policy, competitiveness, and supporting high-tech industry, and it is in these terms that science policy is being reevaluated. This attitude justifiably makes those engaged in fundamental research nervous, for fundamental research brings long-term benefits, while the debate is couched in terms of short-term improvements. Though there is a consensus that fundamental science is good, there is a danger that a lack of understanding of how fundamental science leads to the development of new technologies and applications will end up shortchanging the long term and thus damaging the prospects for succeeding at what the policymakers are trying to do.

My own perspective is that of a physicist who has done research in a university has directed a large laboratory involved in a spectrum of research and technology development, has been involved with industries large and small, and has some experience in the interactions of science, government and industry. I know that the road from a basic scientific discovery to the development of new technology applications is not the broad, straight highway that many would like to believe. To be sure, basic discoveries are at the heart of the development of new technologies, but there are many twists and turns in the road before industrial applications are realized, as well as large investments of both intellectual and financial resources.

One can have endless and probably useless debates on whether science creates technology or technology creates science. These arguments are of little value, because both statements are true. Today’s technology is based on yesterday’s science; today’s science is based on today’s technology. The science that even now is making discoveries that will create new industries cannot be done without, for example, the lasers and computers that have been developed from previous science. The road from science to new technologies is not a straight highway, but a kind of spiral of science enabling new technologies that, in turn, allow new science that again creates new technologies and so forth.

In the US the rationale for a public policy that supported scientific research was set forth by Vannevar Bush at the end of the Second World War, in a now-famous
THE TRADITIONAL DIVISION of research into "basic" and "applied" is too simple to describe how science yields new technologies. As exemplified by this "R&D matrix" for the development of optical fiber communications, the basic and applied work must each include both fundamental components (done with little understanding of potential applications) and strategic components (in which applications are expected) if a useful application is to arise from a "pure" discovery. Figure 1

report to President Harry Truman entitled "Science: The Endless Frontier"—a report probably quoted more often in the last few years than in its first 45 years. Bush had directed the wartime Office of Scientific Research and Development, and in July 1945 he issued this relatively brief (40 pages) document. In the introduction he first mentioned penicillin and radar as examples of critical technologies with immense practical benefits that had come from long-term research. He then went on to say: "Advances in science when put to practical use mean more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for learning how to live without deadening drudgery which has been the burden of the common man for ages past.... But to achieve these objectives—to secure a high level of employment, to maintain a position of world leadership—the flow of new scientific knowledge must be both continuous and substantial."

He then concluded the opening section: "Science, by itself, provides no panacea for individual, social, and economic ills... But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world."

This last remark is most important, for it must be recognized that it is industry, not science, that produces products. Science enables industry to develop new technologies, and to reduce scientific discovery to practical applications efficiently and quickly, there must be a continual interaction between scientists in the laboratory and engineers in industry.

Evolution of new technologies

Research is most often broken down into two simple categories: basic and applied. Basic research is generally thought of as that which develops new knowledge, and applied research is defined as that which develops new technologies. This distinction characterizes what scientists do—explore the unknown and solve problems. But it is too simple a description to describe how science produces new technologies.

There is another dimension, which I shall divide into fundamental and strategic research, characterized by different time horizons and rationales for support. As far as new technologies are concerned, in fundamental research there is little if any understanding of possible potential applications at the time the work is done, while in strategic research practical applications are expected, though there may be much of the unknown to explore and understand before one gets to those practical applications.

Figure 1 presents a useful example. Fiber optics is revolutionizing communications. Hair-thin pieces of glass or plastic can stretch thousands of miles under the oceans to connect continents and can carry telephone, television and computer communications in the most efficient and lowest-cost way known. The "basic fundamental" research underpinning this technology is quantum mechanics, developed from the 1920s through the 1940s, particularly the work of Einstein on stimulated emission and absorption (the so-called A and B coefficients). The "fundamental applied" work was the development of the laser. While theory had shown that the laser was not impossible, it was not obvious that the required conditions could be achieved in practice. The "basic strategic" research was a vast amount of work on the interaction of light with materials. Optical fiber communication comes from combining advanced solid-state lasers with advanced materials.

Virtually all of today's technologies can be described in like terms. The transistor (1950s) comes from the fundamental basic work in condensed matter (1920s and 1930s). Magnetic resonance imaging (1980s) comes from the work on nuclear magnetic movements of I. I. Rabi (1938). The examples all share certain characteristics. At their root lies fundamental science that leads to some new understanding and that in turn leads to further basic research that is strategic in nature or to fundamental applied research that develops a new enabling technology.

Even this picture can be criticized as much too simplistic. It does make the point, however, that behind new technologies lies a considerable amount of basic and applied research. While the time horizon from the fundamental basic work is long one, this work lies behind all of the advances in our modern world.

What is missing in this picture is a kind of third dimension that shows how, in developing new technologies and products, results from many areas of science and technology usually must be combined. To borrow a metaphor from my colleagues in biology, there is a kind of "double helix" in the interaction of science and technology. (See figure 2.) Science is one strand of the helix; the other strand is technology. The two are inextricably linked, and neither can advance in the long run without advances in the other. Policymakers in government who think that focusing on short-term applied work can increase economic competitiveness ignore at their (and our) peril the implications of the science-technology double helix for long-term development. To advance along this double helix, fundamental science is necessary to develop new capabilities that benefit humanity.

Perhaps this is best illustrated by a story that is reputed to be true. It concerns a time around 1850 when much of the fundamental work on electricity and magnetism was being done. In England, Michael Faraday was one of the giants of this work, making many of the basic discoveries linking electricity and magnetism. He is said to have been visited at his laboratory by the then-chancellor of the exchequer (and eventually prime minister), William Gladstone. After looking at Faraday's work and his untidy laboratory, Gladstone said to Faraday, "This is all very interesting, but what good is it?" Faraday is said to have replied, "Sir, I do not know, but someday you will tax it."

Lessons for the policymakers

There is a strong temptation in times of economic difficulty to cut back on long-term research to reduce costs. This measure can benefit industry and the economy only in the very short run, for without long-term research the engine of technology development will run out of fuel and eventually we will all be the losers. The loss can be very large if one's economic rivals do not also cut back.

The technologies that lie at the end of the long road
from scientific discovery to new technology are most often not visible to the scientist doing the basic work. Thus one should not try to target research funding exclusively toward areas where one expects technical advances. History shows clearly that we are not wise enough to do so successfully. A recent case in point is the development of high-temperature superconductors. A decade ago everyone regarded superconductivity as a dead field. It was believed that the Bardeen-Cooper-Schrieffer theory explained it all and that materials science through great effort could increase the superconducting transition temperature by perhaps 1 kelvin per decade. But in 1987, Alex Müller and Georg Bednorz were awarded the Nobel Prize in Physics for the discovery of a new kind of superconducting material with much higher transition temperatures, and it did not fit the model of the BCS theory. We still do not fully understand how these materials work, but applications are already beginning.

The pace of advance toward new technologies speeds up greatly when the technical and industrial communities both realize that something new can be produced from scientific advance. Once this realization occurs the most efficient and effective method of moving through this final phase is to encourage the close interaction and exchange of ideas between the research community and the development community. That is what happened in the creation of Silicon Valley, and that is what is happening now in biotechnology.

Someone once said that “technology transfer is a contact sport.” In industry it works best when scientists, engineers and product developers are brought together. The universities contribute by developing knowledge; by fostering strong interactions among their scientists and engineers and the industrial community; and perhaps most important, by training students who will work in industry and bring with them both the habits of mind that go with the investigation of the unknown and the latest information on science and engineering. The importance of properly preparing students is strongly emphasized in the report of the National Science Board’s Commission on the Future of the National Science Foundation.

We in the universities do very well at developing new knowledge in both the fundamental and strategic areas. We do fairly well in fostering interactions with industry, though there are problems about consulting time, conflict-of-interest policies and so on. While we do well at training our graduate students, I wonder if we are giving them the right message. There is a tendency on the part of faculty to want to clone themselves and, by their attitude, to make students feel that “success” means a career in research at a university or at one of the few large industrial laboratories that are left. This tendency is misguided, for most jobs for our graduates have always been in industry and not in research. One of the reasons society supports us is to train people who will transform the work done at universities into something of more direct benefit to society.

In retuning the nation’s science policy, some realities must be taken into account. Most of the nation’s civilian research and development is carried out in industry. While “development” has always been the major portion of industrial R&D, industry has made many critically important contributions to “research.” But competitive pressures have forced industry to shift R&D efforts toward work with shorter time horizons. Relatively little industrial R&D now has an anticipated time to application of longer than five to seven years. This is the case even at Bell Labs and IBM. Hence government support for long-term R&D is now more important than ever.

We also have to face the reality that support for science in the Federal government is fragmented. Major players include the Department of Agriculture, the Department of Commerce, the Department of Defense, the Department of Energy, the Department of Health and Human Services, the Environmental Protection Agency, NASA and the National Science Foundation. I have never been a supporter of the idea of a Department of Science and Technology to centralize all of this work, for I believe that the close coupling of research to an agency’s mission is vital to carrying out that mission efficiently. (In industry, a close coupling of R&D to the product development mission is the hallmark of our most successful corporations.) Also, a little anarchy and overlap in support of science is a good thing, for a good idea can most often get
R&D FUNDING for fiscal year 1996 proposed by the Clinton Administration is increased by a total of $1.4 billion in all the agencies that support physics except the Department of Defense, whose R&D budget would drop by $1.1 billion. The percentage change is shown in red and the absolute change in blue. This promising picture may be adversely affected by Congressional efforts to reduce the budget deficit. FIGURE 3

support from someone.

Some coordination of the nation’s science effort is, however, necessary to advance the goals of society. Former Presidential science adviser Allan Bromley and the Bush Administration took a major step forward with the revitalization of the Federal Coordinating Council on Science, Engineering and Technology, and the Clinton Administration has taken another important step with the creation of the National Science and Technology Council. Congress probably has too many committees and subcommittees looking at pieces of the problem, but I don’t think that is particularly harmful; while it is not neat, it does get the job done (leaving aside the question of “pork”).

In summary, in returning Federal science policy, we have to remember the following:
▷ Both fundamental and strategic research are vital to progress, and an appropriate balance must be struck. That balance should be struck across the government and not necessarily by agency.
▷ Industrial contributions to on long-term R&D are decreasing, and the government should mirror the situation by maintaining or increasing its long-term R&D component. This is fully consistent with the notion that the government should support what industry cannot in areas of importance to the nation.
▷ A close coupling of industry to the science community must be maintained if new generations of technologies are to be introduced.

Supporting views

This view of the importance of science to technology and of technology to economic activity is supported by economists and industrialists. The American Enterprise Institute’s conference on “The Contributions of Research to the Economy and Society” (3 October 1994, to be published) presents the economists’ view. A paper by Michael J. Boskin and Lawrence J. Lau of Stanford University, “The Contribution of R&D to Economic Growth,” estimates that the introduction of new technology accounts for 30-50% of economic growth.

Edwin Mansfield of the University of Pennsylvania, in his paper “The Contributions of New Technology to the Economy,” examines the return on investment in R&D. He finds that the rate of return to industry is around 20%, while the societal rate of return is considerably higher, around 50% (since technology spreads from the firm that introduced it). Mansfield finds academic research to be of great importance in underpinning industrial innovation.

Richard R. Nelson of Columbia University and Paul M. Romer of the University of California, Berkeley, in “Science, Economic Growth, and Public Policy,” examine the role of government policy. They emphasize the importance of interactions between the university and industrial R&D communities and the dangers of excessively narrow targeting of research funding by the government.

The leaders of industry strongly endorse Federal support for university research. On 13 March 1995, the chief executive officers of 15 of our largest technology-based industrial firms wrote to House Speaker Newt Gingrich (see PHYSICS TODAY, May, page 54), concluding their letter as follows:

Our message is simple. Our university system and its research programs play a central and critical role in advancing our state of knowledge. Without adequate Federal support, university research efforts will quickly erode. American industry will then cease to have access to the basic technologies and well-educated scientists and engineers that have served American interests so well. We, therefore, respectfully request that you maintain support for a vibrant, forward-looking university-based research program.

With all of this support for the Federal science program, why should we be worried? The President’s fiscal year 1996 budget submission does well by R&D (see figure 3), with increases for all of the agencies that support physics except the Department of Defense. (While most of the DOD decrease affects development, there is a large

![Domestic discretionary ($265.8 billion)](1.3% International discretionary ($21.6 billion))

Mandatory—Social Security ($131.4 billion) 1.6% Defense discretionary ($602.2 billion)

Mandatory—Medicare and Medicaid ($270.6 billion) 15.9% Net interest ($257.0 billion)

Mandatory—other ($184.2 billion)

BREAKDOWN of the 1996 Clinton budget proposal by category. The outlays add up to $1,612.2 billion, but expected revenues are only $1,435.5 billion. Most of the cuts needed to reduce the resulting deficit of $1,567.2 billion will probably come from the “domestic discretionary” slice of the pie. Most science spending lies in this slice. FIGURE 4

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cut in university research, where DOD is the largest supporter of research in engineering and computer science. There are $1.4 billion in increases, balanced by $1.1 billion in decreases.

The problem is that this outcome is not likely. If you read, look or listen, you cannot escape the constant discussion of the budget and the deficit. The deficit problem is very difficult to deal with. Figure 4 shows a functional version of the President's budget. The total outlays are $1612.2 billion, but anticipated revenues are just $1415.5 billion, leaving a deficit of $196.7 billion. Science lies mostly in the "domestic discretionary" part of the budget, along with such things as the Environmental Protection Agency, the national parks, airports and roads, and school lunches. All of domestic discretionary spending makes up about one-sixth of the budget. Compounding the deficit problem is an expected explosion in "entitlements" due to an aging population and increases in interest payments on the national debt.

Congress and the Administration will struggle with this problem for some time. It can only be solved with a combination of economic growth, tax adjustments, and budget cuts. Science comes into the picture through economic growth. I urge all members of the APS to tell their representatives in Congress about what they are doing and the importance of their work to their respective Congressional districts and to the nation.

The urge to understand

I have so far focused exclusively on practical outcomes from scientific research. However, I feel that I must as a scientist close with another dimension to the scientific enterprise: that of the discovery of new knowledge for the sake of knowing more about the universe in which we exist and our place in it. Most members of the scientific community do their work for the joy and satisfaction of learning what no one has known before or of doing something that no one has done before. It is that motivation that drives the young scientist to the typical 60-80 hour workweek, not the technologies that may come from his or her scientific work. This urge to understand is part of the human makeup and should not be ignored. The long tradition of exploring the unknown goes back as far as recorded history. Our lives are enriched by the understanding that this exploration brings. It is sometimes said that such things are only the concern of the scientist, but I do not believe that to be so. The sale of books like Stephen Hawking's A Brief History of Time; the audience for television shows on anthropology, biology and cosmology; and the popularity of the science magazines are all testimony that there is broad interest in new knowledge.

Gallileo's work supporting the thesis of Copernicus that our Earth was not the center of the universe changed fundamentally the way we think of ourselves, and that change too is what science can bring to humanity.

Governments have supported science for thousands of years. Alexander the Great took Aristotle on his marches through Asia. Today we launch space observatories like the Hubble Space Telescope and support research aimed at revealing the ultimate structure of matter at laboratories like Fermilab and SLAC in the US and CERN in Europe.

Of course we hope for practical benefits, and that hope has been amply fulfilled. We should not, however, focus too narrowly on the practical, for to do that is to deny the needs of the spirit. Those very practical people who would deny the importance of knowledge for knowledge's sake should keep in mind the limits to our imagination. Remember Gladstone's question to Faraday, "What good is it?" and Faraday's reply, "Sir, someday you will tax it."