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The Other Frontiers of Science

D. Allan Bromley

The frontiers of science are usually seen as those boundaries where human knowledge is pushing most vigorously toward the unknown. These are the internal frontiers of science.

The centennial issue of *Science* in July 1980 was devoted to a sweeping overview of many of these internal frontiers. We are, without question, in the midst of remarkably interesting and exciting times in science and technology. Dramatic progress on a number of these internal frontiers has been occurring with breathtaking speed: Einstein's dream of a unified theory of the natural forces may be within our grasp; advances in the understanding and manipulation of genetic material have revolutionized modern biology; and, after a triumph of engineering and science in the NASA Voyager missions to the outer planets we, for the first time, have detailed knowledge of our sister worlds and a glimpse back in time to the period when our sun and our planet were new. There are a great many other areas of equal excitement.

Summary. Frontiers of science are usually considered as those areas where the boundaries of human knowledge are being pushed most vigorously into the unknown. These are the internal frontiers. But no less important are the external frontiers. Those bordering on the federal government, on education, on private industry, and on international affairs and the developing world are among the most critical and demanding. Some of the outstanding problems facing science, and scientists, in these external interactions, are discussed within the context of our changing national and international priorities.

But no less important are the other frontiers of science—the external frontiers—bordering on the federal government, the educational establishment, the private sector, national security and defense, world science and technology, the developing world, and U.S. society itself. There are critical challenges and problems here that bear close examination.

We are now at a time of rapidly changing national priorities and expectations. Science and scientists will inevitably share in these changes. AAAS has a tradition of working on these other frontiers. Its 1934 Annual Meeting held in Pittsburgh was a major landmark in the history of the interaction of U.S. science and government.

At that time, the scientific community was engaged in a heated debate about the kind of relationship that should be established with the federal government. In the late 1920's there had been substantial pressure from government for the private sector to assume major responsibility for applied research and development; this turned out not to be particularly successful. In the early 1930's some believed, deeply, that involvement with the government would lead to endangered traditions, compromise, and loss of independence for science and scientists. Others, including Karl T. Compton, recognized the potential dangers but argued that science and scientists were central to economic and social progress. Moreover, they believed that aggressive governmental support of scientific work was essential in building for future national welfare.

At the 1934 Annual Meeting, AAAS members installed Compton as president; in doing so they helped lay the foundation for the vast expansion in the support and use of science and technology in the years ahead. The AAAS members clearly recognized that they were not only supporting Compton but also were opting for "getting involved." It bears emphasis that this was a full decade before Vannevar Bush's remarkable document, *Science, The Endless Frontier*—a document often credited with initiating the major expansion of U.S. science.

Not only did AAAS install Compton as president, it also passed a resolution specifically endorsing federal support for scientific work—a dramatic action at the time; it passed a resolution endorsing the Science Advisory Board, which had been established by President Roosevelt at the urging of Isaiah Bowman and of which Compton was chairman; and the AAAS Committee on the Place of Science in Education, reflecting its concern regarding the quality of elementary and secondary science education, played a prominent role in the creation of the American Science Teachers Association. History does seem to repeat!

Despite ever increasing complexity and intertwining of science and society, many of the central issues remain the same half a century later. Before turning to the other frontiers it bears emphasis that, with generous support from U.S. taxpayers over the years, we still have in this country, overall, the strongest science and technology enterprise that the world has ever seen. It is a national resource; it is essential to our survival.

One of the primary sources of this strength has been the fact that, unlike other countries, we have since World War II established a complex web of

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federal support channels and mechanisms so that very few good ideas have failed to find support somewhere. But this multiplicity is shrinking rapidly.

Again unlike other countries, we have not developed coherent national science policies. Indeed, the very idea is abhorrent to many. Our free enterprise laissez-faire system has served us well during periods of expansion and growth, but in retrenchment the development of more formal science and technology policies seems essential if we are to preserve the best aspects of our system.

Frontier with the Federal Government

In turning to this frontier, it would be difficult to improve on a statement made by President Truman to a joint session of the Congress on 6 September 1945, only 3 weeks after V-J Day:

> Progress in scientific research and development is an indispensable condition to the future welfare and security of the Nation. No nation can maintain a position of leadership in the world of today unless it develops to the full its scientific and technological resources. No government adequately meets its responsibilities unless it generously and intelligently supports the work of science in university, industry and in its own laboratories.

The nation has responded to this challenge. Currently some $70 billion are spent annually, about equally divided between federal and private sectors, on research and development. This corresponds to about $315 per citizen. Basic research, of course, accounts for only about $8 billion or about $36 per citizen. This latter is probably the wisest investment that the citizen makes, even if few have any direct control over it or, indeed, ever think of it.

This linking of research and development has become traditional. However, it is essential, if we are to have informed discussions of the issues, that they be separated. The Reagan Administration is moving in this direction with its insistence that the private sector fund a larger share of development costs for technologies intended for civilian applications. As this occurs, however, it is important to recognize, and remember, as has been the case for 40 years, that the principal support of basic research must remain a public responsibility. Economists have repeatedly shown that the private sector will not necessarily allocate optimal resources to research in all the areas that are of national interest.

There are several reasons for this. It is widely recognized that the overall benefits to the nation of much, though not all, long-range research and development certainly exceed the benefits to the organization that paid for it. By its very nature long-range research is risky; in many areas of science the scale of the instrumentation required to reach the frontiers—telescopes, accelerators, phytotrons, and the like—puts them beyond the scope of all but perhaps the largest private sector organizations; and current industrial management philosophies in this country, with their emphasis on short-term evaluation and payoff, all mitigate against significant industrial investment in many areas of long-term research. Whatever the problems may be, it remains essential that research and development be separated and that basic research be discussed on its own merits as an investment in both the short- and long-term future of this nation.

The numbers here are large. William D. Carey, executive officer of AAAS, has estimated that over the decade of the 1980's government and industry in this country will spend about $1 trillion on research and development. However, support numbers like these, in the billions and even trillions of dollars, cannot be examined in isolation and, indeed, can be misleading. The sheer size of the U.S. economy results in larger research and development expenditures than those of other countries; it is in comparative perspectives that the serious concerns arise.

For example, compared to Japan and West Germany, relatively we invest far less of our resources in civilian research and development which are directly oriented toward economic and social needs and to the search for new knowledge. One reason is rather obvious. In recent years Japan has allocated only 2 percent of its governmental research and development expenditures for national security and defense, West Germany about 12 percent, and France 30 percent; we have been investing about 50 percent of our research and development funds in this sector, and this fraction is growing. World military expenditures now are at the level of $550 billion annually, and this is growing at a rate of more than $50 million per day. We are carrying much of the defense load for the Western world.

Our total expenditures on research and development, considered as a percentage of our gross national product, have been declining steadily since the middle 1960's—from 2.97 percent in 1964 to 2.27 percent currently; we may have the first slight upward trend in 1981. In contrast, the Japanese percentage in this same period has risen from 1.48 to 1.93 percent and the West German percentage from 1.57 to 2.36 percent—now above ours.

Investment by U.S. industry in research, as a percentage of U.S. industrial sales, has decreased by one-third between 1968 and 1980.

Indeed, we are currently investing a smaller fraction of our resources in our future than at any time since the mid-1950's. This must be a source of serious concern.

There are other concerns. The establishment of budget committees in the House and Senate has introduced important changes in the mechanisms whereby science and technology are supported. Robert Giaimo, then chairman of the House Budget Committee, discussed some of them in a remarkably candid and illuminating talk to the 1980 AAAS R & D Policy Colloquium. Let me quote from his talk:

> You have to fight harder for your own programs because you are now competing with other people in the United States who are fighting unusually hard for their programs. If they win you are going to lose—and vice versa. This is a new phenomenon in Washington.
>
> You have to work doubly hard because, while I understand the importance of R & D, I can tell you that you are competing with school lunch subsidies, and postal services and social security and pensions and with twice a year cost of living adjustments as opposed to once. And while you may have a pretty good lobby and while I know that you are articulate, you don't have the numbers that some others do and you don't scream and raise hell as well as they do.

This is applied civics, and the question Giaimo addressed is a very real one for all of us.

And no contemporary discussion of the federal frontier would be complete without mention of accountability. No responsible member of the scientific community questions for a moment the obligation to account for the support received from the taxpayer. But the premise that scientists must be held to the same accounting standards as hourly workers in a factory is one that deserves much more attention and discussion than it has received thus far. Too often we have, by default, left such questions to administrators, and in the absence of coherent response on our part we must live with their decisions and negotiations. Most particularly is this true in the research universities.

I have already noted that we have the world's strongest science and technology enterprise. As part of this we have evolved a complex mix of university facilities, national laboratories, and industrial research organizations that has served us well. Some of these have more effective internal renewal mechanisms than others and are more able to respond to changes in mission objectives and public expectations. In some areas our national research capacity is seriously underutilized at a time when we are seriously in need of more, and better, research.

We have never found it necessary to rationalize our present mix of research facilities and institutions; they grew, adiabatically, in response to local and immediate needs. When resources are in critical supply, when new and urgent demands for both research and researchers are being made on the system, however, the time has come for us to undertake this rationalization, to reexamine our national research enterprise in the light of present and future needs. Frank Press, president of the National Academy of Sciences and science adviser in the Carter Administration, commented on this point a few months ago:

> . . . [The scientific community] may also direct its attention inward, offering to reexamine the national research enterprise—including academic research, national laboratories, and industrial research—to learn whether new institutional relationships and other structural changes can preserve our scientific strengths in a period of financial stringency. All sections of the scientific community must be prepared to set aside the shibboleths of the past and perhaps propose new modes of research just as effective yet less costly. . . .

And because research groups, particularly the most productive, are fragile entities that once disbanded can never be reassembled, I would urge that whatever changes may emerge from these considerations be made gradually so that the system can adjust with minimal damage.

For better or worse, science and scientists are committed and involved with the government; they are integral to the major missions of virtually every agency. The major issue, today, is not whether to become involved as it was 50 years ago, but how best can science be employed for the well-being and security of our nation.

Frontier with the Educational Establishment

Perhaps the greatest challenge, and at the same time the greatest opportunity that we, as a nation, face is in the area of education. It is an area to which AAAS has made, and is making, a major commitment of its effort and resources.

I am on record as believing that we still set the style and pace for the whole world in terms of graduate education. And, although quality variations at the college level are more extreme here than elsewhere in the developed world, where in general there is more central control, on average we remain competitive. At the precollege level, however, we have fallen far behind our international competitors both in quality and in number; our system has very serious difficulties. All of you are familiar with some of the dismal statistics, but they bear repetition.

The latest National Research Council study entitled "The State of School Science" shows that:

1) Only one-third of the nation's high schools offer more than 1 year of mathematics or of science.

2) At least half of all U.S. high school graduates have taken no more than 1 year of biology, no other science, and no mathematics beyond algebra.

3) Only 105,000 U.S. high school students study any calculus at all, while 5 million in the Soviet Union take 2 years of it. The Chinese situation is similar to the Soviet one.

4) Japan graduates five times as many engineers as does the United States.

5) Shortages of supplies and equipment in the schools have, in the last decade, cut by more than half the exposure to any form of laboratory experience of even those students who take science.

And there is more:

6) At present, only 75 percent of those enrolled graduate from U.S. high schools; in some areas of the country this percentage drops to 55 percent. In contrast, 98 percent of all Soviet youth complete, successfully, a 10-year secondary school program generally agreed to be substantially more demanding than ours.

7) Even worse, recent studies show that 20 percent of those who do graduate from U.S. high schools are illiterate and unable to function effectively in our society.

8) And, across the board, average scores of high school seniors on Scholastic Aptitude Tests have continued to fall. The average score for which these tests were standardized is 500. In 1979 the national averages of those who took the tests were 427 and 467 for verbal and mathematical aptitude, respectively; College Board estimates suggest that if all 3 million U.S. high school seniors had been tested the results would have been 368 and 402, respectively. Most serious of all, and contrary to popular belief, the fraction of those scoring in excess of 600 on these tests is now also decreasing although for many years it had remained essentially constant.

This is an unhappy litany and not one worthy of this nation.

Let me then focus on mathematics and science. There are two major interrelated questions here. First, we have the urgent problem of developing scientific literacy on the part of our citizenry. Over 80 percent of our citizens receive their last exposure, if any, to mathematics and science during their high school years. In a society, such as ours, of growing technological sophistication where the questions of consequence increasingly have scientific and technological aspects, if our public cannot at least appreciate the nature of the issues, quite apart from contributing to their resolution, they inevitably will tend to become alienated from the society. This is a trend that no nation can long endure.

From a more parochial point, to which I shall return below, increased public scientific literacy is a necessary—if far from sufficient—condition for the development of the new constituency for science and technology that I see as essential.

That the term "creationist science" and what it implies can be taken seriously by so many people is perhaps the most damning indictment we currently have of our failure in science education. If our lawmakers, school superintendents, publishers, and citizens understood the nature of scientific inquiry and evidence and the kind of knowledge that flows from it; if, in short, they had had education in science appropriate to our times, then "creationist science" would be seen not to be science, whatever else it might be, and there would be less danger of the sort our schools now face. Although the current engagement is taking place in biology—let there be no misunderstanding—the attacks represented by "creationist science" are drawn from the same narrow intellectual base which powered 19th-century assaults on science in general. Now, as then, the "creationist scientists," despite their apparent new garb, are attempting to stifle rational investigation, freedom of research and teaching, and wish to reshape the basic fabric of education. Make no mistake, this is not a matter which can be dismissed lightly or laughed away. We must engage the creationist scientists directly.

Second, we have the question of providing science and mathematics in high schools of such character that they will attract a greater fraction of the nation's most able youth into mathematics, science, and engineering careers as well as provide them with the educational foundations appropriate to such careers.

These two questions of scientific literacy and of preprofessional education are quite distinct and must be recognized as such. Programs and changes designed to answer one may well be inappropriate for the other.

We must avoid the common trap of assuming that since U.S. scientists continue to receive the lion's share of Nobel Prizes in science, our educational enterprise cannot be all that bad. Prizes won now reflect research of 10 to 20 years ago and education of perhaps 20 to 30 years ago.

What can we do to turn around a system that involves more than 25,000 schools, some 16 million students, more than 1 million teachers and administrators and that each year now accounts for about 95 billion tax dollars? Perhaps little, but we must at least try—we must not expect miracles—and we must begin now. We must return to objective standards of performance and learning; we must maintain discipline so students can study and learn; we must remove raw violence from the classroom; and we must stop social experiments carried out at the expense of our children. For the good of our nation we must begin to spend at least as much time and effort on the most able 10 percent of our students as we do on the 10 percent least able.

And most of all, we must give all our students some knowledge and appreciation of all our cultures. It is shocking to find that high school graduates know no mathematics or science; it is even more shocking to find a great many who have never read a novel or who are unable to write a coherent paragraph—sometimes because they have never been expected to!

We currently are experiencing a serious shortage of mathematicians, natural scientists, and engineers in this country. It will inevitably worsen in the mid-1980's since educational time constants prevent any quick fix.

Let me illustrate with a few concrete numbers assembled by Lee Grodzins for physics and astronomy; similar statistics can be assembled for chemistry and engineering.

1) The number of Ph.D.'s awarded in 1980 in physics and astronomy was 985—almost identical to the number in 1965 and only 57 percent of the 1740 awarded in 1971.

2) The number of Ph.D.'s employed in the United States who actually practice physics in 1977 was 18,000, virtually the same as in 1968 and down by 10 percent from the 1970 peak.

3) During the 1979–1980 academic year the number of foreign students enrolled in U.S. colleges and universities rose to a record level of 286,430—more than eight times the number enrolled in 1954–1955. Some 55 percent of the present foreign students are enrolled in scientific and technical fields; almost half of them are in engineering.

4) Of the 2379 Ph.D.'s awarded in engineering in 1980, 49 percent were to foreign citizens. The percentage of foreign citizens receiving Ph.D. degrees in physics has increased from 14.3 percent in the early 1950's to 24.4 percent in 1980 (and to an extrapolated 28 to 30 percent in the late 1980's; comparable figures for chemistry are 12.1, 21.8, and 23 to 27 percent, respectively; and for engineering 21.4, 49, and 50 to 60 percent, respectively).

At a time when we may just be beginning to see an increase (11.5 percent in the number of graduates in 1980—the first increase since 1970) in the fraction of U.S. high school graduates entering and graduating from engineering schools, we see a growing exodus of engineering faculty to the private sector. Similar trends are apparent in college and university mathematics and natural science departments and in high school science departments.

When industrial salaries twice those in higher education and often three times those in high schools are offered we cannot be surprised to see them accepted. Nor can we question the private sector need for such persons. It has never been greater. But as I have emphasized elsewhere, we really are eating our seed corn. The time has come when the academic and private sectors must recognize and address more directly their interdependence. I shall return to this below, but I am happy to report that there have been recent encouraging developments. A group of Pittsburgh companies has set up a $750,000 fund to provide, among other things, computer services to the city's junior and senior high schools. Exxon has made a grant of $150,000 to Florida State University specifically to slow the brain drain of young faculty to industry and substantially larger ones to the Massachusetts Institute of Technology and some 65 other universities for the same purpose. Phillips Petroleum has made a contribution of $6.45 million to be administered by AAAS and used for improving secondary school education in mathematics. IBM reports that over the past 5 years it has contributed $23 million for programs, faculty, and equipment in science, mathematics, and engineering departments across the nation. Companies such as Hewlett-Packard and Intel have developed programs that annually contribute millions of dollars of equipment to colleges and universities throughout the nation, and Johnson & Johnson has taken over sponsorship of the "Nova" science program on public television. We can hope that these corporate initiatives will be widely recognized and paralleled; several of the corporations have indicated that they view these initiatives as experimental, with substantially greater funding to follow if they are successful.

Faced with very real personnel shortages we still do a miserable job of attracting women and minority group members in mathematics, science, and engineering. Current statistics suggest that we are making progress toward increasing the participation of women in science and engineering—although not in mathematics. Doctoral awards to women in science and engineering have increased from 7 percent in 1965 to 23 percent in 1980, but women still have higher unemployment rates and lower salaries than men in all fields.

The situation regarding minorities is much bleaker, and indeed we appear to have regressed, with the fraction in science, mathematics, and engineering significantly lower than it was 10 years ago. In physical sciences, life sciences, and mathematics, for example, the fraction of total Ph.D.'s awarded to Blacks has decreased by almost a factor of 2—from 2.96 percent in 1973 to 1.71 percent in 1980. In 1980, American Indians, Blacks, Puerto Ricans, and Mexican Americans received 0.3, 2.1, 0.2, and 0.2 percent of the doctorates, respectively, in science and engineering; of these, well over 50 percent are in the social sciences.

We are wasting talent here for which the nation has urgent need. I am convinced, however, that the heart of the problem remains in the secondary school and that we cannot realistically expect much improvement elsewhere until we can make substantial changes at this secondary level.

I have already mentioned the serious problem regarding teaching and laboratory instrumentation at the high school level. The college and university situation is, if anything, worse and is rapidly approaching a national scandal. In field after field, supposedly representing high technology frontiers, we are educating students with instrumentation frequently 20 and more years old—instrumentation of another age and generation. Little wonder that we all too often fail to attract or hold our students' interest!

This instrumentation question is serious for all physical sciences; it is particularly serious in engineering where graduates of even our best known engineering schools are confronted with entirely new and unfamiliar instrumentation on their first jobs and require substantial additional private sector investments in retraining and familiarization.

One of my major worries, in the interface with education, however, is that we may have learned too little from recent history. In 1962, the Gilliland Panel of the President's Science Advisory Committee, responding to a widespread perception of impending shortages of personnel for the nation's space and military programs, recommended a crash program of support for students and universities. Universities responded enthusiastically—in retrospect much too enthusiastically—so that the 1970 manpower goals were achieved in 1967 and, not surprisingly, the crash program was terminated. Such abrupt changes—both positive and negative—applied to any tightly coupled system having several similar time constants, will, as any engineer or physicist will recognize immediately, cause the system to oscillate. And oscillate it has. The large number of students educated in the 1960's in the crash program had difficulties finding employment once the program was terminated. Media reports of these difficulties—frequently exaggerated—influenced a new generation of students away from science and engineering with our present shortage as a consequence.

Obviously this is an oversimplified scenario, but it emphasizes a characteristic of our system that has caused untold wastage, hardship, and heartache among some of our most talented young people, those for whom the country has the greatest need.

Why am I worried? Because I sense pressures for measures that can begin a new oscillatory cycle in response to our current shortages of trained manpower. Obviously we must take steps to meet and correct present shortages; new support for people, programs, and instrumentation is badly needed, but we should not mount a new crash program designed to produce large short-term outputs. Rather, we should concentrate on long-term improvements in education which will attract adequate numbers of our best and brightest.

Frontier with the Private Sector

Before World War II, support from the private sector played a substantial role in academic research and in research generally. With generous postwar federal support flowing from scientific and technological triumphs during the war years, however, the private sector support for academic research dwindled in visibility and perceived importance. Galloping academic arrogance also contributed to the destruction of the bridges between academia and the private sector. All too often these bridges were replaced with mutual ignorance and suspicion.

The rebuilding process is long overdue and, happily, is in progress. In part, this reflects the private sector's recognition of its desperate need for bright young people and for new and better technologies if it is to remain competitive in the international marketplace. In part, it also reflects academia's belated recognition that it needs both financial support and real-world input for its research and teaching activities as well as career opportunities for its graduates. While the emphasis has largely been on the first and last, I believe that the real world input is of greatest importance. Only through interaction can the stereotypes be destroyed. I believe that over the years the content of our college and university educational programs has remained of high quality, but the attitudes that have been inculcated have frequently been questionable. Much of an entire generation of students gained the impression that first-class citizenship implied replication of one's professor's laboratory and program with all speed, while second-class, or perhaps third-class, citizenship was the best one could hope for in any industrial milieu. Such attitudes carry low survival potential in today's world.

U.S. industry, on its part, has been relatively slow in coming to grips with the international marketplace after decades of easy dominance of both national and international scenes. All too frequently the entire focus has been on national needs and opportunities; the federal–private sector interface still largely reflects this myopia. While foreign governments aid, abet, and even organize cartels so that their industries can compete more effectively (usually with us) on the world market, our Justice Department still works at breaking up entities like IBM and the Bell System that are large enough to support the level of research and development that makes them highly competitive internationally.

During the 1977 AAAS R & D Policy Colloquium, several speakers reported that technological advance, the growth of knowledge, has been second only to the labor support increase as a major source of U.S. economic growth over both the short and the long term since 1929. At this same colloquium William Nordhaus, then a member of the Council of Economic Advisers, told us that most economic analysts were convinced that "the role of research and development in technological change in the economy is paramount."

It is then a matter of concern to find that the fraction of scientists and engineers in the U.S. labor force has declined steadily since 1965; in this same period the fraction has doubled in both Japan and Germany. I would argue that such trends, at least, partially explain national productivity results in the past 10 to 15 years.

Between 1961 and 1978 the annual productivity gain in manufacturing averaged more than 9 percent in Japan, 5 percent in Germany, and 3 percent in this country. Total U.S. private sector productivity has actually declined in recent years. More graphically, the Japanese outproduce us by a factor of 15 when making motorcycles and by a factor of 2 when making either steel or pianos. And their quality is frequently superior to ours.

There are many facets to the productivity question—capital investment, management, human resources, and research and development, to name only four. In capital investment per capita, in 1963 we ranked first in the world; by 1975 we had slipped to sixth place behind Norway, Canada, Sweden, Switzerland, and France. More recently, Europeans have been increasing their per capita investment in industrial plant and equipment by 4 percent per year, Japanese and Koreans report 10 percent per year, and our corresponding number is 2 percent.

William Abernathy of Harvard has suggested that we have educated a generation of MBA industrial managers to believe that in order to stay on the "fast track" they must change corporations every 3 to 4 years and that any investment with a longer payoff will inevitably benefit their successors rather than themselves. This is not conducive to the strong support of long-range industrial research and development or significant productivity increases.

In July 1981 the AAAS sponsored, together with the House Task Force on Industrial Innovation and Productivity and the Committee on Science and Technology, a congressional seminar on the human resource facets of productivity. Research results presented to the Congress in this seminar, and in subsequent hearings, pointed to the need for greater attention on the people part of productivity. Henry Ford II has noted that the largest untapped potential for improvement in industrial productivity in this country is the American worker.

All of these matters bear close study. But industry has already recognized that its future depends critically on more and better science and engineering. The partnership among universities, industry, and the federal government that is essential to economic growth and improved international competitive posture is now under construction. The soundness of that construction and its success should be matters of deep concern to every citizen.

Frontier with National Security and Defense

It is often difficult to remember that prior to the 1930's, and really to World War II, natural philosophy—understanding the universe—and mastery of nature—invention—were almost entirely separate endeavors. With the radar and Manhattan projects of World War II this separation, for better or for worse, was gone forever.

Use of technology for military purposes, however, is nothing new; indeed it marked the earliest contact, in our history as a nation, between the federal government and the university community. During the mid-1800's, a truly remarkable Swede, John Ericson, functioned largely as a one-man office of research for the U.S. Navy. Among his early successes was the first propeller-driven warship; why he decided to call it the U.S.S. *Princeton* I have been unable to discover! But in any case Ericson decided that the *Princeton* needed 12-inch rifles; not having any he turned to the universities with the challenge that they design such a weapon for construction and testing by the Navy. The universities responded enthusiastically and on a fine May morning in 1845 the *Princeton* steamed out into Chesapeake Bay for the original tests. The first gun tested was that designed by Captain Stockton of the Navy itself. When it exploded—as it did—it killed the Secretary of State, the Secretary of Navy, the governor of Maryland, four congressmen, three Navy captains—and, as the report of the day goes—sundry other dignitaries. As Elting Morison has pointed out, this is the sort of thing that gives technology a bad name!

But the nation, and science and engineering in particular, owes an enormous debt to Robert Dexter Conrad, Emanuel R. Piore, and other early postwar administrators of the Office of Naval Research for forging a pluralistic and enlightened federal support mechanism for research and development that served us well and that has been the envy of the world. Not only did academia and the private sector benefit enormously from support of their research activities but also the Navy benefited equally from day-to-day contact with some of the nation's most able citizens and with some of its brightest young people. The other services were somewhat later but they, too, developed effective linkages with the research community. During the 1950's the Department of Defense (DOD) was the dominant supporter of U.S. academic research.

When it was finally founded in 1950, after extended and frequently bitter discussion about the extent to which scientists themselves should control it, the National Science Foundation Act of 1950, passed by the 81st Congress on 10 May 1950, had as its preamble the following:

> An act—to promote the progress of science, to advance the national health, prosperity and welfare; to secure the national defense; and for other purposes.

Clearly, this envisaged a broad role for science, specifically including national defense. Indeed, section 3(a) 3 of the act read as follows:

> (3) At the request of the Secretary of Defense, to initiate and support specific scientific research activities in connection with matters relating to the national defense by making contracts or other arrangements (including grants, loans and other forms of assistance) for the conduct of such scientific research.

Subsequently, this section was formally deleted from the National Science Foundation Act—a step in the direction of separating science specifically related to defense from questions regarding the general support of science. This separation continued, and was greatly accelerated, by two events in the 1960's and early 1970's. Evolving inexorably during the 1960's, U.S. involvement in the Vietnam conflict triggered violent antimilitary and, secondarily, antitechnology sentiments across the nation, but particularly on university and college campuses. The resulting often dramatic separation of the universities and the DOD hurt both.

In 1969, following hard on this, and reflecting widespread public sentiment, Congress enacted a rider to the Military Authorization Act for fiscal year 1970 (Public Law 91-121, section 203), the so-called Mansfield Amendment, which read as follows:

> None of the funds authorized to be appropriated by this Act may be used to carry out any research project or study unless such a project or study has a direct or apparent relationship to a specific military function or operation.

The following year, the language of section 203 was modified in response to general recognition that the original Mansfield Amendment was counterproductive, and section 204 of the Public Law 91-441 read:

> None of the funds authorized to be appropriated to the Department of Defense by this or any other act may be used to finance any research project or study unless such project or study has, in the opinion of the Secretary of Defense, a potential relationship to a military function or operation.

In a follow-on section 205, the Congress affirmed the necessity for federal support of basic scientific research and went on record that the National Science Foundation should assume a larger share of such support.

Passage of the original amendment was necessarily followed by detailed examination of the research portfolios supported by each of the DOD program officers, and a large number of high-quality research projects were deemed not to meet the requirements of the amendment, as strictly interpreted, and lost DOD support. Projects totaling \$8 million were dropped.

Today there are different views about the legal status of the Mansfield Amendment; some argue that it is still in effect; others argue that it was repealed with the substitution of "potential" for "direct and apparent."

Whatever the exact legal status of the Mansfield Amendment may be, a vastly more effective entity, the "ghost Mansfield Amendment," is firmly in place and both it and the actual modified amendment still influence DOD funding decisions. The "ghost" amendment describes the situation wherein program officers, having once been held responsible for supporting research projects not obviously having a "direct or apparent" relationship to DOD missions, as required by the original amendment, were reluctant to consider, if not adamantly opposed to, rebuilding programs in such areas—this despite the modification of the amendment and quite concrete and repeated pronouncements by higher officials in the DOD in one administration after the other—to the effect that DOD was back in the business of supporting long-term basic research, was interested in rebuilding bridges to academia, and the like. The program officer reaction was a quite understandable one.

But the time to rebuild these bridges is long overdue. In a democratic society such as ours it is essential that those responsible for national security and defense neither be, nor feel to be, cut off or isolated from the general society. And at a time when the DOD research budget has been increased by almost $5 billion—by 47 percent since 1980—and when it is experiencing an urgent need for manpower able to cope with ever more sophisticated weapons systems, it is essential for both the universities and the DOD that they establish new relationships and interaction. It will require goodwill and flexibility on both sides.

All too frequently, discussion of DOD manpower needs focuses on research and engineering personnel. Serious shortages exist in these areas, but a much more critical question is whether we can produce high school graduates with sufficient background and scientific and technical literacy so that they can be trained in the military services to maintain and operate the complex weapons and communications systems now in place and on the drawing boards. It is time that DOD accepted part of the responsibility for strengthening secondary school education.

For decades the military services have provided personnel and equipment for Reserve Officers Training Corps programs in both high schools and colleges. Perhaps there is a comparable way in which the services could provide scientific equipment and scientifically trained personnel to supplement existing capabilities in at least selected secondary school systems. In summary, this is an area where the new science education initiative of AAAS may be able to play a catalytic role.

As I view the frontier between science and national security I see the need for close and enduring relationships between scientists and engineers and those in the military forces. Yet we must recognize inherent tension in these relationships: national security often calls for secrecy; science almost always calls for open communication. Devising the appropriate balances is surely one of the most vexing, and challenging, questions in an open society such as ours. Hyperanxiety on the part of government officials, and that of scientists, must be avoided lest we fall into twin idiocies: attempting to hide all knowledge or eliminating research of importance to national security from the university world, as we attempted to do in the late 1960's and early 1970's.

Frontier with World Science and Technology

In almost every area of scientific research and development, U.S. activity established the framework and set the pace for world activity following World War II. Preeminence in all fields was both an explicit and implicit cornerstone of our national approach to science and technology.

As was, perhaps, inevitable, this situation has changed in one area after another of modern science, in particle and nuclear physics in Western Europe, in computer science in Japan, in applied mathematics in the Soviet Union, for example. Other countries, by focusing their resources, have mounted salients in these and other fields that are equal to, if not indeed ahead of, ours, although as I have emphasized above, we still have a commanding overall lead.

The Reagan Administration is the first to explicitly recognize this changed situation. In his remarks in the 1981 AAAS R & D Policy Colloquium, George Keyworth, the President's science adviser, said:

> Undoubtedly, our country has relinquished its preeminence in some scientific fields, while others are strongly threatened through efforts in Europe, Japan, or the Soviet Union. It is no longer within our economic capability, nor perhaps even desirable, to aspire to primacy across the spectrum of scientific disciplines. The constraints of reality require discrimination and vision, attainable only through a collaboration of the government and the scientific engineering communities. It is simply unreasonable for us to expect to be best in everything.

With this recognition, all the more importance attaches to full U.S. participation in the international scientific and technological community—one which is perhaps the only community that fully transcends political boundaries and one in which we have played a major role since World War II.

Unhappily, just the opposite seems to be happening. Current budgetary limitations have already forced likely cancellation of such international projects as the U.S.-European International Solar Polar Mission—to the consternation of our European colleagues. Similar limitations on National Science Foundation budgets for international activities will require sharp curtailment of our participation in such bodies as the International Council of Scientific Unions and its member disciplinary unions. It would seem that when we are falling back from preeminence in international science and technology is surely not the time to slam shut our windows on the world!

We have never attempted to focus or jointly plan governmental and private sector science and technology in ways that are commonplace throughout the developed world. We have never felt a need for such planning, but as we reexamine our changed role in the international economy, total laissez-faire may be a luxury that we can no longer afford. The role of MITI, the Ministry of International Trade and Industry, in orchestrating the Japanese national and international activities, for example, is one we can no longer ignore. If we are to be competitive in the international marketplace, it would seem that reexamination of the policies, laws, and traditions controlling the interactions of our industries, our universities, and our federal government is long overdue.

Frontier with the Developing World

Very special opportunities and problems emerge in our interaction with the developing world, which sees the application of science and technology as a major means of achieving economic and social progress.

It bears emphasis that, according to World Bank statistics, in 1973, the average gross national product per capita (in U.S. dollars) in North America and Japan—the most affluent two subareas considered—was $5340, while in Africa and Asia (excluding Japan)—the least affluent two subareas—it was $215. The ratio here is 24.8. In 1978, after 5 years of active discussions and projects directed toward reduction of the ratio, the two corresponding numbers were $9029 and $328, and the ratio was 27.5. The gap between the most and the least affluent had widened; it continues to do so.

All of us in the developed world share, to a greater or lesser degree, the humanitarian desire to improve the quality of life of those less fortunate than ourselves. With the advent of satellite communication links and bicycle-powered television sets in even some of the most remote native villages, however, there has been a qualitative change in our interaction with much of the Third World. Prior to this change, few in that world realized that we, and many like us, enjoyed a quality of life beyond their wildest imagining; but having seen and appreciated this distinction, Third World expectations have taken a quantum jump. And unless we act, and are perceived to be acting to better their lot, we run the serious risk of a world in turmoil, with the developing world making common cause to fight for what they view as a fairer share of the earth's resources. In this sense, the Organization of Petroleum Exporting Countries may be only a pale precursor.

There has been much talk in this context in recent years of technology transfer—vastly more talk than transfer. In part this reflects the fact that some of the early proposals were premature; others were ill conceived. Many were premature in the sense that no adequate infrastructure existed in the receiving country. Recipients lacking an adequate agricultural base to stave off hunger are not yet ready to receive jet fighters and computer-controlled machine tools; those lacking economic and political stability are unlikely to absorb new technologies effectively; and those lacking an adequate indigenous scientific and technological educational base have no one who can receive and propagate new technology effectively. The latter may well be the most important consideration.

Large international ventures have not been particularly successful. For example, the recent United Nations Conference on Science and Technology for Development in Vienna produced little beyond unfulfilled expectations. While political debates continue about what kinds of programs will encourage or promote development, there are modest measures which we in the scientific and engineering communities can take independently. Professional and scientific organizations and societies can provide channels for the involvement of some of the most talented scientists and engineers in the development process. While such individuals are not likely to join United Nations or governmental agencies concerned with foreign aid or development, they well may participate in projects or tasks sponsored by the organizations to which they belong.

Under such arrangements there would be no loss of peer status, or standing, in their respective communities; the objectives of service in international development could be meshed with personal career objectives. Moreover, it bears emphasis that in this way the special skills required for this work can be acquired without requiring permanent career changes.

In moving in this direction it would be important for organizations such as the AAAS and other professional societies to provide the organizational means for working with governments, international organizations, and other national and international scientific and engineering groups. But I cannot emphasize too strongly that all such institutional or organizational structures must be designed to facilitate and not to replace the person-to-person interaction on which all successful projects of this kind ultimately rest.

In view of all this, except in special cases, it appears to me that we would be well advised, at least for a time, to change the focus of our interactions with the developing world from technology transfer (to the usual extent that this implies high technology) to science transfer. We can and should—and at much reduced expense—assist developing nations to build educational structures in which science and technology would appropriately receive considerable pragmatic emphasis. And most important, we must help the developing world create challenging and rewarding career opportunities for their most able and highly trained citizens, at home. Only by retaining a large fraction of their best people—which is certainly not now the case—can they hope to develop a stable and growing educational system and a pool of educated persons who can function as midwives and developers for the future transferred technologies fundamental to economic growth and stability.

In our long-term best interests, we must forgo the short-term advantages of the continuing brain drain wherein our universities and hospitals are increasingly populated by the best minds we can find anywhere in the world. And we must make it in the individual's best interest, both personally and professionally, to build a career at home.

Here, again, we must be much more sensitive to the special needs of other countries, other cultures, other systems than we have been. Whether overtly or not, much of our interaction with the rest of the world has rested on the frontier assumption that, "if it's good for us, it's good for anyone." Particularly has this been true in our interaction with the developing world.

The concept of appropriate technology, even if frequently misused, has real meaning, and it will require much more effort than we have thus far been willing to devote to it, and much more listening to recipients before acting than has been customary for us, if we are to succeed on this critically important frontier. The Third World does not want us to tell them what to do; rather they want us to tell them how to do what they want to do.

Frontier with U.S. Society

Science and technology are inevitably conditioned by the society in which they are embedded. There has been much talk in recent years in this country of rampant antiscience sentiment. I do not believe that this exists, but there is widespread antitechnology sentiment and, unfortunately, a large fraction of our public is unable to distinguish between the two.

I have already touched on the question of improving science teaching, and thus science literacy. But this is clearly not enough. Our present adult population can no longer be directly affected by changes in our high school systems.

There is evidence to suggest that a very significant fraction of these adults have a real hunger for accessible, authoritative information about science and technology. There has been an explosion of new popular magazines—*Science 82*, *Discover*, *Next*, *Science Quest*, *Science Digest*, *Technology*, and many others directed to this market; the success of the "Nova" and "Cosmos" television series provides additional evidence.

The science and technology community in this country has a responsibility to respond to this public interest, partly in accounting for support received, partly because its members want to talk and write about what they are doing, and partly because it is in the best interests of the science and technology community to foster public awareness.

This raises, again, Giaimo's question of the U.S. constituency for science and technology. Although rarely stated overtly, for several decades following World War II, public support for science was tied, consciously or unconsciously, to national security and defense. In part, this a holdover from the war years themselves. During the late 1960's, in the shadows of the Vietnam conflict and with burgeoning antitechnology sentiment, this linkage became increasingly precarious and suspect.

On 7 November 1973, in a television address to the nation, President Nixon attempted to shift major support for science and technology to the quest for energy self-sufficiency. He called for energy independence by 1980 through a major national commitment, "in the spirit of Apollo, with the determination of the Manhattan Project." As part of this commitment he called for the creation of an Energy Research and Development Administration (ERDA).

As we all know, ERDA came and has gone; its successor agency, the Department of Energy came and now it, too, is going—although our energy problems certainly have not gone. Energy, it seems, is not the star to which our science and technology wagon should be hitched.

I am convinced that the ultimate answer must lie in an informed, interested public prepared to understand, at least in outline, and support science and technology on their own merits and in recognition of the vital role they play in almost all aspects of contemporary life: energy, health care, environment, commerce, trade, national security, and international affairs, to list only a few.

If this is to happen, it requires a major commitment by members of the science and technology community, by members of AAAS to be specific, to improving adult scientific literacy. It is not enough to leave the task to the tiny group of professional science writers, able as many of them are, to Carl Sagan and others who have learned to use television in ways captivating to a general public. Improving public understanding of science is one of the stated goals of AAAS, and one toward which we are making significant progress, but we have not, as yet, found the necessary mechanisms to mobilize all our members as catalysts in this important mission.

In working toward this goal of public understanding it is well to bear in mind that a much deeper question is involved. Can science and technology be permitted to go their own way—to follow their internal logic—in isolation from the societies in which they are embedded, or must some system of independent value judgments be made first by those societies forming a framework within which science and technology must function? We are closer to this situation than you may think. Remember that the Cambridge, Massachusetts, city council, by democratic vote, prevented any research on recombinant DNA at Harvard for almost a year. There is substantial question as to whether any member of that council had any real idea of what the vote implied or that the vote might well delay a possible cure for cancer much more probably than unleash any danger on the citizens of Cambridge. But, increasingly, the public is demanding to be heard in decisions which even now are entirely internal to science and technology.

A related question, increasingly being posed, is whether scientists have special responsibilities by virtue of being scientists. After all, lawyers are officers of the court, physicians and engineers must adhere to standards set by their peers. Are there collisions between such notions of responsibility and the traditional notions of scientific freedom?

I find it convenient here to return to my earlier dichotomy between natural philosophy on the one hand and mastery of nature on the other. In the former, the pursuit of knowledge (and I believe deeply that none of us are wise enough to even guess the future uses for new knowledge), I believe that there should be no artificial limitations or boundaries. Ultimately, I cannot believe that ignorance is ever preferable to understanding.

At the same time, when we turn to the utilization of knowledge, either old or new, I am convinced that there must be adherence to generally accepted standards and limitations. But I am not convinced that scientists and engineers are wise enough to establish these standards and limitations in splendid isolation and by peer agreement. Input is essential from those outside our guilds.

Let me illustrate with three examples from among the many pressing problems facing us nationally and internationally today:

1) Human population growth is the most deadly specter looming over us today, and its control is one of our greatest challenges. In 1950, we had 2.5 billion people on this small planet; in 1980, we have 4 billion, and in 1990 our best estimates suggest 6 billion. This is exponential growth, but our public is programmed to think in only linear terms. Crucial human values are involved here; in the last analysis, we are balancing freedom to reproduce against the quality of subsequent life—if not, indeed, against that life itself—in those areas of the world where starvation is a constant threat. The technology is in hand—although it needs improvement—to turn off human fertility unless an antidote is taken. I see no other solution ahead, but I also see enormous social and political problems in implementing any such solution.

2) I have mentioned the energy problem as crucial. Here, again, we know the technology that would give us essentially unlimited energy, but none of the technologies, coal, nuclear, or solar, will provide the energy necessary for maintenance of anything beyond a rural lifestyle unless present societal values can be changed to permit their more effective implementation.

3) Health care delivery is another area of growing stress. With rapidly improving technology, as long as we are prepared to pay the cost, we can keep people, who only a few years ago would have died early, alive almost for their full, and growing, span of years. Dialysis, required regularly after kidney failure, is a case in point. Right now, we in the United States have the technology. Right now, something like 100,000 Americans are on regular dialysis, and right now, we are paying about $2.5 billion a year to support this program alone. Where do we draw the line? As things now stand, will we, in the near future, find ourselves forced to tell someone, "We are sorry but we can't afford to keep you alive, even though we do have the technology." Who will make that decision? And on what basis? How do we decide who gets the benefits of advancing medical technology?

Genetic engineering raises other specters. If and when it becomes possible to influence significantly the characteristics of one's offspring, for example, should parents have complete freedom to make whatever changes may appeal to them? If not, what are the limits? And who decides? And on what basis?

In all of these examples—and there are many more like them—examples that are normally presented as problems for science and technology—much of the technology and science is already at hand. What we lack is agreement on the underlying values and priorities and adequate knowledge of the social, behavioral, and economic consequences. All of us, humanists, social scientists, natural scientists, and engineers are in these problems together. And the time when we face up to this and get to work is long overdue.

Humanists, deeply involved in the study of mankind, are well acquainted with the seamier sides of our nature, with our shortcomings and failures. In consequence, if I may be permitted a huge oversimplification, they tend to be pessimists. Social scientists tend to be pragmatists, to take the world as it comes and not get too excited about it. Recently, I took a group of distinguished economists to lunch because I wanted an answer to the deceptively simple question, "What is our economy going to do?" The answer, entirely unanimous, was, "How the hell should we know? It's never behaved this way before!"

Natural scientists tend to be optimists; they are inclined to be impatient to see if something can be done and inclined to believe that it can, until proved otherwise.

These are caricatures, but there is truth in each of them. What we badly need is a fusion of all of them. Not only must we work together, and in so doing learn to actually communicate with one another, but also we must be mutually supportive. In this past year, it has been of the greatest importance that natural scientists and humanists were willing to speak out in defense of their social science colleagues faced with precipitous and unprecedented funding cuts. There is a unity to all science and technology that we will destroy or let perish only at great peril. Our goal must be that of supporting excellence wherever we find it; the obverse is that in a time of limited resources and high competition we must never be satisfied with less than excellence. And at a time of growing shortages of scientists and engineers, we cannot be comfortable with the fact that we have failed so miserably to bring more women and more minority group members into the forefront of our activities.

Conclusions

Let me, in conclusion, emphasize a number of points.

1) We still have, overall, the world's strongest science and technology enterprise, but this strength is in substantial jeopardy.

2) This is a time of rapid change in the Legislative and Executive branches of government and in public expectations of science and technology.

3) We must build a new public constituency for science and technology.

4) We must rebuild science and mathematics in the nation's schools to foster both increased public literacy and the foundations for professional development.

5) Whatever we may eventually decide regarding change in the mix of our research and development institutions, and whatever we may decide to do in response to current personnel shortages, we should not embark on crash corrective programs, but rather make changes consistent with the time constants of the systems involved.

6) We must rebuild bridges to the national security and defense enterprise.

7) We must rebuild bridges to private industry and help it focus on the international marketplace.

8) We must act, and be perceived to be acting, to better the quality of life in the Third World, and we must maintain our role in the international science and technology communities.

9) We must face up to the fact that there are areas wherein science and technology may appear to be on a collision course with the democratic process and address these issues openly and intelligently now.

10) Only by working together—humanists, social scientists, and natural scientists—can we hope for success in attacking our most important problems.

I have touched on many concerns and problems. I know that you, too, are concerned about many of these issues, and I have a very specific suggestion. Take your representative or your senator to lunch some time when you do not want something specific. This in itself will astonish and intrigue the individual involved. By expressing your concerns, on a personal basis, you can have a vastly greater impact than you may suppose. I know of no more effective contribution that any single scientist or engineer can make, particularly if this interaction with your representative in the Congress becomes a regular, and a continuing one.

There is a mood of pessimism loose in the science and technology community, and in the nation. And there is reason for it. But before we go too far with this pessimism, let me remind you that it is nothing new in man's long history. Back at the turn of the century, British society was sinking into pessimism. The Boer War in South Africa had started in 1899, and many British citizens simply could neither understand nor support their role in it. In 1901 Queen Victoria died, and with her died Victorian optimism. The Boer War dragged on—the Vietnam of its time. But I want to conclude with a paragraph picked up by Freeman Dyson from a paper entitled "The discovery of the future," which H. G. Wells published in *Nature* in 1902.

> It is possible to believe that all the past is but the beginning of a beginning, and that all that is and has been is but the twilight of the dawn. It is possible to believe that all the human mind has ever accomplished is but the dream before the awakening. We cannot see, there is no need for us to see, what this world will be like when the day has fully come. We are creatures of the twilight. But it is out of our race and lineage that minds will spring, that will reach back to us in our littleness to know us better than we know ourselves, and that will reach forward fearlessly to comprehend this future that defeats our eyes. All this world is heavy with the promise of greater things, and a day will come, one day in the unending succession of days, when beings, beings who are now latent in our thoughts and hidden in our loins, shall stand upon this earth as one stands upon a footstool, and shall laugh and reach out their hands amidst the stars.

Somehow, I do not believe that this paragraph could—or would—be written by many of today's leading figures. We need more who both could and would!

The problems that lie ahead demand all our skills, all our wisdom, all our experience, and all that we have learned from the past. Only by focusing on our agreements rather than on our differences can we hope to survive. We can do much more; we cannot afford to do less.

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