

SHAPING THE FUTURE: SCIENCE AND TECHNOLOGY 2030

Questions about today's science policies and education will need to be answered with vision and boldness for a robust and productive future.

Frank H. T. Rhodes

In observing its 40th anniversary last year, the National Science Foundation held a special symposium to celebrate its achievements and to look ahead to the next 40 years for the foundation as well as for all of science and technology in America. NSF's accomplishments are impressive. These include a major role in producing successive generations of scientists and engineers; in supporting pace-setting research in a multitude of fields, including some, such as high-temperature superconductivity, that it did much to initiate; and in monitoring the pulse of the nation's science and engineering enterprise.

Its future is more difficult to predict. But one thing we can be sure of, given the pace of change in the world—technical as well as political and social—is that the future will be far different from the present. My task in the symposium, which took place in Washington on 11 May 1990, was to peer 40 years into the future and to predict what might be in store. This essay relies heavily on that talk, though it has been updated to reflect, among other things, some of the events that have occurred since, including actions taken by the 101st Congress.

It is possible to sketch at least two scenarios for the future—one optimistic, the other pessimistic:

▷ *Population.* We will either stabilize the world's population at a level that enables people to improve their standard of living or we will expand beyond the limits of the Earth's carrying capacity, with devastating consequences for all.

▷ *Disease.* Advances in the treatment of viral, genetic and chronic disorders will occur, comparable in influence to those that conquered infectious diseases 40 or so years ago, or we will face new pandemics of AIDS and other diseases.

▷ *Education.* We will meet President Bush's goal of being first in science and mathematics achievement by the end of the century or we will remain at or near the bottom of the international heap, in which case our society will find it difficult to match the achievements of the more highly educated and technically skilled communities in the world.

▷ *Environment.* We will learn effective stewardship and how to mitigate the effects of environmental change or we will suffer from a loss of biological diversity, a global warming of the climate and a growing buildup of toxic pollutants.

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At its 40th birthday party, The National Science Foundation asked Frank Rhodes, president of Cornell University (above), to address the issues of science and education that need to be dealt with to sharpen the vision of Vannevar Bush in the next 40 years. Four former NSF directors (in photo at left) attended the event. They are (from left): Erich Bloch, Edward A. Knapp, H. Guyford Stever and Richard Atkinson.



▷ *Urban environments.* We will see a rebirth of cities as centers of commerce and community life *or* we will see persistent decay, with high levels of unemployment, increasing dependency on welfare programs and continued social problems such as drug and alcohol abuse and crime of all sorts.

▷ *International relationships.* We will make continued progress toward greater individual and economic freedom and true global community *or* we will have a backlash of nationalism, sectarianism and repression.

Which of the scenarios become realities will be influenced in no small part by NSF and the science and technology enterprise it helps nurture. In turn, the health of NSF and of science and technology in general will be affected by the extent of progress or of decline in our ability to deal with the issues I have listed.

What, then, are the foundation's options in allocating its resources and in managing its research programs in the coming years? I realize that "managing research" is considered by many to be an oxymoron—a contradiction in

terms, somewhat like "postal service" or "airline cuisine." One might as well speak of managing a piano concerto by Mozart or an Impressionist painting by Monet or an elegiac poem by Milton. A basic scientific discovery is just as much a creative masterpiece—unpredictable and unmanageable—as works by these great artists. Yet there are four "macroquestions," each involving management issues, the answers to which will profoundly influence the shape of NSF, of science and engineering, and of national and international life 40 years from now.

Can we retain our national scientific and technological strength?

This is partly a question of dollars—not only the total spent but also expenditures as a percentage of our GNP and the distribution between civilian R&D and defense-related work. How we answer that question is at the heart of our global economic competitiveness, our personal well-

being and, indeed, our national security.

The good news is that the US spends more on R&D than the next four nations—Japan, the country formerly known as West Germany, France and the United Kingdom—combined. (See the figure below.) Our country's position in relationship to the others has remained relatively stable over the last decade, even though its share of the combined R&D budgets of the five countries has declined by 14% since 1966. Moreover, Federal support for basic research and for all academic research and development has continued to grow, albeit at a slower rate than in the past, while the rate of increase for defense-related R&D, which has consumed so many research dollars in the past, has been reduced.

Still, such relatively encouraging figures mask more disturbing trends: For two decades, Japan and Germany have been spending a greater percentage of their GNP on civilian R&D than has the US, and since 1981 their rates of

investment in civilian R&D as a percentage of GNP have been increasing more rapidly than the US rate of investment. (See the figure on page 45.) It is particularly distressing that the rate of growth of corporate funding of R&D has declined, even though the country's position as the world's largest supplier of high-technology goods is precarious at best. Although American inventors are patenting their discoveries at a higher rate than in the past, foreigners are acquiring US patents at a significantly faster rate.

What are we, as a nation, to do to ensure our future strength? What will preserve the vitality of American science and technology as we move toward the year 2030?

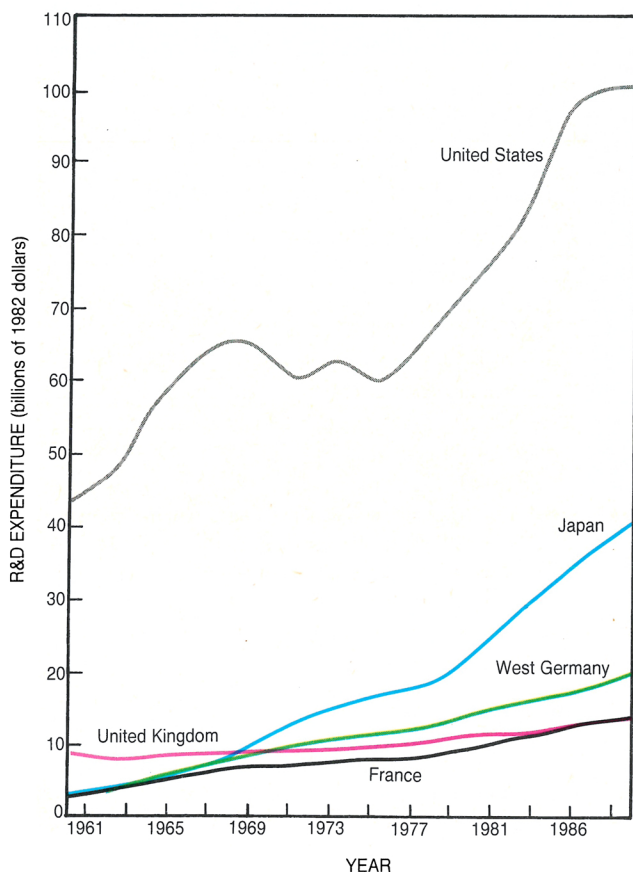
First, the nation must maintain funding for R&D, and particularly for civilian R&D, at a level that is at least comparable to what our international competitors spend. It has been said that money never starts an idea; it is the idea that starts the money. That old axiom continues to be true generally, though today there are far more ideas than there are funds either in government or in corporate enterprises to make the ideas come true. Indeed, we shall never transform ideas into marketable products and processes at a rate comparable to our competitors unless our spending is also at least comparable to that of our competitors.

Second, we must encourage industry—which performs roughly three-quarters of the nation's total R&D work (about \$95 billion in 1989), compared with roughly 10% each for universities and Federal laboratories and 5% for other entities—to continue its commitment. We especially must find ways of encouraging small companies to make investments in R&D. Among the initiatives that deserve support are extending R&D tax credits, easing restrictive legislation that sometimes stands in the way of cooperative R&D endeavors and encouraging more industrial consortiums in particular fields to share the information and the expenses involved in so-called generic, precommercial research.

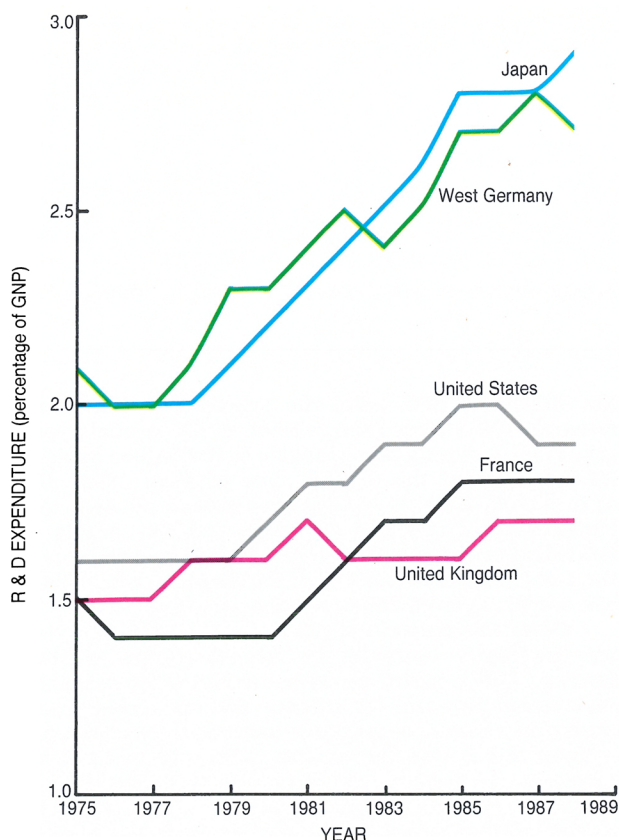
Yet even these kinds of incentives may be insufficient for many small-and medium-sized firms, whose research budgets are usually minimal at best. To help such companies with their manufacturing and productivity problems, we should develop a university-based industrial extension effort, similar to the agricultural extension programs that put American farming on a sound scientific base. A pilot program in my own college of engineering, begun with modest state funding, has proved valuable in that regard and has potential for expansion beyond New York's Southern Tier. A few similar programs also exist in other states.

Third, we must preserve the health of the nation's great research universities, especially those independent research universities, which have been under siege lately, sometimes for reasons of their own making. Despite the continuing growth of academic R&D brought about by increases in Federal, corporate, and institutional support, there are several issues that give cause for concern.

For example, although recent investments in university facilities and equipment are welcome, they fall far short of needs. *Science and Engineering Indicators 1989*, a biennial publication of the National Science Board, noted



Funding of all R&D within the major noncommunist industrialized countries in constant 1982 dollars, between 1961 and 1988, shows the US in the lead by a wide margin, though the gap has been narrowing in the 1980s. Sources: NSF and OECD.



that universities deferred \$2.50 for every \$1 of construction planned through 1989, and they deferred \$3.60 in renovations and repairs for every \$1 spent. This is a substantial problem in an era when the quality and sophistication of facilities and equipment can significantly influence the outcome of research.

The acquisition of state-of-the-art facilities and equipment is a major reason that indirect costs at many private institutions have soared in recent years, and it is a far more significant factor than the charges made for the homes of university presidents, say, which is a subject that has gained widespread attention in recent months. While some institutions may have misjudged the appropriateness of certain items included in their indirect cost pool, many find themselves in no-win situations: If they exercise their right to recover the full cost of research, including the cost of new buildings and equipment, they may make the research proposals submitted by members of their faculty uncompetitive with those from institutions with lower indirect-cost rates.

High indirect-cost rates already are taking their toll. When one looks at a list of the top ten research universities in terms of total research expenditures, only three (Stanford, first; Cornell, second, and MIT, fourth) are private. I fear that unless we, as a nation, come to terms with the problems of the indirect costs of academic research and the need to modernize facilities to which research is connected, there may be virtually no private universities left among the top 20 by the year 2030. If that were to happen, the loss to the nation would be incalculable, not just in terms of research output but in terms of our future work force and our democratic culture. For it is the private research universities that have been by tradition particularly concerned with gifted students, most supportive of the liberal arts, particularly open to innovation and

As a percentage of GNP, Japan and West Germany spend much more on nondefense R&D than the US.

experimentation and particularly devoted to enlarging the nation's reserves of those scholars, scientists and professionals who hold advanced degrees. Not surprisingly, the private research universities have been in the vanguard in defense of institutional autonomy and academic freedom against all assaults. If private research universities are to survive another 40 years, we will need to solve these problems, not only with the Federal government, but also with our corporate sponsors and with members of our own faculties.

Can and should we develop a national policy for science and technology?

Those who argue against a national policy suggest that it would make us less able to respond to changes. Our present system, they point out, is analogous to a diversified stock portfolio, in which risks are widely spread, both in terms of sources of funding and expenditures. Along with inevitable misses and "dry holes," our present system can be expected to achieve a fair measure of success.

There is certainly much to be said for multiple sources of funding. A national science policy embracing expenditures, if narrowly focused, might target funding into some areas of promise while completely missing others considered of lower priority. High-temperature superconductivity was once considered out of the mainstream, and recent advances in the field might never have come about if only certain targeted topics of basic science had been supported by Federal program officials and corporate research managers.

Yet science and technology have become so expensive that there must be some more effective system for establishing priorities. We need some rational basis for choosing our investments in periods of limited discretionary funds. Even in good times, however, we need to ask ourselves how much should be channelled into basic research and how much into applied work? What proportion of government funds should go to civilian R&D and what should be given to military programs? How much should be discipline-specific and how much for interdisciplinary work, especially in an era when research involving synthesis, in addition to the more traditional analysis, seems necessary to solve many of the global challenges we face? How much should be awarded on the basis of merit; how much on other criteria such as the need to build strong institutions in certain regions or for certain groups? Awards for science and technology based on criteria other than scientific merit have received more and, to my mind, misguided—emphasis in recent years.

We need to answer other immediate questions that have implications for the future. How much should be used to fund multibillion-dollar projects such as the Superconducting Super Collider and Space Station Freedom? In both cases, Congress decided last October that the projects will grow more slowly in 1991 than their champions would like. Questions about such giant projects raise seemingly unrelated questions about their effect on the funding of individual investigators, the so-called bench scientists. This issue is bound to become more acute

in the future. As such it requires our attention.

There are also questions concerning educational initiatives, such as support of graduate and undergraduate students, and efforts to improve science and mathematics in the schools. There are policy questions about international collaborations in science and technology. What can we reasonably expect to achieve by ourselves? What can be done most effectively in partnership with other nations?

Our current system disperses responsibility for science and technology through numerous Federal agencies, each with its own priorities in developing the Executive budget, as well as a cumbersome legislative process that includes some 100 different Congressional committees and subcommittees with responsibility for science and technology policy. In addition, numerous special interest groups are at work advancing their own agenda. As a result it is almost impossible to view the Federal role in science and technology as a whole.

D. Allan Bromley, the Assistant to the President for Science and Technology, whose appointment many of us advocated as a way to bring a greater degree of rationality and coherence to the process, has made some welcome progress in these areas. He has, for example, revitalized the Federal Coordinating Council for Science, Engineering and Technology to give more attention to scientific issues that cut across disciplines and involve several agencies. It was a FCCSET (pronounced "fix-it") panel on global climate change, for example, that helped bring about a 57% increase in Federal funding for climate studies.

To his credit, Bromley has also identified six priority areas for future work under his White House Office of Science and Technology Policy. These are (1) science, technology, and the economy; (2) global climate change; (3) high-performance computing; (4) science and mathematics education; (5) materials science and technology; (6) biotechnology. As crosscutting examinations of science and technology policies, these are a useful beginning.

One further area of real concern is the level of support for small science and investigator-initiated research, especially in relation to both the number and the size of proposals presently competing for support. Bromley has been an enthusiastic supporter of investigator-initiated research. Nonetheless, the proportion of approved grants actually funded by the National Institutes of Health and NSF this year is less than 30%, an all-time low.

The 101st Congress, reacting to this situation, mandated that NIH find a way to award 6000 new grants out of its \$8.3-billion budget, with the aim, over four years, of achieving a stable pool of 24 000 grants with an average duration of four years. Many researchers worry that, given NIH's limited budget, Congress's mandate will force it to fund less expensive projects and at institutions with low overhead rates.

NSF's 1991 budget, hammered out in the final days of

the 101st Congress, gives the agency \$1.7 billion for research—6.3% more than in 1990. NSF's annual appropriation is now projected to double to \$3.2 billion by fiscal 1994, instead of the original date of fiscal 1992. But according to a study by the Association of American Universities, if support for core program grants to individual researchers continues to increase at the rate of the past three years, the goal of doubling support for them will not be achieved until after the year 2020.

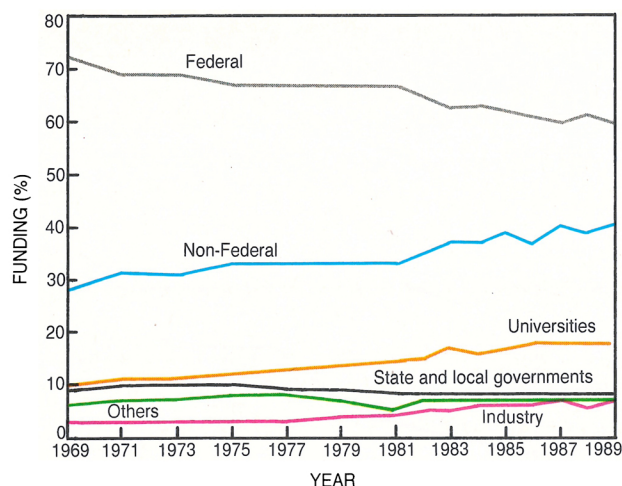
Those who lament the plight of individual investigators frequently overlook the role of centers in their funding. NSF's controversial centers for engineering, for supercomputing and for science and technology were created to advance cooperation between universities and industry and to stimulate studies in fields where there is a high expectation of rewards to science, technology, education and, ultimately, to the country's economic competitiveness in the global marketplace. We will not improve funding for individual investigators simply by complaining about the centers concept.

Still, we must find additional ways to support individual investigators. It is, in many respects, the most serious funding problem facing the nation's science and technology enterprise. It makes no sense to encourage young science graduates to embark on careers in research if we have no meaningful prospect of funding their work.

Continued internecine sniping between and within the disciplines will scarcely strengthen long-term support for science and technology. What we need instead is informed and responsible scientific advocacy and additional mechanisms, which would supplement that of the Assistant to the President for Science and Technology. In this way we could obtain thoughtful, impartial advice on issues of science and technology policy and on their relationship to social and behavioral issues of public concern, which compete for Federal funds. In establishing these additional mechanisms, there is a role not only for individual researchers but also for professional scientific and educational organizations. Indeed, the work of a 15-member panel of astronomers appointed by the National Research Council and headed by John N. Bahcall of Princeton, which produced a list of the highest priorities for US ground- and space-based research in the coming decade, provides a model that should be applied more broadly. (See *PHYSICS TODAY*, April, page 24.)

Can we provide a work force skilled to meet the obligations and challenges of 2030?

In his 1990 State of the Union address, President Bush declared that, "By the year 2000, US students will be first in the world in science and mathematics achievement." With that statement, he gave the country a challenge as ringing as John F. Kennedy's charge to land a man on the



Federal support of academic R&D has fallen significantly in the 1970s and 1980s as universities and industrial corporations have made up the difference. Source: NSF.

Moon by the end of the 1960s—and one that will be far more difficult to achieve.

Despite some eight years of highly publicized changes prompted by the release of *A Nation at Risk*, the results of school reform efforts have been disappointing. American students still rank at or near the bottom in international assessments of achievement in science and mathematics. Nearly a quarter of America's young people—nearly a million individuals each year—drop out of school before earning a high school degree. By contrast, Japan claims a high school completion rate of more than 90%.

Equally distressing is the extent to which we lose people, along the way from elementary school to graduate school in science and engineering—the fastest-growing fields in terms of employment opportunities today. The pipeline narrows at every turn, as fewer and fewer students, beginning with middle school and continuing through high school and college, take courses in science and mathematics. Of the 340 000 freshmen who entered college with an interest in natural science and engineering in 1980, only 206 000 (61%) earned degrees in those fields four years later. Only 61 000 (18% of the original total) went on to graduate programs in those fields, and a meager 10 000 “survivors” (3% of the original total) are expected to earn PhDs by 1992. If current trends continue, the nation may face a cumulative shortfall of 700 000 technically trained individuals, including 400 000 with a BS degree, by the first decade of the 21st century. At the PhD level the shortage could reach 9600 per year.

Shortages of this magnitude would be a crippling national handicap. Even if we still have the geniuses to devise the most creative research investigations in science and engineering, we may not have enough well-trained “foot soldiers” to put ideas into productive practice as they carry out the work of science and technology day by day.

Many worthwhile ideas have been proposed for improving science and math education and plugging the leaks in the pipeline leading to science, mathematics and engineering careers. These include revamping the curriculum from kindergarten to the 12th grade so as to stress concepts over facts and process over memorization, and to make instruction parallel the way that science and math are actually done. They include establishing more specialized high schools, such as the North Carolina School of Science and Mathematics and the Bronx High School of Science, to provide opportunities for advanced study to those who show substantial aptitude and interest in science and math. They include providing special enrichment programs for minority youngsters to encourage

them to attend college and consider science and engineering careers. This is something that the General Electric Foundation has done at Aiken High School in Cincinnati and at several other sites around the country where GE has plants or offices.

Colleges and universities can play a major role in these efforts. They should, first of all, require all undergraduates to complete meaningful programs in science and mathematics or “quantitative reasoning.” These subjects are important, not just for a wide variety of careers but for effective citizenship in an increasingly technological society. Public policy issues, from solid-waste management to the development of nuclear energy to international trade policy, involve technical considerations that can be evaluated intelligently only by a citizenry literate in science and mathematics and comfortable with quantitative thinking. Scientists and engineers must actively engage in the process of determining “core” requirements for all undergraduates, and they must realize that meaningful reform of undergraduate education requires changes in both the style and the substance of science and technical courses, along with changes in other parts of the curriculum.

Second, colleges and universities should insist that prospective teachers in elementary and secondary education programs complete rigorous college-level courses in math and science, and these courses should also be required for certification. At present, fewer than half of the nation's 200 000 high school mathematics teachers and fewer than 10% of US elementary teachers meet professional standards for teaching in their field. Many science teachers are similarly ill-prepared. We can no longer allow elementary teachers, especially, to be drawn from the three-quarters of the population that stopped taking math after two or three courses in high school. Such teachers too often convey the impression that science and mathematics are dull and difficult disciplines designed to “weed out” all but the gifted few. Their expectations become a self-fulfilling prophecy when students reach the middle and high school years.

Third, colleges and universities must renew their commitment to undergraduate teaching, including the teaching of introductory courses in science and math, and they should provide incentives and rewards for faculty members who carry out these responsibilities well. For too long, introductory college courses have been foisted off on the most junior members of the faculty, who have passed on the unwelcome responsibility at the first opportunity. Now is the time to commit serious intellectual and financial resources to improve introductory undergraduate courses.

Fourth, colleges and universities, in partnership with the Federal government, industry and others, must encourage more of the best students in science, math and engineering to go on for advanced degrees. Universities

Foreign students make up an increasing proportion of the graduate enrollment in the physical sciences, mathematics, computer sciences and engineering in PhD granting universities in the US. Source: NSF.

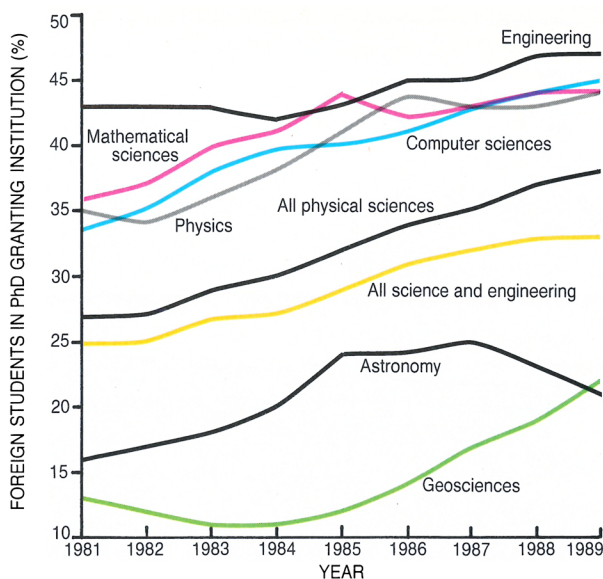
last year awarded more doctorates than ever before, but foreign students accounted for much of the increase. This is especially true in science and engineering fields. Of those earning engineering doctorates in 1989, non-US citizens represented 55% of the recipients whose citizenship was known. At my own institution, foreign students accounted for 41% of the graduate students in engineering last year, up from 34% just four years before. (See the figure at right.)

But the problem is not that there are too many foreign students because about half will remain in the US after completing their PhDs and contribute substantially to the nation's science and engineering base. The problem is that there are too few American students in advanced degree programs. Only a mere 3% of American students who major in mathematics as undergraduates, for example, go on to earn mathematics PhDs. Improving those numbers will take more than better undergraduate education, important though that is. It will also take fellowships and assistantships to finance study beyond the baccalaureate, and it will require upgrading academic research facilities with state-of-the-art equipment—something more easily attainable in industry than in academe.

Fifth, we must face the fact that, no matter how well we prepare students in science, engineering or any other field, it is no longer realistic to talk in terms of a terminal degree, whether high school diploma or PhD. In electrical engineering the half-life of information is now two years; in many other technical fields it is less than five. As a result, we need to devise better programs—for campuses and the workplace—to enrich and elevate the job skills of workers throughout their lives. We also need better ways for individuals to combine continuing education with their other responsibilities—work, family and community.

Just as new partnerships are required in post-baccalaureate education, so new partnerships are urgently required in pre-baccalaureate education. Hundreds of individual cooperative ventures already exist between universities and local schools. What is now needed is creative leadership, coordination and long-term financial support.

Education is a continuous process, and the fragmented responsibilities at different levels of schooling do not serve us well. The task of training a work force competent in science and technical fields is big enough to require increased effort and cooperation from many diverse players—colleges and universities, the Federal government, the states, industry, foundations, local school boards parents and teachers. But success will take more than isolated initiatives, good intentions and good ideas. It will require total mobilization and a new sense of national priority and urgency. And, without supplanting the local control that has been so fundamental to the concept of public education in America, it may well require more state and Federal coordination and oversight than it now receives.



Can our institutions use their scientific base to assist in 'nonscientific' societal problems?

As we look ahead 40 years, it is clear that science and technology, important though they are, will not by themselves solve the problems we face. Problems as diverse as population balance, disease control and environmental conservation have profound social as well as scientific dimensions. They require not only technical knowledge of cause and effect, action and reaction, but also understanding and appreciation of how such knowledge can be applied most effectively. Can our institutions play a larger role in developing models to assist in the solution of such non-scientific societal problems?

If they are to try, they may need, at one level, additional support from NSF or some other source for work in the social and behavioral sciences. I realize that NSF support for behavioral and social science research has long been a sore point for investigators working in those fields. A March 1990 report by an advisory committee to NSF's Biological, Behavioral and Social Sciences Directorate pointed to severe underfunding, a legacy of the sharp cutbacks in funding that occurred in the early Reagan years. Yet better understanding of people, as well as better knowledge of things, will be essential if we are to meet the challenges ahead and realize the positive rather than the negative scenarios I outlined at the beginning of these remarks. If NSF is unable or unwilling to provide adequate support for the social sciences, perhaps the responsibility for these disciplines should be moved elsewhere.

Beyond that, it seems to me that the challenge of the next 40 years for science and technology will be to achieve a new synthesis that enables the results of analytic and deductive work in disparate fields to be applied in new and more useful ways. This challenge goes far beyond integrating the work of biologists with physicists or chemists or engineers, although that kind of integration is important and is already occurring on a modest scale. On my own campus, for example, Tom Eisner, a biologist, and Jerrold Meinwald, a chemist, shared the 1990 Tyler Prize for their role in founding the field of chemical ecology.

The greatest challenge involves uniting the various scientific disciplines with the broader realm of intellectual thought and human experience in ways that consider both

things and people. As John Hersey has written:

In the physical sciences and engineering, laws hold sway. That to every action there should be an equal and opposite, or contrary, reaction is absolutely confirmable. One can count on it. Literature, on the other hand, is a tangled bank of honeysuckle gone wild. In letters, there are no laws, only conventions, whose greatest beauty lies in their sweet frangibility. Here we can count on nothing. Nothing can be proved. The two worlds are antithetical, but they desperately need each other.

The challenge of the years ahead is to bridge those two worlds, of feeling and knowing, in ways that solve the complex societal problems at hand. In this, I wonder if it is time to reinvent the land-grant universities, which long ago discovered, through their cooperative extension programs, how to apply the fruits of university research in the service of human needs and to address the compelling problems of our age.

Problems such as industrial competitiveness and urban decay are admittedly far more complex than agricultural productivity, which cooperative extension has done so much to foster in this century. Still, some land-grant universities, including my own, have made a modest start in directing extension work toward other areas. Cornell Cooperative Extension, for example, has gradually enlarged its focus to address challenges of urban as well as rural life, including nutrition education for the poor and elderly, home-day-care advice and leadership development for teenagers. Yet, funds for pilot projects, much less comprehensive nationwide initiatives, have been elusive at best.

In my more expansive moments, I see the possibility of the land-grant model being extended, not only to meet a broad range of human needs in our own country but also to address problems—from disease prevention to agricultural productivity to environmental protection—on a global scale. A handful of land-grant universities of truly global scope could develop partnerships and cooperative agreements with sister institutions abroad to train faculty and students and to address common concerns where university-derived research might be productively employed to meet human needs. Cornell's involvement in the most comprehensive study to date of the linkages between nutrition and disease in China, which brought together researchers from three continents to address a common question, provides one model for organizing such global partnerships.

All that is in keeping with the mandate of NSF's original charter: "To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." It is in keeping, as well, with the vision of science that Vannevar Bush sketched in *Science: The Endless Frontier*, which set the stage for the establishment of the foundation. This slim volume, large in new ideas, still bears close

reading today. In his summary section, Bush wrote: "Science can be effective in the national welfare only as a member of a team, whether the conditions be peace or war. But without scientific progress no amount of achievement in other directions can ensure our health, prosperity, and security as a nation in the modern world."

Those words are as true today as when Bush submitted his report to President Truman in July 1945. Without science and technology of the very first rank, the US cannot hope to compete in the markets of the world or secure the health and happiness of those within its own borders. Yet how well we use science and technology will depend on team effort, within and beyond science and technology, and that, in turn, will depend on the quality of government both here and abroad.

It is also in keeping with the vision of Franklin Roosevelt, who originally asked Vannevar Bush to study the Federal role in science and technology in the postwar years and in so doing laid the groundwork for NSF. In his letter to Bush, which now hangs framed on the wall outside the boardroom of the National Science Board, Roosevelt wrote, "New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life."

Our continued hope for a fuller and more fruitful employment and fuller and more fruitful lives, not only for our own citizens but for those in the world community of which we are a part, will depend on the "vision, boldness, and drive" we can bring to the continued exploration and extension of the frontiers of the mind. That remains our ultimate challenge; that must be our ultimate goal.

I should like to think that at this significant milestone in NSF history, the nation will rededicate itself to that goal. We should not drift through by neglect or inadvertence. The time is ripe, I believe, for a science board task force to analyze each of the macroquestions I have identified and to draft a set of guidelines that will serve the nation well.

I hope that by our tackling these four macroquestions now, *Science and Engineering Indicators—2030* will portray a vibrant and productive science and engineering enterprise, supported by and, in turn, supporting a nation whose people, living in harmony, enjoy the benefits that Vannevar Bush described 45 years ago as the fruits of that enterprise: health, prosperity and security. In doing so I believe the enterprise will serve all the people of our planet.

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Robert Barker, Constance Bart, Malden Nesheim, Norman Scott and John Wiesenfeld have all been most generous in discussing this topic with me. I am grateful for their help and also for the particular help of Connie Bart in writing the paper. ■