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The National Science Foundation Looks to the Future

John B. Slaughter

I wish to address three major topics. First, I want to share with you some recent landmark achievements in fundamental scientific research. At the same time, I hope to show that gathering new knowledge is not only rewarding in itself but represents an investment; the aggregate payoff will surely be great, even though the future applications are sometimes hard to foresee. I will put the case as strongly as I can that continuous and substantial support for basic research is a necessity for all great nations. At the same time, I will assert my own conviction that support of the best research and education in the sciences and engineering is and must remain the central purpose of the National Science Foundation (NSF).

Next, I will take up the role of research that directly addresses some of the pressing needs of our society, such as energy, natural resources, and productivity. Much of the research that addresses such "real-world" problems is quite fundamental in character. We may call it applied research because we see clearly the problem it addresses, but whether the distinction between basic and applied research represents in every instance a real difference I will leave to your judgment.

Finally, I will turn to two areas that I believe require closer attention and more intense effort in the 1980's. One of these is engineering science, that is, the theoretical body of knowledge and technique underlying the practice of engineering. Much of this work is every bit as fundamental in character as corresponding work in the disciplinary sciences. The other area is education in the science and engineering disciplines. It is apparent that we will face increasing difficulties in securing talented and well-trained minds for the professional disciplines unless we act promptly to improve our education processes, not only at the university level but in the elementary and secondary schools as well.

Recent Scientific Achievements

In considering major achievements of fundamental scientific inquiry in recent years, I have chosen a handful of examples that I am familiar with because of NSF's involvement or interest in them. I could as easily have chosen many others, equally exciting, if there were space to discuss them. Science is virtually exploding with new developments, and it is a great privilege and responsibility to be rejoining NSF during these heady times.

Certainly a historic advance in our times has been the recent progress toward the theoretical unification of the several forces in nature. Today we have an extremely persuasive conceptual argument, supported by experimental evidence, that the electromagnetic and weak nuclear forces are different expressions of a single phenomenon. Moreover, we sense a possibility that this unification can be extended to the strong nuclear force as well. Gravity—the

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fourth force—is presenting problems of its own. But this unification, a problem with which Einstein labored during the last 30 years of his life, deserves a solution.

One startling implication of such a large-scale unification is its prediction that the proton—heretofore supposed to be the immutable nuclear "rock" on which all creation rests—may be unstable; it may decay radioactively and lose its identity entirely. The proton has appeared immutable because its computed lifetime—some 10^{31} years—is at least a billion trillion times the present age of the universe. Nevertheless, searches are under way to detect proton decay. Its confirmation would firmly install in the textbooks what are now incompletely tested theories of the universe's organization on the smallest scale.

Another exciting development in particle physics concerns the organization and dynamics of the universe on its largest scale. Recent experiments with neutrinos suggest that these elusive and uncharged bits of spin may oscillate in flight from one to another of the three states in which they are presumed to exist—the well-substantiated electron and muon neutrinos and the presumed tau neutrino. If that is so, then the supposedly massless neutrinos must actually possess a small but finite mass, which so far has eluded detection. And if that is the case, it can explain why experimentalists have been able to find only about one-third of the predicted number of neutrinos coming out of the sun and why galaxies do not fly apart. An even grander consequence may be that the aggregate mass of the neutrinos in and among galaxies may be sufficient to close the universe—to arrest and reverse the current expansion that began with the Big Bang. That some of this research comes under the aegis of the Department of Energy says something further about the line between "basic" and "applied" research.

Summary. Great advances have been made in fundamental scientific research in recent years. The new knowledge gathered, in addition to deepening our understanding of the physical universe, contributes a range of abilities and opportunities to society that would not otherwise be available. Much research that may be called applied because it addresses needs of society is quite fundamental in character, and support of such research at the National Science Foundation is to be handled in tandem by the research directorates. Other areas that require a refocusing of support are engineering science and education, at all levels, in science and engineering. Increasing our strength in these areas is essential to achieve our national economic, social, and political goals. Steps are being taken by the National Science Foundation to make its structure better able to deal with engineering and applied research and to provide greater mutual reinforcement between applied and basic research.

Closer to home, we have all shared in the excitement of the Voyager flybys of Jupiter and Saturn. The close-up views of Saturn's vast ring structure were breathtaking and important. We can all take pride in this achievement by the engineers and scientists of NASA's Jet Propulsion Laboratory, bearing in mind that the technical excellence required to overcome such barriers of space and time does not come without unremitting effort.

Back on a smaller scale, barriers are also falling in chemistry—between the organic and the inorganic—as a result of investigations of metal-bearing proteins and enzymes. A discipline called, of all things, bioinorganic chemistry has been born. So are barriers between chemistry and biology coming down as a result of efforts to synthesize enzymes and to understand and modify such vital organic processes as photosynthesis and nitrogen fixation. Some of the most exciting work in chemistry involves efforts to devise synthetic chloroplasts which, instead of manufacturing carbohydrate and emitting oxygen as they do in plants, will be capable of using the energy of sunlight to split water into recoverable hydrogen molecules and atomic oxygen.

The new chemistry needs to see intermediates of chemical reactions, not just their beginnings and ends. This has posed a challenge to technology. Technologists have responded—with lasers—and chemistry is experiencing a revolution comparable to that enjoyed by astronomy once it was enriched by Galileo's telescope. New generations of powerful, tunable, fast-pulse lasers are permitting chemists to identify intermediate states of excited molecules having lifetimes measured in trillionths of a second, and to detect carcinogens and toxic molecules in concentrations of only a few parts in 10^{18}.

Here on the earth, studies of the atmosphere, the oceans, and the processes shaping the continents have achieved notable advances. A large-scale field study of Asian monsoons, for example, disclosed a tenfold increase in the kinetic energy of the winds over the Indian Ocean approximately 1 week before the arrival of the monsoon rains. This discovery of a precursor could prove of great practical value for South Asia, where agriculture is critically dependent on the arrival and strength of the monsoon rains and where catastrophic floods are common.

Armed with a growing body of paleomagnetic data, geologists have reconstructed the geography of the earth back to the beginning of the Paleozoic Era, 570 million years before the present. And study of one of those ancient continental margins—at the roots of what are now the southern Appalachians—has proved to be more than just interesting. Deep seismic profiling has revealed a vast overthrust of old crystalline rock on top of younger sediments, and it is possible that conditions may be right there for trapped hydrocarbons.

Surely one of the more dramatic recent discoveries is the anomalously high concentration of iridium found in a thin layer of sediments marking the 65-million-year-old boundary between the Cretaceous and Tertiary periods. This high abundance of iridium is found in nature only in certain meteorites, raising the awesome possibility that a celestial object—possibly an asteroid—may have plunged into the earth and somehow triggered extinctions of land and marine life, including the dinosaurs, in that instant of geologic time. That the collision could have occurred is clear. The biological scenario that could have followed is still incomplete.

Last spring saw the resumption of volcanic activity at Mount St. Helens in Washington. The immediate consequences were tragic for those in the near vicinity, and the scientific community shared in the loss: David Johnston of the U.S. Geological Survey was killed at his post monitoring preeruption changes in the mountain. Despite this tragedy, or at least unrelated to it, it soon became evident that the volcano offered unprecedented investigative opportunities in the atmospheric, earth, biological, and social sciences. Within a few weeks—joining the Forest Service, the Geological Survey, and other organizations—NSF was able to produce short-term support for scores of investigations of transient social, geologic, and ecological phenomena. NSF intends to follow up these fast-response awards with a major effort to monitor the restoration of an ecosystem and study volcanism in a place where subduction of oceanic crust under continental crust is taking place. The Cascade Range is an example of explosive subduction-zone volcanism—typical of many ranges on the "ring of fire" that circles the Pacific.

In the life sciences, we see the same pattern of rapid-fire discoveries in many disciplines. One of the more impressive findings of the past year has been the discovery of the fossilized remains of at least five different microbial life forms that thrived at the bottom of a shallow sea $3\frac{1}{2}$ billion years ago in what is now Western Australia. That is almost the age of the oldest known terrestrial rock, and it is almost four-fifths of the age of the earth itself.

The advances we are witnessing in molecular biology are staggering. Twenty years elapsed between the Watson-Crick model of the structure of DNA and the first successful cloning of a gene in 1973. Since then, blocks of DNA and even entire genes have been sequenced and synthesized. Instrumentation advances have led to startling discoveries about the organization and dynamics of DNA in living cells. For example, in higher organisms, large stretches of DNA are apparently silent, seeming to serve no function in the cell. Some DNA sequences are repeated many times, while others display remarkable mobility, moving from one location on the molecule to another. These latter traits may be associated with a cell's ability to suppress unstable mutations as well as with the ability of the organism to manufacture antibodies to an immense variety of disease organisms. Recombinant DNA research is another story. Suffice it to say it is putting molecular biology on the "Big Board."

Cellular biology has made significant advances in the creation of hybrid human cell lines—hybridomas—to produce monoclonal antibodies for use as superbly sensitive probes and as vehicles for medications. One early application may be the production and use of antibodies against hepatitis B. These new techniques, which permit cloning of antibodies, may also find application in rapid diagnosis of infections, manufacture of vaccines, and precise targeting of anticancer agents and other drugs to specific sites in the body.

In the behavioral and neural sciences, powerful new techniques are improving our understanding of nerve development and repair. Recent work has revealed mechanisms that guide developing neurons to their proper connections. And the scientists doing the work are now saying with some confidence that knowledge of the ways in which lower organisms regenerate pathways in their central nervous systems will be applicable to some of the most grievous of human maladies.

We are also learning that our seeming failure to understand the limits to which the environment can be exploited is not necessarily a recent phenomenon. The abrupt collapse of the Mayan civilization in about A.D. 800—an enduring archeological mystery—turns out to be relevant to that point. Within the span of a century, the population of the tropical lowlands of Guatemala dropped from a peak of 500 inhabitants per square kilometer to about 20, approximately what it had been 2000 years earlier. At its peak, this population required intensive agriculture for its support. Studies of lake sediments suggest that the loss of vital soil nutrients and the buildup of phosphorus and human wastes became most severe at the time of maximum population density. This may explain why the Mayan culture subsequently collapsed. Studies such as this one, which track the relationship between environment and human society over long periods of time, may have direct relevance today to Third World nations pressing for rapid development in fragile tropical environments.

It has not been possible in this brief tour of some of the high points of recent discoveries to note the myriad advances in all the disciplines of science. I hope the examples I have offered convey something of the answer to the question: Why do we pursue fundamental new knowledge? Of course, the scientists' excitement, the ever-renewed thrill of the chase, the challenge to wit and imagination, the sense of participation in a vast collegial undertaking—all of these are self-evident to practitioners. But there are, as well, other justifications for the pursuit of science. And these justifications underlie the relationship between science and government.

Harry S Truman, on the occasion of the establishment of the National Science Foundation in September 1950, said it best: "No nation can maintain a position of leadership in the world today unless it develops to the full its scientific and technological resources. No government adequately meets its responsibilities unless it generously and intelligently supports and encourages the work of science in university, industry, and in its own laboratories."

Supporting science is a necessity for all great nations, and certainly for the United States. Why is this so? Science extends and refines our understanding of the physical universe from the smallest to the largest scale in both space and time. This investment in knowledge opens the door to an expanding human dominion over resources and processes of the physical world. The investment also contributes to society a range of abilities and opportunities which surely would not be available otherwise. But notice that I say that scientific inquiry "opens the door" to the realization of these benefits to society. It does not itself assure that these benefits will be realized. For that to happen, the great wealth of knowledge we are accumulating must be communicated and applied in a deliberate way. This brings me to my second topic—the role of science and its applications in meeting the practical concerns of society.

Research Related to the Needs of Society

I want to stress at the outset that the bulk of the work in this "applied research" category borders on being as fundamental as anything we have so far discussed. It involves only the additional nuance that it is directly responsive to a felt or expressed need of society; it answers a question that has already been asked. Its place in NSF requires no apology. Indeed, so interconnected do we see the so-called basic and applied sciences that from now on their support at NSF is to be handled in tandem by the research directorates. No longer will selected research programs be separated from their disciplinary mainstreams just because they can be construed as addressing so-called real-world questions. That neuroscientists, for instance, now believe their work on nerve regeneration can apply to the problems of paraplegia should not require them to be put in a compartment other than the one housing basic neurobiological studies.

For another example, the modeling necessary to understand the circulation of the atmosphere for its own sake and the modeling necessary to understand the effects of halocarbons on the ozone layer or of carbon dioxide on heat retention may be all but indistinguishable from each other. Nevertheless, one is called basic and the other applied. They, too, should be housed in the same NSF directorate.

Energy is another area pervading a variety of research efforts. We know it is imperative that the United States reduce its dependence on imported oil. We are all familiar with the major research sponsored by the Department of Energy on alternative energy sources such as solar, fusion, and synthetic fuels. But at the same time it is clear that techniques that will help us to use all sources of energy more efficiently will also reduce our dependence on imports.

In the United States, industry is responsible for almost 40 percent of total energy consumption. A significant fraction of this energy is used in separating and processing materials. Because we now have so many new materials, chemical pathways, and end products, the old engineering approach of case-by-case evaluation and experimentation is no longer sufficient for selection of the optimum process. More general and fundamental theories and models must be developed to compare the efficiencies and energy requirements of distillation, extraction, membrane transport, absorption, and other separation processes. NSF is responding to this need with the development of a new research program in this critical area of chemical and process engineering. Again the question arises: Is it basic or is it applied?

Materials for manufacturing industries are, like energy, vital to our national well-being. NSF is actively supporting a variety of programs aimed at developing new and more efficient extraction techniques, new materials with novel properties, and biological alternatives for a large range of polymers and basic industrial materials now derived from petrochemical feedstocks.

The search for substitute materials or those offering entirely new combinations of properties is a particularly exciting area. Molecular alignment of polyethylene can produce a polymer with a tensile strength that exceeds that of glass or steel on a weight-for-weight basis. By means of an "ultradraw" technique, an organic polymer filament 1/8-inch thick can support a weight of almost 3700 pounds. This pioneering work is now being scaled up to produce insulation for superconducting magnets.

Metallic glasses are another case in point. These are produced when molten metallic alloys are "splat-cooled" at rates of 100,000 to 1 million degrees per second. Because such rapid cooling prevents crystallization in the resulting solid, its molecules are arranged in essentially amorphous, random patterns like those in glass. Glasses can be produced that have yield strengths far in excess of those of commercial steels and are more corrosion-resistant than stainless steel and lighter and stronger than aluminum. The potential for these and other new glasses is enormous, perhaps rivaling the impact on modern society of the semiconductor technologies born a little more than three decades ago. Should these programs not be housed with those that support other materials research?

In recent years we have all become concerned with the pace of technological innovation. We see foreign industry seeming to swamp American competitors in the innovative manufacture and marketing of consumer electronic products. Japanese manufacturers are mounting a vigorous challenge in areas where the American lead at one time seemed unassailable—computers, communications, semiconductor microcircuits, robotics, and others. In only 3 years, Japanese companies have captured 40 percent of the world market for 16,000-bit random access memory chips, a key component of modern computers. Hewlett-Packard Company, one of the three largest users of these chips in the United States, reports that the Japanese devices are more reliable in several respects than those from American sources.

There is a comment I read once which was intended to be humorous but which possesses some truth. That is, the development of a new product is a three-step process: first, an American firm announces an invention; second, the Russians claim they made the same discovery 20 years ago; third, the Japanese start exporting it.

The problem is one that has many facets; one of them, certainly, is vigorous product or process innovation. NSF has focused considerable attention on some promising avenues of innovation during the past year. One of these is very-large-scale integration—the construction of immense numbers of electronic microcircuits on semiconductor chips. To develop such dense, high-speed circuits we must be able to fabricate structures on the order of 1 micrometer in size and smaller. To this end, NSF sponsors the National Research and Resources Facility for Submicron Structures at Cornell University.

Available to all qualified researchers, the facility is both a fabrication resource for the academic and general research community and a research center for fabrication technologies. Significant advances have already been achieved there in the use of ion, electron, and x-ray beams to etch finer and denser integrated circuits on semiconductor chips than is possible with conventional optical techniques. Also addressed are such fundamental problems as physical limits.

How far we can go, for example, in compressing the size of microcircuits? There is now evidence that when the dimensions of a metallic conductor are reduced to a very small scale, its properties differ markedly from those observed on larger scales. For example, in experiments with metallic wires about 100 angstroms thick, resistance was found to increase with decreasing temperature to the point where the wire becomes an insulator. This is a limit of one sort, but an opportunity of another. Although we are still some orders of magnitude away from being stymied by such barriers to further compression of microcircuits, it is obvious that as dimensions continue to shrink, ultimate constraints will become increasingly important.

Another area of vast promise lies in the marriage of increasingly versatile chips with production machinery. The eventual result would be programmable robot systems with an array of sensors and articulated "arms," "wrists," and "fingers" for precision manufacturing tasks. We are currently supporting a project with Westinghouse to develop a robot system to assemble electric motors. And we are supporting research on how intelligent machines can perform such cognitive functions as logical inference and self-learning, how they can see and have other types of perception, and how they can control manipulators.

In the cognitive area, researchers at the University of Rhode Island have taught a robot manipulator how to pick up parts of moderate complexity from a cluttered bin when only a portion of the target part is visible. At Purdue, an aural data processor under development will permit robots to respond to voice commands. Ultimately, this work on robot cognition will be extended to systems operating in nonpredictable environments and changing problem domains.

A large part of this applications-oriented research is, of course, of keen interest to industry. NSF encourages the submission of joint university-industry proposals to undertake research of mutual interest. It is noteworthy that in many of these ventures the industrial partner shoulders its own share of the project's cost. This permits the available funds to support a larger number of these undertakings than would otherwise be possible. Long-term joint projects between industry and university research teams can contribute as much to the basic strength of our national R & D community as they can benefit the individual parties to these joint ventures.

Areas of Concern for the Future

Now I would like to turn to my final topic: How should we refocus our support for research and education in the sciences and engineering in the 1980's to achieve our major goals? I have indicated already that vast areas of research inspired by a combination of curiosity and need promise rich rewards in the future. But I am convinced that we must be more aggressive in the management and planning of science and technology if we are to achieve the high rates of advance necessary to sustain our traditional economic, social, and political posture in the international community.

There is no need more pressing than the need to ensure that our science and technology enterprise is driven by the best and most highly trained individuals our society can produce. At the minimum, this means that we must improve the opportunity for young people to gain first-class science or engineering educations. It also means that we must try to ensure that career opportunities are available to graduates in these disciplines.

Further, at every step in this process, we must ensure that opportunities and encouragement are available to women and minorities, both of whom are strikingly underrepresented in science and engineering careers. Although racial minorities make up 22 percent of the population of this country, they comprise but 4 percent of our nation's scientists and engineers. Even this figure is distorted because the bulk of this number are Asian-Americans, who are fortunately overrepresented in participation.

The problems are manyfold. But we must address and solve them. I say that it is our responsibility to do so, yours and mine. Simply look around you. You can see the problem. We need real affirmative action, not the numbers games that have been in vogue for the past 10 years or so. The reason we must do so is simple. We need all the talents we can find to unlock the mysteries of science and to work on the technological problems of our world.

With respect to the actual state of education in the sciences, mathematics, and engineering, despite past efforts, we continue to be confronted with an urgent need to reinforce science and mathematics education in our secondary schools. We must also embark on a new commitment to the education of engineers, scientists, and technicians seeking baccalaureate and higher degrees. (These are the central conclusions of a study completed last year by NSF and the Department of Education: *Science and Engineering Education for the 1980's and Beyond*.)

At the secondary school level, the emphasis on basic skills seems to be associated with a decline in the numbers of students taking advanced science and mathematics courses. Only about one-third of the nation's high schools require more than 1 year of mathematics or science for graduation. Colleges and universities have reduced the number of these subjects they require for admission. What is so worrisome about this trend is that students who take no mathematics or science after their tenth school year have effectively eliminated science and engineering as careers. Moreover, as society becomes more dependent on technology, technologically illiterate students may be forsaking the ability to be fully productive citizens in many walks of life.

In higher education, we are experiencing severe shortages of qualified faculty members in many fields of engineering, particularly the electrical and computer sciences. Industry is luring engineering and computer science faculty to challenging and well-paid positions and attracting new recipients of bachelor's degrees who might otherwise pursue graduate work in these disciplines. It is difficult to see how adequate numbers of engineers and computer professionals can be educated in the 1980's unless we can alleviate this problem of faculty erosion.

International comparisons are of considerable interest here, too. Between 1963 and 1977 Japan awarded approximately as many degrees to engineers as did the United States, even though Japan's population is only about half the size of our own. In Japan, about 20 percent of baccalaureates and 40 percent of master's degrees are in engineering, compared with 5 percent for each degree level in this country. Interestingly, only about half of Japan's engineers actually enter the engineering professions; the rest become civil servants or managers in industry. In fact, about half of Japanese senior civil servants and industrial directors have engineering qualifications. The fact that Japan almost doubled its share of world trade between 1963 and 1977, while the U.S. share declined about 25 percent, may owe much to the engineering skills of managers of the Japanese national enterprise.

Peter Drucker, in an article in *Fortune* magazine last November, quoted a Japanese official who said: "You in the United States have in the last ten years doubled the number of people in law schools, while you barely even maintained the number of people in engineering schools. We in Japan have not increased the number of lawyers but have doubled the number of engineering students. Lawyers are concerned with dividing the pie, engineers with making it larger."

With respect to the higher education of engineers and computer scientists, there are a variety of steps NSF can take along with other agencies of the government. These include support for the purchase of state-of-the-art research and teaching equipment for engineering and computer science departments, particularly in areas of computer-aided design and computer-assisted manufacturing methods. NSF can develop incentives to encourage engineering and computer science graduates to enter university teaching, for example, by providing traineeships and fellowships for Ph.D. candidates, and the mission agencies can extend salary, traineeship, and facilities support in accordance with their needs.

There are many measures we can take to quicken interest in the sciences and engineering in the secondary schools, not only among those who will pursue research careers but also among those who will not. As a minimum, we should provide these people not only with an understanding of the relevance of science and engineering to personal and societal problems and how scientists and engineers actually work, but also with a fundamental grounding in the mathematics and science of tomorrow's world.

In this connection, it seems that the long-standing notion that Americans are somehow blessed with an innate "Yankee ingenuity" for coping with technical problems has become increasingly questionable. According to the report, *Science and Engineering Education for the 1980's and Beyond*, evidence is accumulating that Americans in general are becoming less adept at handling complex and exacting tasks. Industry sources report anecdotal evidence that productivity in technical areas among U.S. workers has dropped because base levels of understanding of science and mathematics have declined over the past decade. Similarly, the U.S. military is finding it increasingly difficult to find commissioned and noncommissioned officers capable of learning to operate increasingly sophisticated military hardware.

I am aware that attempts to forecast future needs for scientists and engineers are fraught with uncertainties. But I am impressed with the forecast of the Bureau of Labor Statistics that opportunities in science and engineering occupations will grow by about 40 percent at all degree levels between 1978 and 1990. This growth would create 180,000 new jobs in the mathematical, physical, life, and social sciences, 250,000 new engineering jobs, and 480,000 jobs in the computer professions over the 12-year period. In addition, there is evidence of a high degree of mobility among scientists and engineers in terms of their ability to shift to "hot" fields. For example, in a survey of 1977 engineering and science baccalaureates, it was found that almost three times as many were working in the computer professions in 1979 as had obtained bachelor's degrees in that field 2 years earlier. The trend is even more marked at the doctoral level; in 1979 it was found that three and a half times as many Ph.D.'s were working as computer professionals as had *ever* earned degrees in the field.

It may be helpful at this point to consider how NSF organizes itself to support research—and to consider some changes we are in the process of making. NSF's structure reflects the fact that it has statutory mandates to support basic research and education in all the sciences and in engineering, and also to seek ways to apply scientific and engineering knowledge in the service of national needs. The challenge to the Foundation is to create a flexible structure that can accommodate creativity in both the search for new knowledge and the seizing of exciting and useful opportunities to apply it. This is not something we expect to do by the mere shifting of organizational boxes or reallocation of dollars. It involves a subtle but fundamentally significant broadening of perspective on the part of those throughout the science and engineering communities who have been accustomed to think in terms of science versus engineering, or basic versus applied research.

In an organizational chart, just as in research itself, some of the hard and fast lines we have been accustomed to draw between science and the frontiers of engineering research also begin to look pretty fuzzy. Although engineering was born as a practical and intuitive art, today it embraces a range of knowledge from the highly theoretical to the very practical. Engineering builds linkages with physical, social, and life sciences on one side, and with industrial practices on the other. Those engineers who devote their lives to creating the engineering of the future are as concerned with the discovery of new knowledge as with the application of knowledge already attained. Thus, it is wrong to think of engineering research as applied research or vice versa.

As an example, consider the problem of turbulent flow. This is a phenomenon associated with bodies moving through a viscous medium, as well as fluids moving through pipes, pumps, turbines, heat exchangers, and the like. Designers of a tremendous range of equipment want to ensure a smooth flow, because once the flow separates from hulls, airfoils, or ducts, drag or resistance rises abruptly and the efficiency of the system decays sharply. Some of the greatest scientific minds in history have wrestled with the problem, including Da Vinci and Newton, and the conventional wisdom gained from this prolonged effort has been that flow separation means total randomness and chaos in the flow. Hence only statistical techniques can be applied to the problem. But recent research suggests that the onset of turbulence may actually exhibit a pulsating structure or repetitive pattern, and that it may prove more tractable to mathematical analysis than anyone had thought. If this can be verified, it will have a great impact on all sorts of problems—not simply in the design of aircraft and ships, but in the design of efficient mixing and heat exchange systems like rocket engine combustors and steam condensers. Efforts to understand the human circulatory system and other biological fluid-flow phenomena will also benefit.

NSF is now taking an important step to strengthen its organizational posture for dealing with engineering as a discipline of fundamental inquiry. We are establishing a Directorate of Engineering, which will help us focus on the development of the intellectual foundations of engineering science. I want to emphasize that this reflects a shift in the way we plan to allocate our resources, rather than specific immediate decisions on dollar amounts or proposed allocation of those resources.

The steps we have taken to emphasize research in engineering do not imply any major shift in the allocation of our resources between basic and applied research or between the traditional and the engineering sciences. NSF has devoted the bulk of its resources to the support of basic research in accordance with the dictates of the statute that created it 30 years ago. The House Science and Technology Committee recently stressed that these core research programs "must be maintained as part of the Nation's effort to maintain world technological leadership and [to] protect national security."

NSF has done nothing to alter that emphasis. The new moves do, however, make the Foundation's structure more agile in dealing with engineering and applied research. They should permit a greater degree of mutual reinforcement between applied research and basic research in both engineering and scientific disciplines.

I like the way Robert Marshak put it. He said that "Pure science is unquestionably the jewel of modern culture and will remain the indispensable ingredient of human progress for many decades to come. . . . However, the burden of global challenge mandates that the American scientific academic community attempt to balance the celebration of scientific creation with the application of scientific knowledge to societal needs and the sensitivity to human values."

Conclusion

I know I was asked to address the future of NSF, and I have dwelt more on the past and the present. There are two reasons for this. First, one looks at the future in light of the present and past, and second, it is important to me that the scientific community understand that the Foundation exists today with its basic mission unchanged. It addresses the future from that solid base. And I know of nothing in the future that will change that base.

This has been a rather lengthy tour of the range of the Foundation's interests and activities in scientific and engineering research and education. Even so, it is far from exhaustive. What stands out for me is the sense that the sciences have rarely generated such excitement and such a flood of achievements in so many different disciplines at once as they are doing today. I am convinced that the United States maintains and will continue to maintain its preeminence in virtually all areas of fundamental inquiry.

This will not come easily. We live in a far more competitive world today than we did 30 years ago, when NSF was born. Then, the United States led all other nations in wealth, economic productivity, military power, the sciences, and technology. Today we face challenges in all of these indices of national stature. But challenges are almost invariably associated with opportunities, some of which I have considered here. Challenge, opportunity, and the imagination and ingenuity to make appropriate changes and adaptations—these are the very stuff of scientific and engineering enterprise. Not only am I convinced that we have in full measure all the requisite talents for pursuing and applying scientific knowledge, I am supremely confident that we will continue to do it very well in the years ahead—perhaps even better than in the past.