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ABSTRACT

This document reports on the results of an ad hoc workshop called "S.E.E.ing the Future: Science Engineering and Education" Held at Dartmouth College in November of 2000 and sponsored by Dartmouth, the National Science Foundation, the Dow Chemical Company, and Science Service of Washington, DC. This transdisciplinary conference was one of a series of events that took place across the country to mark of the National Science Foundation's 50th Anniversary (NSFSO). The conference brought together leading thinkers in the sciences and arts-winners of National Medals of Science and Technology, Presidential Early Career Awards for Scientists and Engineers, leaders in industry and small business, university presidents and deans, writers, theologians and financiers--discussed the future of government funding of basic science and engineering research in the United States. Representing a diverse spectrum of those affecting and affected by science and engineering research, this grassroots group's findings and recommendations for the best uses of public monies are reported here. Among those findings are: (1) a deteriorating national infrastructure that may threaten U.S. leadership in science and technology; (2) public funding needs to balance the shift of industry research and development dollars from new research to short-term product development and profits; (3) funding agencies must expand their traditional definition of cost and benefit analyses for scientific research beyond dollars spent, discoveries made, and products developed to include the intellectual vitality of science, U.S. responsibility as a leading global citizen, and the fate of areas that are not founded; (4) in order to maintain its leadership positions in science and in the world economy, the U.S. must encourage, recruit, and retain a wide range of American young people--especially women and minorities--in science and engineering careers; (5) all Americans must be educated in the fundamentals of science; (6) the U.S. executive branch must establish a plan to promote long-term funding and evaluation of research initiatives and projects of benefit to the entire nation; and (7) the need for the federal development of a program to renovate the laboratories and teaching facilities at small and medium size non-research colleges. A list of conference participants is appended. (Contains 15 references and 39 endnotes.) (YDS)

S.E.E.ing the Future: Science, Engineering and Education

A White Paper
on the
Issues and Need for Public Funding of
Basic Science and Engineering Research

Commentary from the Scientific Grassroots

Report of a Workshop held at
Dartmouth College
November 10–15, 2000

Editor, Mae C. Jemison, MD, Project Director
Professor, Environmental Studies, Dartmouth College
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A Jemison Institute of Dartmouth College White Paper

S.E.E.ing the Future

Science, Engineering and Education

A White Paper

Commentary from the Scientific Grass Roots

Abstract

This document reports on the results of an ad hoc workshop of leading thinkers in the sciences and arts who met at Dartmouth College in November 2000. These individuals—winners of National Medals of Science and Technology, Presidential Early Career Awards for Scientists and Engineers, leaders in industry and small business, university presidents and deans, writers, theologians and financiers—discussed the future of government funding of basic science and engineering research in the United States. Representing a diverse spectrum of those affecting and affected by science and engineering research, this grass-roots group's findings and recommendations for the best uses of public monies are reported here. Among those findings are: a) a deteriorating national infrastructure that may threaten U.S. leadership in science and technology; b) public funding needs to balance the shift of industry research and development dollars from new research to short-term product development and profits; c) funding agencies must expand their traditional definition of cost and benefit analyses for scientific research beyond dollars spent, discoveries made and products developed to include the intellectual vitality of science, U.S. responsibility as a leading global citizen, and the fate of areas that are not funded; d) in order to maintain its leadership positions in science and in the world economy, the U.S. must encourage, recruit and retain a wide range of American young people—especially women and minorities—in science and engineering careers; e) all Americans must be educated in the fundamentals of science; f) the U.S. executive branch must establish a plan to promote long-term funding and evaluation of research initiatives and projects of benefit to the entire nation; and g) the need federal development of a program to renovate the laboratories and teaching facilities at small and medium size non-research colleges.

The workshop and White Paper were convened and coordinated by the Jemison Institute for Advancing Technology in Developing Countries at Dartmouth College with the support of the Dow Chemical Company and the National Science Foundation.

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Perspective

Just as we completed *S.E.E.ing the Future (Science, Engineering and Education): Commentary from the Scientific Grassroots*, we, like the rest of America had to stop and focus our attention elsewhere. With the deliberate destruction of the World Trade Center Towers, damage to the Pentagon and airliner crash September 11, 2002, we had to reevaluate the appropriateness and significance of this report. In light of the tragic events and current global political climate, was the need to get this message out still pressing? After many hours of thought, the answer remained a resounding "yes".

The critical nature of the issues facing public funding of science and engineering research outlined in this paper has been in evidence and growing for a long time. And in some ways, the new challenges we face as a nation now demonstrate even more urgently the need to have a thoughtful roadmap for dealing with future contingencies in all areas concerning the prosperity of our country.

The political and social backdrop against which the incredible technologic advances that we take for granted today were born—for example, space-based remote sensing, genetic engineering and the Internet— has changed. New priorities, researchers, consumers, and motivation for science and engineering research must be recognized and addressed by the funding process.

S.E.E.ing the Future is much more than a call to enhance funding for basic science and engineering research. It is the voice of individuals who form the heart of American science and technology strength, but who often go unheard in the formulation of national policy that both supports and depends on that strength. It is not by accident that the participants in the workshop from which this paper derived are leaders in their fields—industry, physics, industrial engineering, religion, mathematics, biology, chemistry, aerospace—and at all stages of their careers, from across the country with numerous honors. S.E.E.ing the Future we believe is integral part of an organized, purposeful plan to keep our nation continually on the leading global competitive edge

We hope you find these ideas useful.

Sincerely,

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Overview

The increasing prominence of science and technology issues in our lives and in the context of national debates compel us as a nation to ask crucial questions about the role of government funded science and engineering research and to answer them in the near future. In November 2000, an *ad hoc*, deliberately diverse group of some two dozen leading thinkers in the sciences and arts met at Dartmouth College to discuss the future of government and science funding in the U.S. These individuals—winners of National Medals of Science and Technology, Presidential Early Career Awards for Scientists and Engineers, leaders in industry and small business, university presidents and deans, writers, theologians and finance—discussed the future of government funding of basic science and engineering research in the United States. Sponsored by Dartmouth College, the National Science Foundation (NSF), the Dow Chemical Company, and Science Service of Washington, D.C., this informal conference was called *S.E.E.ing the Future: Science, Engineering and Education*. The project was developed and hosted by the Jemison Institute for Advancing Technologies in Developing Countries at Dartmouth College.

Representing the full spectrum of those affected by and affecting science and engineering research—gender, geographic distribution, discipline, age, ethnicity, academia and industry—the discussions of this grass-roots group ranged widely, from large database computation, biotechnology, and atmospheric research to religion, ethics and what constitutes public funds. There were no formal papers or prepared position statements. Instead a series of topical presentations, exercises and discussions provoked new thoughts on how the U.S. currently sets and should set priorities for public funding of basic science and engineering research. Social and national conditions and trends that the group identified as critical to understanding the current situation of American science and engineering include:

- American supremacy in science and engineering in the last fifty years was founded on political conditions that no longer exist: military, social, political, and economic competition, first with fascism, and later with Soviet-style Communism.

- In recent years, there has been an alarmingly rapid shift of industry funds away from new research to short-term product development and profit. Science and industry engineering giants from both the old and new economies are investing less in basic research. Investment in basic research in the 1960s and 1970s is the foundation of today's high tech companies.

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- The American public's poor awareness and understanding of science and engineering are in direct conflict with the importance science and engineering has in American lives and lifestyles. This paradox exists against a backdrop of a mass media that overwhelmingly favors coverage of sensationalism and pseudo-science (crop circles, haunted houses, and UFO's), not serious attention to and explanation of scientific research and debate on critical issues impacting our lives.

- American colleges and universities are training the technical labor force with increasingly inadequate and obsolete equipment.

- U.S. student enrollment in science and engineering programs is in decline. The nation's demographics are changing and we can no longer fill critically needed positions in science and technology without recruiting and retaining talented Americans of all types and backgrounds.

- Science and engineering research no longer relies on single disciplines but on a mixture of disciplines and increasingly on the efficient functioning of teams of researchers.

In light of these and other opportunities, risks, and challenges to U.S. leadership in science and technology, the group identified a set of characteristics or attributes that should be found in projects well suited for public funding. The characteristics, which are not meant to be applied rigidly or inflexibly, nor found in every research project worthy of public funding, can be evaluated by asking a sequence of questions. The ten questions the conference developed to help to make national choices are as follows.

1. **Do the benefits of the project fully offset its costs?** Costs include not only the dollars, but the scientific talent and time not applied to other research, the ethical costs of the research, and public perception of the relative importance of science. Benefits accrue to the general public, industry, scientists, and U.S. prestige and responsibility as a leading global citizen.

2. **Does the project promote improved science and engineering infrastructure and development of human resources?** The physical plants of academic institutions, large and small, formal training of the workforce and general public awareness of science are essential parts of that infrastructure.

3. **Does the project help foster a fundamental understanding of nature?** For example, research done twenty to thirty years ago on

fundamental cellular and molecular biology led to an understanding of DNA and RNA replication that is basic to the success of the current biotechnology industry.

4. **Does the project favor fields poised for rapid progress?** A critical mass of talent, knowledge, facilities, and questions—an alchemy of synergistic factors—makes certain fields ripe for exploitation through enhanced, short-term investment.

5. **Will the project help improve science and engineering education and promote the public's understanding and awareness of science?** The improvement of K-12 science education, providing opportunities for undergraduate research, nurturing the increasingly diverse, multi-cultural potential pool of the American technical work force and building a well-informed public are important roles for public funds.

6. **Does the project promote the intellectual vitality of science as a whole?** The capacity for self-renewal, growth and new discoveries—room for vision, passion, creativity, controversy and new paradigms—is a requirement for advancement and maintenance of U.S. leadership in science and engineering.

7. **Does the project favor fields with long-term potential?** Consistent support (ten to fifteen years) in fields with minimum expectations for immediate breakthroughs or applications have historically yielded critical advances, but are often subject to yearly reviews and budget changes.

8. **Does the project create significant tools for scientific inquiry?** Like automated DNA sequencing equipment, scanning electron microscopes, and particle accelerators, tools of observation often provide the basis for scientific breakthroughs and knowledge.

9. **Does the project create synergy between academia and industry?** Public funding can help guide the development of a model for industrial investment in academic research that considers stumbling blocks to cooperation such as intellectual property, open scientific inquiry, rigorous peer review and publication.

10. **Does the research have support from experts in other fields?** In this era of transdisciplinary research and discovery, the opinions and knowledge of experts outside of the sub-segment discipline in question is increasingly important.

Part I. Background to U.S. Research in 2001

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Research is formalized curiosity. It is poking and prying with a purpose.
Zora Neale Hurston,
in Dust Tracks on a Road, 1942

The "Scientific Method"

Science and scientific progress are not easy concepts to define. Journalists, the general public, and even many scientists often overlook the fact that "scientific" has meant different things at different times and in different contexts. How science is defined is always partly a social process. In turn, understanding the process of scientific progress has an important impact not just on scientists but society as a whole.

Francis Bacon defined scientific progress as banishing the accumulated errors of the past, the "idols of the mind."

Scientific research attempts to help us understand the universe around us, the impact of our interactions with it. Modern scientific methodology generally requires that information added to our accepted knowledge base be independently observable by more than one person, and given the same set of circumstances is consistently reproducible. From analyzing these observations, scientists then go on to develop descriptions (hypotheses) of the world that can predict the outcome of an event (effect) and how it happens (cause). So progress occurs in fits and starts as new observations are made, new tools to test theories are developed and new insight is gained.

Today, when understanding science is crucial to thousands of decisions at every level of society, relatively few Americans fully grasp the idea of scientific method. It is common to confuse the rigorous testing of hypotheses—part of the best tradition of modern science—with scientific uncertainty, or to think that a theory remains "unproved" as long as some scientists can be found to disagree with it.

In political or economic debates, in considering environmental or energy policy or missile defense systems, both sides typically enlist scientists to support their arguments. Can Americans filter out the science from political bias and financial self-interest?

Our future as a nation and society may depend—more than we realize it—on our understanding of scientific method as a flexible, nuanced, and continually evolving path.

How We Make Choices

"Philosophy is written in this grand book, the universe, which stands continually open to our view gaze," Galileo wrote in *The Assayer.*

Galileo's belief—that nothing should impede the free inquiry into the truths of nature—has since become an axiom of modern science. But Galileo himself often warned that things were not quite this simple. Between the universe and the philosophers who observe it, the world intervenes.

Galileo is now a powerful symbol—a hero and martyr of the cause of unfettered research. His struggles with the Catholic Church and the Inquisition are unforgettable lessons in the triumph of reasoning over ignorance and dogma. Less well- remembered, however, is the fact that Galileo's *real* battle was not with religion but with how science was done in his time, especially with its reliance on the statements of long-established authorities like Aristotle, rather than on fresh, original observation.

For, as philosopher Peter Caws has pointed out, the scientific method itself has a history and provides for many variations. Scientific method, Caws claims, "allows for variation of method not only from one discipline to another but also from one epoch to another in the history of the same discipline."[1]

Scientific progress consists in continually revisiting this history and re-evaluating these assumptions. This report, in its own small way, aspires to continue in that tradition.

"Research proceeds by making choices," Donald Stokes wrote.[2] The first assumption this report seeks to challenge is that the researchers themselves make all—or even most—of these decisions.

Research proceeds only with the support of larger society. If a scientist has the freedom to pursue his or her own interests and passions, it is only because a host of agencies and bodies—university departments, tenure committees, Congressional legislation, corporate executives, market forces, government bureaucracies, defense strategists, city councils, school boards, state planning commissions—have tacitly endorsed those interests and provided the means to continue. Often without even realizing it, these forces push, prod and cajole scientific and engineering research in one direction or another.

Those of us who consider ourselves researchers know all this intuitively, but even we don't always think through the implications or the questions. Will Adam Smith's "blind hand" guide genetic engineering as efficiently as it supposedly guides the larger economy? Are the "people's representatives" equipped to evaluate the importance of physics' string theory? Can local school boards dictate the facts of modern biology? Are democratic principles compatible with the free, unencumbered inquiry into the nature of the universe? How does scientific inquiry affect technology progress, and in what ways does technology progress benefit society?

Finally, can questions in the interest of society be answered, or even posed, before science and technology research have moved on to a new place beyond them?

S.E.E.ing the Future: Why This Conference? Why This Group? Why This Report?

This report grows out of a transdisciplinary conference held at Dartmouth College, November 10-15, 2000, and sponsored by Dartmouth, the National Science Foundation (NSF), the Dow Chemical Company, and Science Service of Washington, D.C. Called *S.E.E.ing the Future: Science, Engineering and Education,* the conference was one of a series of events that took place across the country to mark of the National Science Foundation's 50th Anniversary (NSF50). The project was developed and hosted by the Jemison Institute for

Advancing Technologies in Developing Countries, housed in the Environmental Studies program.

S.E.E.ing the Future brought together two dozen leading thinkers to focus on one corner of the puzzle of scientific choice—government funding for research—but it tried to at least consider all the pieces.

The participants in the *S.E.E.ing the Future* conference were chosen by an unusual set of criteria. Most studies on the future of science and science funding are composed of groups of senior figures in their field, usually well advanced in their careers and established in specialized disciplines, but the participants for *S.E.E.ing the Future* were chosen with quite a different perspective in mind. Authority and individual accomplishments in science, the arts and humanities were important, but lionization was less important than soliciting a wide range of opinion from the point of view of many different kinds of experience.

While participants included winners of the National Medals of Science and Technology, Presidential Early Career Awards for Scientists and Engineers, and cutting edge innovators in science and technology, we were, in fact, looking to assemble something similar to the classic Hollywood idea of a trial jury—a group of peers of many different ages and backgrounds that would present their opinions with passion and diversity, but nevertheless reach a consensus on matters of significance.

Accordingly, we sought out participants in many stages of their careers, from industry, small business, government, as well as academia, working in as many disciplines, cross-disciplines, and sub-disciplines as possible. The idea was to hear the voices of the individuals who make up the true scientific landscape of our nation—those who deal with the day-to-day choices and struggles of the field, as well as those affecting and affected by those choices.

By using this "grass-roots" approach, we discovered there was, in fact, agreement on some rather fundamental ideas. Like a jury of peers, we focused our discussion of these ideas until the group as a whole agreed upon the most pressing issues facing science and engineering. These issues were further defined, refined and discussed, and are addressed and presented in this paper.

This report is wide-ranging in scope and non-prescriptive in intent. It provides no easily constructed blueprints for how to maintain American pre-eminence in science and technology. It does not predict the major discoveries and inventions of the next several decades, or the impacts they will have on the American society.

What this report *does* attempt to do is to highlight the context of where U.S. science is now and how it got there, and pose a series of questions and

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recommendations to help shape future discussions and decisions on American science funding. One of its primary arguments is that understanding the full social context of science is crucial to its future. Our goal is to encourage others to speak up as well, and test our ideas and experiences against their own.

Such things, after all, are in the best tradition of science.

The Urgency of the Knowledge-based Economy

This report is written with a certain sense of urgency. Our affluent, progressive society, our much-touted "knowledge-based economy," is dependent on technological supremacy as never before. To most appearances, the dominance of American technology seems secure, bolstered by the advances it continues to foster in science and engineering.

Yet the social and political conditions that originally created this so-called "new economy" no longer exist. In the last fifty years, the entire social matrix of American science—especially its relationship to government—has changed dramatically.

If the United States relies on the vanished past to continue to support both advances in science and its economic supremacy, it is in for a rude awakening. It may find itself in the position of the consumer on the east coast who buys a shiny new car to travel the Interstate to California, only to discover the road has been badly maintained and crumbles apart deep in Utah.

Like the Interstate Highway system, the infrastructure of American science and engineering—and thus, to a large extent, the American economy—grows out the social and political conditions of the 1950s and 1960s.

The vast sums spent on the highway system were justified, in part, by the need for a military transportation system in the event of a war with the Soviet Union. Similarly, much of the scientific infrastructure of the U.S., including the Internet and even college and university dormitories, was built with the defense of the nation in mind and competition with outside forces. The great social changes and economic benefits that both systems have brought to the nation were, in part, byproducts of a "hot" war that never caught fire.

A Changed and Changing Landscape

Radical changes in the U.S. social and scientific context demand that we reconsider the basis from which we evaluate government funding of science and engineering research. The recommendations contained in this paper are predicated on the perception of the following changes in the national landscape.

American supremacy in science and engineering was founded on political conditions that no longer exist.

As noted above, the great advances of the second half of the twentieth century began with the efforts of World War II and continued through the struggles of the Cold War. Even today, the Department of Defense (DOD) is still one of three federal agencies who together are responsible for over four-fifths of the federal obligation for academic research and development (R&D).[3] DOD's academic R&D obligations are more than those of the National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE) combined. Moreover, within the overall FY 2000 federal R&D budget of $75 billion,[4] the DOD controlled almost 50% of expenditures.[5]

The threat of war justified the great concentration on science and engineering that supported program after program, from the Manhattan Project and the National Science Foundation to NASA and the Internet. But it is important also to remember that the impetus was not just military competition, first with Nazi Germany and Imperial Japan and later with the Soviet Union, but social, political and economic competition, first with fascism, later with Soviet-style Communism.

Now that the Cold War has waned, Russian military power is in decline and Communism shaken, the great sense of need that once propelled investment in the American scientific and engineering establishment no longer exists.*

The great upsurge of doctoral degrees awarded in science and engineering, spurred by the Cold War and Space Race, declined in the 1970s. It rose again in the 1980s, with increases in academic research and development budgets, but in recent years the number of science and engineering doctoral degrees earned by foreign students in the U.S. grew four times faster than the number earned by U.S. citizens.[6]

If the scientific impetus of the Cold War Era has run its course, will something equally powerful and compelling replace it in American society as we move into the twenty-first century? Do changes in the larger American society support or threaten future advances in science and engineering? We feel there is an urgent need to assess the changes, not only to the infrastructure of American science and engineering, but also to the social context that created them.

* The tragic events of September 11, 2001, that propelled the United States to declare a "War on Terrorism" occurred after the substance of this report was completed. The nature of this war's dependence on new resources and technical advances—and hence impact on science and engineering funding—is not in evidence.

The federal government's role in R&D funding has changed dramatically over the last thirty years.

Although, at its peak, the federal government funding provided up to 67% of all R&D funding in the United States, federal support now accounts for less than 30% of R&D expenditures. Industry has taken over as the primary source of funding for American R&D.[7]

Within industry, approximately 7% of funds are allocated for basic research, 22% for applied research and 71% for development.[8] Clearly, the emphasis for developing new products and potentially profitable ideas takes precedence in today's economy.

Traditional assumptions defining "basic" and "applied" research are changing.

As director of the U.S. Office of Scientific Research and Development during World War II and intellectual founder of the National Science Foundation, Vannevar Bush's influence on research was enormous. Bush believed in a strong separation between basic and applied research. He proposed the highly popular "linear model" of research and development, which began with basic research, proceeded to applied or practical research, and then to development and production. This model was widely accepted as the role of basic science in technological innovation during the period of the greatest expansion of American science, engineering, and technology.[9]

The linear model has, however, been questioned. Donald Stokes, among others, has recently pointed out that the relationship between basic and applied research, and between research and technological innovation, is actually far more complex than the linear model suggests.

As in the case of Louis Pasteur's research into preventing spoilage in vinegar, beer, wine, and milk, the search for a practical solution often leads to advances in basic understanding—in Pasteur's case, in microbiology. Similarly, a technological innovation, achieved without understanding the underlying scientific reasons, can often inspire a search for the underlying principles in basic science.

"The paradigm view of science and technology that emerged from World War II gave a notably incomplete account of the actual relationship between basic research and technological innovation," Stokes concludes. "The incompleteness of the post-war paradigm is impairing the dialogue between the scientific and policy communities and impeding the search for a fresh compact between science and government."[10]

Funding support for academic science and engineering research and development show *significant shifts away from industry and the federal government to academic institutions themselves.*

Overall investment for academic sector research and development has continued to grow over the last fifty years. Measured as a percentage of gross domestic product, academic R&D rose more than 400% between 1953 and 1998.[11] Thus basic research is more and more the realm of the academic institution.

At the peak of the science boom in the 1960s, the federal government provided 73 percent of the funding for research and development at academic institutions. Since 1994, non-federal support has grown more rapidly than federal support. Although the federal government continues to be the largest single funding source for R&D in academic settings, its share had shrunk to an estimated 59% by 1998. After the federal government, academic institutions themselves provide the second largest share of academic R&D support. The academic share has increased steadily since 1994, reaching an estimated 19% in 1998.[12] Industry's share in academic R&D grew to an estimated 7% in the same period, though it remains one of the smallest shares of academic R&D funding.

In 1999, the academic sector performed over 50% of all basic research in the U.S., continuing to be the largest performer of basic research in the nation. Federal research laboratories and programs accounted for about a quarter, industry and other nonprofit institutions 10% or less each.[13]

U.S. industrial investment in R&D is shifting farther and farther from basic research to short-term product development and profits.

Despite the current economic emphasis on technology development, a 1999 report published by the National Institute of Standards and Technology (NIST) suggests that industry may actually be "under-investing" in technology for a variety of business reasons. According to the report's author, NIST senior economist Gregory Tassey, "The dominance of the United States as a source of technology for other economies is declining, with reduced shares in practically every foreign market."

Although the U.S. still holds the largest technology share in the world economy, other economies are growing faster. The report suggests that concern for profits has lead U.S. corporations to avoid risky, yet potentially important, investments in technological research.[14]

Other studies have shown that, when R&D expenditures are calculated as a percentage of net sales ("R&D intensity"), the R&D investments of many industries actually declined between 1987 and 1997. Among those industries whose R&D budgets declined were electronic components (5% decline), scientific and mechanical measuring instruments (20%), industrial chemicals (20%), and office, computing, and accounting machines (25%). Among those with the lowest R&D intensity in 1997 were such economically crucial industries as petroleum refining and extraction and electric, gas, and sanitary services.[15]

At the same time, there has been a shift away from both basic and applied research in American industry. As already noted above, American industry now concentrates its major scientific and engineering efforts on development and relatively little on research. As one conference participant dubbed it "small r and BIG D."

Industries involved in development have also become increasingly internationalized. Many have now located parts of their development efforts in facilities outside the U.S., taking advantage of highly trained, low-cost labor forces in places like India. Major U.S. high tech firms such as IBM, Internet giant America Online, Cisco Systems, Nortel Networks, and communications market leader Lucent Technologies and Avaya have recently made or announced R&D investments in India amounting to hundreds of millions of dollars.[16] Many other U.S. companies are outsourcing development work to firms based in India's "Silicon City" of Bangalore, suggesting that development job opportunities may one day be more plentiful in the subcontinent than in the U.S.[17]

Nanotechnology: A Transdisciplinary Field

Nanotechnology is the creation and utilization of materials, devices and systems through the control of matter on the nanometer-length scale (10^{-9} meters or one billionth of a meter). Initially, nanotechnology was synonymous with molecular manufacturing, that is, building small molecule sized factories. But the practice of nanotechnology has come to include materials, electronic devices, and medical/biological tools with critical dimensions in the nanometer regime. One fascinating aspect of the nanometer regime is that it is larger than most molecules that can be precisely synthesized using standard chemistry methods, but smaller than what can be achieved by lithography, comminution, or other techniques which whittle away unwanted material (often used in computer chip manufacturing, for example). The other fascination is that many key components of biological systems such as antibodies, enzymes, and DNA all have critical dimensions between one and one hundred nanometers.

Nanometer-sized pieces of matter behave differently from their larger (or smaller) analogues and have potentially revolutionary applications. For example, electrons become confined in this domain, giving rise to quantum effects, disruptive in conventional electronic devices. Yet, these same quantum effects can also form the basis for new, dramatically smaller devices and new methods of computing. Materials that are usually known as semiconductors luminesce when shrunk to nanometer dimensions and may lead to new ways to image biological systems. Other materials may benefit from being formed at the lower temperature allowed by nanometer-sized grains. The behavior of materials at the ten nanometer length scale is just now being explored, but the available data herald heretofore unachievable combinations of characteristics.

The few years of research into nanotechnology has both demonstrated that the original concept of manufacturing atomically precise materials with tiny manipulators will be very difficult to achieve, and increased our understanding of how biological systems achieve exactly that kind of precision manufacturing. From these pioneering efforts, interest and inventions have sprung forth which interface biological motors, transport systems, or information storage into more conventionally manufactured architectures. These hybrid systems highlight the manner in which nanotechnology research crosscuts all traditional scientific and engineering disciplines. The fruits of this research span all technology-related areas of society.

Science and engineering research no longer relies on single disciplines but on mixtures of disciplines and increasingly on the *efficient functioning of teams of researchers.*

In all realms of science, there is an increasing emphasis on interdisciplinary and collaborative research. Such cutting edge fields as nanotechnology require not just a basic understanding, but also a fundamental grasp of what traditionally have been several distinct disciplines, taught in different academic departments and sometimes funded by different agencies. Nanotechnology research alone currently involves expertise in a formidable array of fields and subfields, including biotechnology, biomimetic chemistry, subatomic physics, microelectronics engineering, molecular biology, cellular biology, computer science, mechanical engineering, and mathematics.

As a measure of the increasingly complex research problems of contemporary science and engineering, National Science Foundation figures cite the increasing proportion of multi-author and multi-institutional scientific and technical articles in the U.S. Especially significant is the fact that the bulk of the increase in "corporate" authorship (i.e., joint authors with different institutional affiliations) reflected international collaboration. This suggests a growing need for effective scientific communication not only across disciplines but over borders as well.[18]

U.S. student enrollment in science and engineering programs is in decline.

Although Ph.D. enrollment in science and engineering at American universities has increased in recent decades, the majority of the increase can be attributed to foreign student enrollment. Of the foreign students who receive a Ph.D. in science and engineering, only 53% of these are employed in the U.S. five years after graduation.[19]

Not only are there, as noted above, fewer opportunities to perform basic research in the United States, the U.S. has fewer qualified people to perform that research. The trends in U.S. science and engineering higher education do not bode well for preparing the U.S. for the new millennium. Current retirement patterns indicate that a dramatic increase in retirements for the science and engineering workforce will occur over the next ten to fifteen years.[20]

To try and address the problem of higher education without looking at elementary and secondary education would be futile. The process of education begins before formal, professional institutional science training begins, and it is precisely there where changes need to take place. Secondary school age children in the U.S. consistently compare less favorably with their age group internationally in science and mathematics.

Changes in the fundamental methods of education are needed and have begun to be addressed. But nationwide basic improvements in the quality of teaching and school curricula in science and mathematics still need to be implemented.

America's public education system continues to show weakness in science and mathematics at the secondary school level.

The gap in scientific and mathematics knowledge between American students and their peers in competing economies has been well publicized, but it is worth repeating in this context.

Although statistics show some improvement since the 1970s, and younger students score above international standards, U.S. students in the final year of secondary school scored well below the international average on assessments of general science and mathematics. More worrisome in the mid-1990s, U.S. twelfth grade advanced science students performed below fourteen of sixteen countries in standard physics assessments and below eleven of sixteen countries in advanced mathematics assessment.[21] Studies continue to show that many American students are taught mathematics and science by teachers who do not have degrees in those subjects or at the elementary school level by teachers who never took a college level science class.

These figures suggest that, by the time American young people have graduated from high school, the vast majority of them have already been lost to science and engineering careers and most are not science literate. On the college level as well, the idea of a firm grounding in science as essential to a well-rounded education has declined since the 1970s. Increasingly even introductory undergraduate level science courses are the realm of specialists alone.

The social groups that historically provided talent for American science and engineering no longer fill the demand.

Post-World War II American science and engineering was a club whose membership once consisted of native-born, white, middle-class males and a smaller number of male West European immigrants. Since the 1970s, opportunities for women and minorities in American science and engineering have grown enormously. The U.S. is among the leading countries in the world in the proportion of science and engineering degrees earned by women (by 1996, women earned 47% of the degrees in the mathematical sciences and 46% of the degrees in the natural sciences.)[22] Yet the structure of American science and engineering has only just begun to acknowledge these changes.

As one commentator concluded, as women and people of color enter the professions of science and engineering, change will be the order of the day. "Change will have to happen simultaneously in many areas, including the conceptions of knowledge and research priorities, domestic relations, attitudes in preschools and schools, structures at universities, practices in classrooms, the relationship between home life and the professions, and the relationship between our culture and others."[23]

Workforce gaps threaten U.S. leadership in high technology fields and industries.

As the globalization of research and technology occurs, the need for a highly trained, flexible workforce that can meet the demands of increased competition in today's global economy grows more critical. That work force consists not only of engineers and scientists, but technicians, assembly-line personnel and product developers. Decreasing numbers in enrollment in science and engineering programs and failure to educate a science literate citizenry cannot support an ever-increasingly knowledge-based economy in the United States.

The National Science Foundation lists several reasons why high technology industry—defined as aircraft, communications, office and computers, drugs and medicines—is important to modern nations:

- High-technology firms are associated with innovation. Firms that innovate tend to gain market share, create new product markets, and/or use resources more productively.

- High-technology firms are associated with high value-added production and success in foreign markets, which helps to support higher compensation to the workers they employ.

- Industrial R&D performed by high-technology industries has other spillover effects. These effects benefit other commercial sectors by generating new products and processes that can often lead to productivity gains, business expansions, and the creation of high-wage jobs.[24]

The state of U.S. science and engineering education thus has an enormous impact on a nation's competitiveness, economic growth and overall vitality. To ignore the implications of current national trends in science and engineering education is to ignore an impending peril to the nation as a whole.

The American public's awareness of science and engineering is in direct conflict with the importance science and engineering has in American lives and lifestyles.

A less obvious "science education gap" has also become apparent in the U.S.—what might be called "science ignorance in everyday life." Despite the fact that Americans are proud of their scientific and technological history and progress, despite the increasing emphasis on technology and on-going technological re-education, Americans seem largely unaware of the science that underlies their community, professional, and home life, not to mention those with impacts on national politics and economic activity.

National polls suggest that half or less of the American public understands such key scientific facts and concepts as electrons are smaller than atoms, antibiotics do not kill viruses, lasers do not work by focusing sound waves, and it takes the Earth one year to go around the Sun—even though these concepts underlie the activities of normal, everyday life in a modern society. As recently as the late 1990s, only 16% of Americans were able to define the Internet.[25]

Even a cursory examination of the mass media show that sensationalism and pseudo-science overwhelm serious attention to scientific research and debate on critical issues related to science. American newspapers run daily columns on astrology, but even national "papers of record" cover advances in astronomy mostly in the back pages of weekly supplements.

Most Americans get both general and science news from television. But much of the "scientific" coverage on American television networks is actually devoted to haunted houses, extrasensory perception, crime, alien abduction, crop circles, and unidentified flying objects. Although legitimate scientists sometimes appear in such programs, even so-called "science" networks rarely submit such stories to rigorous scientific reasoning—or, except in the case of forensic science, even to hard journalistic standards.

The Pew Research Center for People and the Press has tracked the "most closely followed news stories in the United States" with "at least some relevance to science and medicine." The top ten stories tracked since the 1980s included nine involving natural and man-made disasters (the Challenger explosion, Hurricane Andrew, Chernobyl disaster, California earthquakes, and similar events). Ten of the top fifteen studies were concerned with the effects of weather.**

Such arguably more important topics ranked much lower on Pew's list of the top thirty-nine science stories: "the debate over U.S. policy concerning global warming" (35), "discovery of scientific evidence of the beginnings of the universe" (36)," and "the cloning of mice by scientists in Hawaii" (39).

Missing entirely from Pew's list of 689 closely-followed stories were any involving advances in computer science (including the Internet), the impact of science on technology and the American economy, human evolution, scientific study of the effects of drugs, endangered species, mathematics, genetically modified crops, or the study of human behavior.[26]

Although Americans have a high respect for science and four out of five agreed that encouraging the brightest young people to go into scientific careers should be a top national priority,[27] the popular image of science, scientists, and

**The Pew research was conducted prior to the voluminous coverage of anthrax and bioterrorism in Fall 2001, also a man-made disaster.

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those who work with technology paints a very different picture. Scientific careers are perceived as difficult, obscure, and financially unrewarding. Scientific research is made to seem the preserve of a tiny group of rather peculiar and somewhat anti-social people. True understanding of science is deemed irrelevant to everyday life, while the study of such epiphenomenona as unidentified flying objects, psychic visions, and poltergeists are promoted relentlessly by the national, local and regional media.

Such scientific and technological ignorance among the electorate surely translates into lack of concern by their elected representatives in Washington—and these are some of American science's most important patrons. That, in turn, identifies dangers ahead for America's scientific and technologic future, but also suggests opportunities for reeducation and change.

Prior Studies and Initiatives

Although it attempts to reach independent conclusions, this report has been produced in an environment of much research and study on the relationship between funding for science and engineering and scientific and technological progress. The contribution of the *S.E.E.ing the Future* report is not recreating the technical findings of the reports below, but rather evaluating, integrating and analyzing those findings with the experiences of individuals who represent the scientific and technological foundation of U.S. society. The participants—physical, social, and political scientists—who called themselves the grass roots of science, used a number of prior studies, several of which are cited elsewhere in this report, as background materials for the conference. Though helping to form the nature of the project, the participants distilled, extracted, identified and formulated crucial concerns through the filter of their observations in the day-to-day fabric of American science and technology.

Donald Stokes' *Pasteur's Quadrant: Basic Science and Technological Innovation* (Washington: Brookings Institutional Press, 1997), re-examines long-held assumptions about scientific progress, challenging in particular the traditional relationships between basic and applied research.

Capitalizing on Investments in Science and Technology (Washington: National Academy Press, 1999), prepared by the Committee on Science, Engineering, and Public Policy (COSEPP) of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, reports on a study undertaken to evaluate "how well... the United States [is] capitalizing on its investments in science and technology." The study's recommendations are informed by previous COSEPP research, by the National Research Council's *Harnessing Science and Technology for America's Economic Future: A Forum on National and Regional* (Washington: National Academy Press, 1999) and the U.S. House of Representatives Committee on Science's *Unlocking Our Future: Toward a New National Science Policy* (Washington: U.S. Congress, 1998).

Also drawing, in part, on COSEPP work is *Investing in Innovation: Creating a Research and Innovation Policy That Works,* edited by Lewis M. Branscomb and James H. Keller (Cambridge: MIT Press, 1998). Branscomb and Keller also question the traditional boundaries between science and technology and discuss the complex issues relating to the need for collaboration and information exchange versus business competition, and intellectual property rights.

Several recent books have taken a broader social and historical view of science and engineering. The anthology *Visions of Technology,* edited by Richard Rhodes (New York: Simon and Schuster, 1999), includes commentary written over several decades not only by such eminent researchers and scientists as Edward O. Wilson, but also by such well-known humanists as Elaine Scarry, Lewis Mumford, and Paul Goodman. Linda Schiebinger's *Has Feminism Changed Science?* (Cambridge: Harvard University Press, 1999) looks at the impact of current social trends and developments on scientific research. She concludes, among other things, that the increasing number of women in scientific research has "in many instances changed the content of human knowledge."

The National Science Foundation (NSF) and many of its grantees have produced regular studies of American science, research, science and engineering educational trends, social trends in science and engineering, and the impacts of science funding on economic growth. The result has been a vast number of studies, professional meetings, books and articles on such subjects as national patterns of research and development resources, impacts of new information technologies on science and engineering research, and trends in the national science and engineering workforce.

The statistics and analysis of NSF's *Science and Engineering Indicators* have been cited regularly in both this report and at the conference that preceded it. Published every two years by the National Science Board (NSB) as part of its role in providing the president and Congress with advice on matters of national science and engineering policy, *Science and Engineering Indicators* is "a quantitative overview of the U.S. science and technology enterprise."

As a companion to *Science and Engineering Indicators—2000,* the NSB has also issued *Science and Technology Prologue*, a reflection on "the conditions that characterized U.S. science and engineering 50 years ago, on accomplishments and changes, and on directions for the future of the enterprise." Among its observations, *Prologue* notes that although "the twenty-first century will be known for the melding of our human- and science-based technology" current research implies that "no more than one in five Americans either comprehend or appreciate the value and process of scientific inquiry."

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The Experimental Program to Stimulate Competitive Research (EPSCoR) is a joint program of the NSF and (currently) twenty-two U.S. states and territories. The program "promotes the development of the states' science and technology resources through partnerships involving a state's universities, industry, and government, and the federal research and development enterprise." Both EPSCoR and the various institutions and agencies that it helps support sponsor research, conferences, and publications on the relationships between science and technology funding, educational institutions, industry, and economic development at the state and territory level.

Working with EPSCoR, the American Association for the Advancement of Science (AAAS) has established the Research Competitive Program (RCP) to research the activities and decisions characteristic of states and institutions that have been successful in improving the competitiveness of their research programs. As the culmination of a series of studies and reports over several years, AAAS published *Strategies for Competitiveness in Academic Research,* edited by J. Scott Hauger and Ceilia McEnaney (Washington: American Association for the Advancement of Science, 2000). Among the topics it addresses are strategies for collaboration between government, academic institutions, and industry and implications of the entry of women and minority in science and engineering.

An Opportunity

The U.S. is the most prosperous nation in the history of the world, and we are currently living in a particularly prosperous time. Although all societies should always be aware of the historical legacy that they are creating, moments such as this, when we as a nation are material-rich and relatively free from war and economic need, are especially propitious for performing deeds of lasting importance to the human race.

Yet, the disturbing trend of the past decade is to set aside future returns for short-term gains. History's assessment of past societies is colored by their achievements in science and engineering and how they have improved the state of humanity. Societies that did not add to mankind's fundamental understanding of nature are spoken of less often. The past achievements of the U.S. in basic scientific and engineering research are major sources of national pride, comparable to our advances in political freedom, industrial and military might, and material well-being.

In the past, public funding of research in basic science and engineering in the U.S. led to the conceptualization, design and initial implementation of the internet, the development and launch of communication and weather satellites and through biotechnology, the ready availability of human insulin to treat diabetes and erythropoetin to stimulate red blood cell growth in cases of severe anemia. These benefits, though just recently available, are the direct and indirect result of basic research funded by the public 20-30 years ago.

But the public coffers that made such research possible—whether at the federal, state, city or local level as well as profits from industry—derive from monies collected not only from corporations and businesses, but from men and women who work daily at all the tasks that keep society running: high school teachers, lawyers, physicians, architects, nurse's aids, taxi drivers, airplane pilots, coal miners, baseball players, English professors, garbage collectors, musicians, cosmeticians, dish washers, and traffic cops to name a few.

These members of our society as a whole may not always recognize the vital role basic science and engineering research play in their lives. Those allocating public funds for research, however, as well as those receiving them have the critical responsibility for ethical stewardship on their behalf. That is, as much as possible, the leaders in science and engineering research and policy must ensure that these public funds work to build a foundation that helps society reach its potential and supports society's ability to choose the best path.

Today, much as we did in Vannevar Bush's day, we have choices to make. Do we use the current prosperity as the springboard to future advances and improvements in quality of life in the coming decades? What role should public funding play in assuring those advances?

These are choices that our nation will make, whether we make them consciously or not.

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Part II. What Kinds of Science and Engineering Research Should Public Funding Support?

In the face of the opportunities, risks and challenges to U.S. leadership in science and technology, how do we choose which project to support with public money? Our deliberations in the *S.E.E.ing the Future* conference resulted in the development of a set of characteristics that we feel should be found in good projects for public funding. These characteristics are assembled into a sequence of ten questions to ask when making these national choices.

We consider it important to use these questions not as a checklist of criteria but as a way to identify *characteristics*. These characteristics are not meant to be applied rigidly or inflexibly. Many of them are intended to suggest methods of evaluation that supplement current governmental agency approaches and no single characteristic is intended to determine if a project should or should not be funded. Instead, they are intended to enrich the process of evaluating science and engineering research for public funding and maximize the benefits that inure to our society.

1. Do the benefits of the project fully offset its costs?

A simple cost-benefit analysis would seem to be the most obvious part of evaluating a research project. However, often both the costs and the benefits of American research projects have been defined too narrowly and there is a need to expand cost and benefit considerations beyond traditional financial definitions. The following points are offered as a way to define these considerations more clearly and completely.

Talent, intellectual effort, and other resources often follow funding support.

Research funding should always be evaluated not only as the money and resources spent on a funded project, but also as money and resources not used on a project left without funding. Each project funded, and the benefits flowing from it, also represents a cost to other areas.

At academic institutions such as universities, colleges, museums, think tanks and institutes, an investigator who receives project funding tends to enlist graduate students who assist in the research, acquire additional office and laboratory space, require more administrative support and library resources, gain more attention both within and outside the field and from the public, and become more prominent in his or her institution, sometimes at the cost of other fields within the same institution. Many of the graduate students so enlisted will train in the same field and also become specialists, soliciting their own funding and resources and recruiting their own students.

As increased funds are made available to a specific field, researchers, universities, and institutions tend to develop "expertise" in these fields in order to become eligible to apply for the funds. This talent, effort and brainpower are thus guided by this funding process and are not employed in other areas. Whether the field is atmospheric physics, psycho-neurocognition, quasars or surface reactivity, the number of experts in these areas will grow as long as they are well funded. Those experts will, in turn, continue to look for and advocate for more funding for their work. And at some point the field or subfield will begin to deliver diminishing returns.

Assessing and breaking the cycle where professors train too many future minds for a field that has fewer contributions to make is difficult and best performed gradually, however. Such transitions may occur for some researchers at the career stage when they should be maximally productive. Suddenly closing off funding to a field is wasteful, as the brainpower of its researchers is, at best, used less optimally in a field different from which they were trained in.

The greater the funding, the greater the perception, rightly or wrongly, of the importance of the funded field, at times to the detriment of other fields.

The amount of government money applied to a specific field of research is often correlated in the public eye with the significance of the research. The implication is that both the science community and the government consider a more heavily funded field to be more important. Credibility of the entire scientific community as well as that of the government funders is attached to the success of the project commensurate with the level of money committed. For example in fiscal year 1999, AIDS affected 650,000-900,000 Americans and received $6 billion dollars in federal funds, while autoimmune diseases (chronically debilitating and often fatal), which collectively affected fifty million Americans (thirty million women), received $382 million in government funds.[28]

In the zeal to increase funding, it is easy to "catastrophize" science. The pressure to produce early—and dramatic—results thus also grows in proportion, and can affect the future of entire fields. Researchers and politicians tend to over-dramatize the importance, urgency, critical nature, success, or potential benefits of a well-funded project, as well as the dangers of failing to meet an early result, beyond the bounds of what can be reasonably achieved. Failure to meet these expectations can exact a great cost on the credibility of the entire scientific and technical community.

The benefits of the research do not automatically outweigh the ethical costs of the research.

The history of research funding in the U.S. has its dark chapters, especially during the Cold War Era. Too often, national security was used as an excuse not only to underestimate the ethical costs of funded research, but also to conceal that research from public scrutiny.

Horror stories of secret human experiments on LSD and research involving purposefully untreated diseases among African-Americans in the infamous Tuskeegee Experiment[29] have exacted a high cost not only from government but from science itself. They continue to cast a shadow over the public's trust of science. Such ethical costs should never be left out of the consideration of science funding, no matter how interesting or important the research.

Time spent is also a cost of research.

The time spent on a specific field of research is also a cost and one that is often miscalculated. Scientific research only rarely conforms to a predictable businesslike timetable, while time spent tends to seem more costly when progress seems slow.

How quickly will the benefits arise? Will progress proceed more quickly with more funding? What benefits are we willing to wait for? What is a reasonable time period to expect between pure research and a practical application of that research? Besides the timeframe over which money is committed, and results are expected, some attention should be paid to the probability that a research project will successfully answer the questions it proposes or contribute substantially to the overall fund of scientific and engineering knowledge.

Public funding has a unique role and should tend to favor long-term research, especially in areas where current industry standards foresee no early results in a marketable commodity.

Recently the trend has been to justify federally funded research projects with a specific end use that will be available to the marketplace. In fact, the argument can be made that government funding is best used to promote those fields where industrial applications are more remote and so less likely to receive attention from industry itself. Waiting for results may be a cost of research, but it may also be a cost well spent.

We expect this question of timeframe to become of increasing significance in research as the nature of industrial competition continues to move from "the big eat the small" to "the fast eat the slow." No matter how attractive, its liberal application in science is a dangerous idea.

There are many beneficiaries of public funding for science and engineering research and they all should be taken into consideration.

Since funding allows them to continue working and in many instances add to their prestige, research scientists themselves are clear beneficiaries of public funding. Funding also supports their institutional research facilities, which adds to their prestige and hence often helps funding in other related and unrelated areas. Furthermore, public funding benefits university students, as more research opportunities are available.

Commercial entities benefit from public funding of research through tax breaks (an indirect support of funding), by gaining licenses to use specific discoveries and inventions, as well as by the general increase in basic science and engineering knowledge that becomes available to all. These benefits are particularly important to the private sector as they invest more and more funds into short-term development of clearly defined products and less and less into long-term research.

Other benefits are spread throughout the general public. Sometimes research benefits will be diffuse—not clearly targeted for a particular group that needs political attention or a specified end product with a clearly defined economic value. But this does not mean the public benefits of such basic research will necessarily be minor or obscure. The coherent light research of the 1950s may have seemed insignificant at the time, even after it led to the first laser in 1960, but the public beneficiaries of the modern laser—in industrial and medical applications alone—are all around us.

Beneficiaries of publicly funded research include individuals suffering disease and their families, farmers who receive warnings of severe weather, and many others. Benefits include such areas as improved human health; improvement, understanding, or maintenance of the environment and ecosystems; improvement of manufacturing techniques, industrial productivity, and crop yields; and the accumulated effects of these improvements on the general quality of life.

In short, even when their results can take years to be obvious even to scientists, these research benefits extend to the everyday lives and work of virtually everyone on the planet.

Public funding of American science and engineering has benefits for the United States both as a nation and as a global citizen.

Cost reduction and improvements in American workforce productivity due to science and engineering funding seem relatively easy to track.[30] Evident, too, is the role public funding has had in building our status as the world's leading military power. However, the concept of "benefit" must not stop there.

Consideration should be given to the potential of a publicly funded project to develop domestic and international commerce, support effective competition as individuals and as a nation, and help maintain American technological leadership.

Research efforts that assist resource-efficient American products and services enter foreign markets merit consideration. However, quite apart from its own narrowly defined national interest, the U.S. also has a leading role as a global citizen. This citizenship should be considered as an important beneficiary of public funding of engineering and science research.

How does the project impact other countries and regions of the world—not only the actual research results obtained and their application, but also the example we set for other nations?

There are many problems facing large segments of the world's population that are essentially unknown in the U.S.: transportation to remote or inhospitable locations, food distribution to prevent famines, medical care in rural areas with poor infrastructure and sanitation, catastrophic agricultural problems, including massive floods and treatment of diseases such as malaria. Nevertheless, the U.S. often remains the most likely source of knowledge-based solutions to human problems outside our borders.

American research for example has been critical in understanding the biology of the parasitic disease schistosomiasis, seen rarely in North America but widespread and crippling in the Southern Hemisphere. Research in intensive agriculture now benefits developing nations and their citizens as much as it does American farmers. Such solutions improve the capabilities of our trading partnerships, earn our nation international political goodwill, and add to our national prestige.

Projects that make us better neighbors should receive special consideration. Such projects deal with problems that, more and more, are global issues, including ozone depletion, global warming, and reductions in biodiversity.

The benefits of each specific field should be periodically reassessed.

Consideration needs to be given to the fact that an area of research that was previously revolutionary may gradually have been supplanted or surpassed in real importance by another area that performs the same task, just as vacuum tube development was eventually replaced by research in transistors and microchip development.

The current technique of bottom-up decision-making—especially peer review when the peers are all in the same discipline—may actually serve to preserve the status quo; money may be funneled disproportionately to some fields, given their limited societal benefit. A cross-disciplinary assessment of the benefits of research would perhaps produce a better assessment of costs and funding. Such an approach would also be more in keeping with the increasingly cross-disciplinary nature of cutting-edge research.

2. Does the project promote improved science and engineering infrastructure and development of human resources?

The ability of the U.S. to maintain its worldwide leadership role in science and technology depends on not only how much funding is available to new cutting edge research, but perhaps even more critically on our ability to build, maintain and support the nation's science and technology infrastructure.

That infrastructure—the underpinning of information networks, laboratories, education and organizations—allows and facilitates our nation's capacity to recognize important new areas of research; to provide the personnel, facilities, and equipment to carry out the research; to distribute, analyze and verify the results; and, as appropriate, to capitalize on discoveries and inventions.

The physical plants for scientific facilities must be effective, up-to-date, and capable of supporting the training and education of the myriad of personnel involved in science and engineering research and development.

Access to up-to-date laboratories and scientific equipment are essential not only to the research scientists themselves, but also the various lab technicians, administrators and public servants who will assess, fund and support research projects.

During the Cold War there was a perceived need and a concerted effort to improve science and engineering facilities across the U.S. Over the last fifteen to twenty years, however, although federal funds for research at academic institutions have grown and diversified, there has been a distinct decline in science and engineering facilities at federally supported American colleges and universities.

For example, although the total academic science and research space increased by almost 28% between 1988 and 1998, the R&D equipment intensity—that is the percentage of total R&D expenditures from current funds devoted to research equipment—has declined dramatically in the past decade. After reaching a high of 7% in 1986, it declined to 5% in 1997.[31] This data suggests that, while American colleges and universities are able to accommodate more science and engineering students, they are educating them with increasingly inadequate and obsolete equipment.

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Except in the large, well-endowed research universities with access to large amounts of private funding, academic science and engineering facilities have also tended to be improved only to meet the needs of specific, funded projects. Additionally, schools that are not major recipients of government science and engineering funding typically receive less funding from other private sources to build science buildings and acquire research equipment. This trend has helped lead to a general deterioration and senescence of science and engineering laboratory facilities nationwide.

Schools in the U.S. that train the vast majority of our science and engineering technicians, professional engineers and science workers are consequently doing so on inadequate and often obsolete equipment. As they enter the workforce, the effectiveness of these workers is compromised until they receive compensatory training from the employer.

Serious consideration should be given to creating substantial public funding initiatives that promote and ensure the vitality and currency of science and engineering laboratories in institutions throughout the country—at community and small undergraduate colleges and regional state university branches, as well as the major research universities.

Formal education of American scientists and engineers, the education of the American workforce for the so-called "Knowledge Economy," and public awareness of science are essential parts of the nation's scientific infrastructure.

For every publicly funded research project, consideration should be given to a project's impact on training new scientists, technicians, engineers and researchers, to educating a science literate workforce, and to increasing public awareness of promoting science.

The U.S. is also encountering a trend in which fewer traditional scientists and engineers (white males) are choosing to continue in science careers. Foreign graduates are filling that vacuum.[32] Our competitiveness as a nation, if measured by student performance on TIMSS (Third International Mathematics and Science Study) and NAEP (National Assessment of Education Progress) tests, is in jeopardy. We must also consider how well we are supporting the human resources portion of our science and technology infrastructure.

In order to build and maintain a stable base of not only principle research scientists, but also laboratory technicians, undergraduates at all colleges and universities should have some opportunity to do research. This does not imply that all institutions must be research universities; rather there should be outreach in some form to all schools so that their students are able to participate in research projects. Undergraduates majoring in science and engineering must have some exposure to research and access to research opportunities regardless of their school.

Current funding assessment protocols often favor factors found at colleges and universities that are already well established as centers of research and science and engineering education. But funding assessments should also consider the benefits of projects that target the incorporation of specific groups with less access to up-to-date facilities and training, and colleges and universities in the process of developing better facilities and a more qualified teaching faculty. Fellowships targeted toward undergraduates should continue to be used to encourage a diverse composition of the principal investigator's research team.

These issues of education are considered in further detail under question 5 below.

3. Does the project help foster a fundamental understanding of Nature?

As the amount of investment in research and development in the U.S. has continued to grow, ironically there has been a concomitant decrease in the relative amount that is invested in basic research leading to a fundamental understanding nature. In fact, not including government funding, the real amounts allocated to funding of basic research have declined in the U.S. in recent years.[33]

Support of fundamental research should be of primary importance to public funders of science and technology because it provides a vital foundation for further breakthrough research, the application of ideas and discoveries to specific technologies, and the dissemination to other fields. The work in fundamental cellular and molecular biology done twenty to thirty years ago led to our understanding of DNA and RNA replication and subsequent translation into the body's proteins upon which the current biotechnology industry's successes and hopes are built. Consequently, public funding should promote and support fundamental research by considering the following as evaluation points for a project:

- Projects in areas of research necessary to advance the basic understanding of a field as well as the amount of fundamental research already done in the field are important factors.
- A project that addresses a stumbling block in an area of research that if solved or overcome will have wide ranging implications and enable other fields to advance deserves special consideration.

- An area of inquiry considered "ripe for investment" by experts in the field might identify places for public funding.
- Fields where increased short-term funding may serve to solve a specific debate over, change of, or advance in understanding may deserve special consideration for public funds.
- Projects that research and integrate knowledge across fields promote fundamental research.

4. Does the project favor fields poised for rapid progress?

The path of scientific discovery and technological advance in a field is seldom a smooth, linear progression from one breakthrough to the next. The amount of effort, funding and activity necessary for progress is variable and depends upon many factors: the number of individuals engaged in the field, the historical precedents, the significant research questions looming or recently answered, the current societal need for the knowledge, and new tools and available measurement and analytic techniques (e.g., automated DNA sequencing machines that facilitated the explosive gains in genetics and biotechnology). Often a field is poised for rapid explosive progress for the very same reasons: a critical mass of talent, knowledge, facilities and questions. This alchemy, so to speak, of synergistic factors makes certain fields ripe for exploitation through enhanced short-term investment.

Public funding of science and engineering research should seek to provide increased funds to those fields poised for such rapid progress on a short-term basis. This additional seed funding, if you will, can provide the spark to rapidly and significantly advance the field. This support should be decided upon and provided based on progress made over a designated time period. The benefits from this type of investment are the building of knowledge and capabilities in shortened time frames.

It is appropriate to review programs falling into this category early and often, but no more than yearly. If the field is poised for rapid progress, then rapid progress should expected of the program.

5. Will the project help improve science and engineering education and promote the public's understanding and awareness of science?

Public funding has a tremendous influence on science and engineering education at all levels—elementary, secondary, university, post-graduate and the general public. Any agency considering public funding of research should work from a philosophical foundation that promotes the overall, long-term impact of education.

The project's impact on education should include broadly defined results, not just specific or detailed quick measurements.

Effective science education must build student interest and curiosity in science, engineering and technology fields, foster the ability to digest and use information, and not just demonstrate their ability to re-iterate "facts." While not all worthy research projects or programs can involve K-12 education, continued emphasis must be given to this group. It is during the elementary grades that students begin to develop the basic skills and grounding that will allow them to become the technicians, engineers and scientists of tomorrow. Elementary and secondary school is also when the lay public has its greatest and most important educational exposure to science. Projects that include hands-on, experiential, discovery-based approaches for students suitable to the targeted age should be given special emphasis.

A program's design must take into account the need to measure its effect on education. Outcomes to be measured should include not only the numbers and types of student impacted, but also the information gained, whether the program stimulated their interests in the science and technical fields and enhanced their critical thinking and problem solving skills. These types of assessments require different tools depending upon the outcome to be measured.

Long-term partnerships between government funding agencies, industry, and K-12 education should be strongly encouraged.

Industry can provide real life practical experience for K-12 education and at the same time supplement needed resources in equipment, skilled workers, and funding that enhance K-12 science and engineering education. Many corporations already have significant programs in these areas that can serve as models and possibilities for such partnerships. Programs such as Bayer Corporation's Making Science Make Sense, Lucent Technologies' Project GRAD, Dow Chemical Company's Scientists in the Classroom, Intel's sponsorship of the International Science Competition and Talent Search, General Electric's ELFUN, NASA's student internships, and DOE's summer programs. These and many others demonstrate how projects involving professional scientists can partner with schools in hands-on science education.

Funding agencies should help inspire and channel children's interest in science careers and present diverse images of scientists.

An important side effect of engaging in research is desire for more knowledge. Humans have a natural thirst for learning about the universe. Children, in particular, have it in abundance, but may not have beneficial outlets for it. Involved in their own lives and jobs, adults may feel that dealing with the significant scientific interests of their children are beyond them and are best left to specialists.

Effective programs in K-12 should provide students with opportunities and outlets to take advantage of their curiosity and energy to explore the world around them. For example, field investigations with practicing engineers or collaborative projects that gather information for national databases, science fairs, and meeting with scientists provide such experiences.

Educational projects should also take care to avoid stereotyping science and scientific careers. They should establish positive, real role models in a wide variety of science disciplines for K-12 education. This is especially important for minority, female and under-privileged children.

Public funding should encourage science education in geographic areas and demographic groups where it is lacking and hence most needed.

Despite the importance of science and engineering research and science and engineering training to the whole of American society, the resources for research and training are by no means evenly distributed geographically. In fact, the six states with the highest levels of R&D expenditures (California, Michigan, New York, New Jersey, Massachusetts, and Texas) account for approximately half of the nations total R&D outlay.[34] These areas typically experience severe shortages of technically skilled labor in good economic times while other regions of the country struggle to create and attract the high-paying jobs in technologically advanced industries.

Economically underdeveloped areas that have few local resources to augment their educational needs and opportunities should be major targets for funding of science. At the same time, national educational initiatives should also foster a trained workforce in geographic regions where there is a present shortage of skilled workers and where future needs cannot be met.

Capturing, developing, and retaining the best minds from the U.S. to work in science and engineering fields is an important consideration of research funding.

National initiatives should also be considered that foster the recruitment and retention of all students, and emphasize traditionally under-represented groups in the sciences. The diversity of ideas that result from the participation of these individuals maximizes the chance of breakthrough research, broadens public support and increases the number of people ultimately entering the fields.

The reason for retention or lack of retention of underrepresented groups at each level of education and training must be understood. Data shows that though children across the spectrum of the U.S. population are excited by science and engineering, and adults understand its importance, sequentially at each educational level, groups traditionally not included drop out in higher and higher numbers. For example, of the undergraduate women who reach the threshold for the engineering path (completion of three required engineering courses) only 42% completed their degree as compared to 62% of men.[35] This lack of retention is a problem as demographics of the nation change and the pool from which the U.S. has traditionally drawn its science and engineering work force shrinks to a smaller percentage of the labor force.

For a democratic society to function effectively, the citizens must be well informed and well educated about science, scientific research, and their implications.

One of the main tasks of public monies in the U.S. is the education of children from grades K-12. A general appreciation of science is not only the starting point for helping young people aspire to be the next generation's scientists and engineers, it is also an essential ingredient in preparing America's citizens for life in an increasingly scientific and technologically advanced society. Basic science literacy, a broad societal understanding of and support for the role of science and engineering research, is essential.

Polls that seek to measure support of science and engineering consistently reveal that the U.S. public is proud of the nation's science and technology advancements and considers continued advancement important to U.S. economic success, world leadership, and the American quality of life. However, the public sometimes fails to understand the *process* (the typical timeframe and costs of basic research) and how it eventually impacts their lives positively or negatively.

Citizens are asked daily to consider individual and societal choices and policies that require basic science literacy and some familiarity with current scientific and technical discoveries and advances. Participation in or exposure to science and engineering research—from K-12 to higher education—will go a long way in helping the general public become more comfortable with the process of scientific research as well as give researchers a better feel for what the public needs and wants to know.

The major burden and responsibility for improving science education outreach should be shared by senior faculty members who are the major beneficiaries of funded research.

Many funding agencies and programs already require investigators to submit a plan to increase public awareness and participation of under-represented groups. The current system, however, seems to place this burden on younger faculty members and others just beginning their research careers.

Public funding should thus find a way to encourage, in fact require, more senior, established faculty members to shoulder a significant portion of this outreach. Not only do they have the time and the job security, but frequently senior faculty have the additional overhead funds and institutional wherewithal to make such programs a reality.

6. Does the project promote the intellectual vitality of science as a whole?

U.S. leadership in science and engineering is dependent on promoting a practice of science that has the vital capacity for self-renewal, growth and making new discoveries. It is specifically the passion and thirst for knowledge and the challenge to understand that attracts talented young minds to science and engineering to begin with. And it is the creativity involved in accomplishing new possibilities that holds and nurtures them throughout their careers. Many of the most revolutionary breakthroughs took place at times of great debate, intellectual interest, and unexpected outcome.

An essential role for publicly funded research must be fostering and maintaining intellectual vitality not only within a given set of popular disciplines, but across the science and engineering communities as a whole.

Retaining a vigorous U.S. science and engineering community must be a priority, and projects and research that promote intellectual vitality should be given additional consideration. Research with such potential might be identified by evaluating the following characteristics:

- Does the project identify new paradigms and research directions for a field?
- Does the research support the emergence of new ideas?
- Does the project encourage young people (both scientists and laymen) in the process and give them the freedom to speculate and dream?
- Does the research allow for vision, passion, creativity, imagination, debate, and controversy and at the same time use accepted, disciplined standards of measurement?
- Is there sufficient versatility in the standards that measure accountability and project success to allow for and appreciate unexpected outcomes?
- Does the research explore the boundaries between fields and disciplines that are fertile ground for new discoveries and for stimulating creativity?
- Does the research show potential to spin off and inspire other disciplines?
- Is the project aimed at resolving an on-going debate, either within science itself or in the larger society as a whole?

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7. Does the project favor fields with long-term potential?

In contrast to fields or topics that receive widespread coverage in scientific and lay media and financial support because near-term benefits and products are immediately recognizable, some fields with exciting long-term potential garner little support. Yet long-term, consistent support (ten to fifteen years) of these fields with minimal requirement or expectation for immediate breakthroughs or applications is necessary to realize that potential.

Public funding in these cases should ensure that an essential minimum number of experts in the field continue to be recruited, trained and practice, and that continued progress is made that leads to the brink of learning the field's significant questions and methods to tackle them.

For example, recent advances in superconducting materials (material with little or no resistance to the flow of electricity) is drawing heavily from the "old fields" of solid state physics and ceramics which were in some danger of becoming passé. Sustaining researchers and skills in those fields is paying dividends in some of the most exciting and potentially beneficial areas of research to date. The Apollo program, the International Space Station, the Human Genome Project, and the Superconducting Super

"Big Science" and Multi-Year Funding Commitments

Projects, especially large scale ones, often need to be viewed from the prism of long-term potential, the ability to invigorate the scientific and lay communities, and providing a significant tool for scientific research. Programs such as putting a human on the moon, the Human Genome Project, the International Space Station and the Superconducting Super Collider demonstrate the range of possible outcomes when funding is not defined and committed to on a long-term basis.

Landing Neil Armstrong and Buzz Aldrin on the moon, July 20, 1969, was the direct result of commitment by the legislature, NASA, and scientists and engineers to completing the project. The plan to put a human on the moon within ten years detailed a series of scientific and technology advances pre and post the actual first landing. For the most part the goals to be reached before the Eagle landed were accomplished along with the accompanying knowledge and benefits to both the scientific, engineering and the human community as a whole. Too numerous to name here, they included advanced materials development, rocket and engine design, atmospheric physics, human physiology and monitoring, national prestige and on and on.

The post-landing benefits however were not fully realized. The majority of the science research and investigations to be accomplished on the moon's surface were not done. Why? Because the last flights to the moon, the ones with the bulk of the scientific payloads, were canceled (i.e., not funded). In fact, three Saturn Five vehicles built and scheduled to go to the moon decorate the lawns of several museums and NASA space centers. And the capability to return to the moon immediately has been lost due to the dismantling of the launch pads at Kennedy Space Center and the equipment that built the vehicles. The overall project, landing on the moon was largely successful even in the face of the Apollo One tragedy. Yet lack of committed funding for the life of the project resulted in the loss of numerous benefits and advances which were waiting to be plucked.

Three recent projects provide additional insight along this continuum of funding. The Human Genome Project, an ambitious national project to map the human genome, has continued to get support each year to complete its work. But the announcement of the sequencing of a single human's DNA brought speculation that the project's goal had been achieved. Reassuringly the project has continued to be funded to reach its goal of mapping and understanding the human genetic pool. The International Space Station (ISS) currently on orbit around the earth, has suffered and continues to suffer severely from yearly budget changes and structural and functional re-definition. The current station is a shadow of the space-based laboratory for cutting edge research originally designed in the 1980s. Scientists and engineers across the spectrum of disciplines question its utility.

Collider are examples of projects and research that would be impacted by multi-year funding.

Fields falling under this category of long-term potential should largely be exempted from monthly review and a commitment should be made to multi-year funding, perhaps up to a minimum of five years. Funding a field because of its long-term potential, and then ending support one year into the project, virtually guarantees a waste of that year's funding and should be avoided. With that in mind, it is even more crucial to choose the projects and their lead investigators with great care.

In these times, a commitment to steady development, rather than rushing from fad to fad or emergency to emergency, needs to be asserted by public funding agencies. Nor should programs be modeled after business requirements of short-term profits and breakthroughs. The government is not a business and should not necessarily be run like one.

8. Does the project create significant tools for scientific inquiry?

It has been said that "One person's tool becomes another's fundamental research." Frequently an advance in a scientific field first involves the development of a new tool for use within that field. Practically all scientific studies and advances depend heavily on the analytical and investigative tools available for use by the scientist. These tools are part of the critical infrastructure upon which scientific advances depend. This infrastructure spawns additional capabilities, leading to new and more powerful tools of science, which in turn are used to develop further scientific knowledge and may facilitate the development of tools with even greater capabilities, and the spiral of increased knowledge continues. Clearly the promotion of this infrastructure—tools—is one of the most critical roles public funding can play.

Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) scans are used in patient care and research to image the human body tissue and understand its physiology and function in health and disease *in situ*—in the living human. MRI and PET scans required both basic science and engineering research to develop and are now assisting in the study of other areas.

As with any tool, understanding the benefits, costs, risks, and limitations of developing and using new tools is needed. Public funding should review scientific tools to be developed by projects in light of the following:

- Tools may enhance laboratory methods; these tools are used to carry out laboratory research experiments and investigations.

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- Mathematical and statistical tools are needed for the analysis and evaluation of research data, goals, plans, progress, and results. Though mathematicians may not have intended it, the building of chaos as a field of mathematical inquiry has led to the possibility of new tools to understand fluctuations and to analyze the data from previously seemingly unpredictable fields such as long-term weather prediction and the stock market.

Tools for "Seeing"

One person's fundamental research becomes another person's tool. Testimonies of how new tools depend upon and in turn lead to fundamental research breakthroughs in science abound in the task of "seeing" the world at the submicroscopic level. For example, Martin Kemp states, "In the earliest years of the century the question was not how we could see what atoms and molecules look like, but whether they were real or simply useful constructs. The crucial proof came not so much from measurements and calculations, valuable though they were, but from what could be 'seen' to exist, or rather, when visual traces or their presence became undeniable.'[86] *These visual traces required tools.*

The cloud chamber was used to plot the paths of single charged particles, recorded as water droplets, while the bubble chamber revealed the behavior of charged particles in superheated liquids under the influence of a magnetic field. Transmission electron microscopy, the electron microscope, first used in the 1930s and a relatively recent specialized variant, the scanning tunneling microscope, both required and contributed to knowledge on the behavior of electrons in the vicinity, atomically speaking, of matter of varying density. X-ray diffraction techniques pass x-rays through a grating of the crystal material to be studied. The pattern of the x-rays diffracted or scattered by the electron clouds surrounding the atomic nuclei of the molecule of interest, is captured on a photographic emulsion. The x-ray photograph of DNA (deoxyribonucleic acid) by Rosalind Franklin played perhaps one of the most dramatic roles in modern science. The complete structure revealed by these photographs required an extremely high degree of "visualization" prior to being translated into a hypothetical three-dimensional structure. This tool "permitted Watson and Crick to formulate the famous double helix scheme for the fundamental genetic components of living organisms.'[87]

- Logic tools are used for non-numerical analyses in logical relationships, concept recognition, and deduction and induction procedures. Means of manipulating large databases such as those in geology, demography and genome research all use such tools.

- Tools that perform of high speed and huge data calculations, simulations and communications are used universally by researchers today.

- Tools of "big" science, such as particle accelerators and space telescopes, are generally very expensive and are shared among investigators in a variety of fields.

9. Does the project create synergy between academia and industry?

A successful relationship between academia and industry helps ensure that technology in the U.S. develops in a way that is beneficial to all. Some fields may have funding potential from industrial sources (e.g., information technology) and potential for short-term profit and therefore a home in industrial development laboratories.

In an era where industry based R&D funding has steadily shifted from basic research to short-term product development, a concerted effort on the part of government, academia and industry should focus on the development of synergistic relationships that build on the strength of each. Yet there are clearly research areas of interest to corporations that cannot anticipate near-term marketability, and therefore may not have a home in industrial laboratories. Academia may be the place for such research. To some extent, public funding would do well to facilitate such linkages.

While the path to building partnerships between industry and academic institutions is not easy, it must be explored. Public funding can help define this path, guiding the development of a model for industry investment in academic and non-profit fundamental science and engineering research. In encouraging synergy between industry and academia, any such model must consider the stumbling blocks that arise from intellectual property issues, concerns of academic freedom, open scientific inquiry, researcher independence, rigorous peer review, publication and open literature.

Partnerships that promote synergy between education and industry should also challenge students to learn while providing industry with some benefit. For example, courses with case studies and significant real world problems offer the balance of collaboration on existing research and the opportunity for students to think of new questions and directions for future research.

The successful relationship between academicians and the industrial workforce is one that continually promotes discussion among both. In this endeavor, universities need to be the responsible catalyst for initiation and continuation of collaboration. Successful interactions at a few universities can be modeled for others to follow. Internships and graduate research in industrial settings should be encouraged for research contracts like Advanced Technology Programs (ATPs).

10. Does the research have support from experts in other fields?

The peer review process is crucial to assessing the validity of a research proposal and deciding which to fund and which have the greatest likelihood of success. Yet, at times, especially during allocation of funds, the increasing fragmentation of peers into smaller and smaller sub-segment disciplines increases the likelihood that the importance of the research will be measured by more and more restrictive parameters and—more ominous for the future of science—that the awareness of specialized research will reside in fewer and fewer people.

In this era of increasingly transdisciplinary research and discovery, it is increasingly important to the decision-making process that the opinions of experts outside of a field in question be used in evaluating the merits of the discipline in question. Since "peers" tend to be in the same or a similar discipline, they often have a favorable bias, on the basis that their own field of interest or research will be furthered and possibly benefit from more research. Therefore, other opinions, from experts in unrelated fields, are necessary to complement the evaluation of a discipline's potential benefits and costs.

Thanks to their different perspectives, outside experts can often help recognize creative proposals and stimulate new creative energy in a field or discipline. Furthermore, knowing that an external reviewer will be evaluating funding forces projects to include explanations that are accessible to those with less background in that particular field. Additionally, reviewing proposals outside one's own niche will help spur cross-disciplinary research and educate reviewers on important work outside their own field of specialization.

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Part III. Looking Forward

We believe the ten questions cited above are crucial whenever evaluating a research project for public funding or support. Which characteristic is pivotal for a research project depends very much on the prevailing national landscape in science and engineering. Existing funding in a discipline, emphasis and type of support being proposed, and perceived national interests will determine the balance between research costs and research benefits.

We conclude this report by looking at "do-able" steps that can be taken *now* to enhance the probability that these characteristics will be incorporated into the national dialogue and be assessed in keeping with the spirit of the framework we have proposed.

We strongly suggest that:

The Congress and Senate (Legislative Branch) should, at regular intervals, hold a hearing or a series of workshops where members might consider the issues raised in this and other reports on federal and public funding of science and engineering. At the same time they could meet with those engaged in research and science and engineering education. The purpose of these sessions would not be to make policy, but instead to inform—to establish the information base and understanding for policies that follow in the legislative cycles. A session that focuses congressional attention on the whole of science and engineering research may best establish the need to consider funding issues as a whole rather than focusing on one agency, budget, geographic area, or committee at a time.

The Executive (Presidential) Branch should work to establish a plan that promotes long-term funding and evaluation of research initiatives and projects. As the executive branch has the entire nation as its constituents, it is in the best position to advocate for projects that bolster the national knowledge and physical infrastructure of science and engineering research without an immediate return on capital.

A federal agency, the executive branch, or congress should consider sponsoring a joint meeting with state and local government groups that considers the role of state and local government in funding and supporting science and engineering research. The focus of these sessions would help spread the word and gain support for incorporating these characteristics in local considerations of science and engineering research and education.

The appropriate federal agency or agencies should undertake a review of the state of science and engineering teaching facilities in colleges, universities, and other nonprofit research institutions across the nation. The review should include a survey of the researchers and the appropriate faculty and administrators at these institutions to gain a complete picture of the state of the science and engineering education infrastructure. A program that specifically funds renovation and building of laboratories and teaching facilities at small- and medium-size non-research universities that teach science should be developed to implement any recommended improvements to these facilities.

Federal agencies should review their outreach and diversity requirements for funding science and engineering projects and amend them such that the responsibility for fulfilling these efforts shifts from junior faculty members and researchers to more senior, established grantees.

A federal science literacy campaign should be developed. This science literacy campaign should not be directed just at improving science education, but also at public understanding of the importance and process of scientific and technological support. The outreach, analogous for example to the "War On Drugs," should reach all segments of U.S. society and make us all aware of our collective responsibility for assuring that human progress benefits from government investment in science and engineering research.

Periodic meetings between representatives of all federal agencies sponsoring science and engineering research in specific disciplines should take place. These meetings would provide an integrated view of science and engineering research being funded.

Congress should establish a body to consider funding in all the agencies that support science and engineering research. This group would be able to offer insight on the distribution of monies as they pertain to disciplines, needs and benefits.

The questions outlined in this report should be distributed widely, so that they may be considered by all federal science and engineering funding agencies regardless of their focus

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Conclusion

Right now the United States as a nation has the wherewithal to make profound, lasting beneficial contributions to our citizens and all humanity through our science and engineering capabilities. To assure that impact, the country must make conscious, informed choices as to how we invest our public resources in science and engineering. We believe the roles best suited to public funding in basic science and engineering research should be to:

- Maintain the vitality of science and engineering disciplines;
- Build a fundamental understanding of nature;
- Build and maintain a robust infrastructure for science and engineering education and research in this country; and
- Above all, consider how the benefits of our knowledge, skills and technological advances truly inure to the benefit of all.

Of course advances in science and technology basic research require money, perhaps more money than is currently being allocated. But it also requires thoughtful and informed evaluation and public will. So in the end, we this "grass-roots group of scientists and thinkers" send out *"Not a plea for unlimited money, but enough money and well placed."*

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S.E.E.ing the Future was one of several projects held in 2000 to acknowledge the fiftieth anniversary of the National Science Foundation. It was proposed, defined, developed, hosted and implemented by the Jemison Institute for Advancing Technology in Developing Countries at Dartmouth College. A project such as this can only be accomplished with significant help—labor and philosophical support—from many, many people and organizations. As Director of the Jemison Institute, I offer these heartfelt thanks and acknowledgements.

The goal for *S.E.E.ing the Future* was to provide a fresh and compelling look at the need for basic science and engineering research. I believed it was critical that a group representing the range of everyday science research in this country be assembled. I want to thank all of the participants who gave freely of their time and intellect not only during the conference, but before and after as we turned these proceedings into a public communiqué.

The group described itself as "grass-roots" and not the "usual suspects." I in turn made a promise that the findings put forth in this report would be representative of the ideas, beliefs and intent of the participants. I promised the participants that those of us involved in the writing, editing and release process of the report from this conference would not be described as the following: "Committee—*cul de sac* in which ideas are lured and then quietly strangled." I hope we accomplished this; any failure to do so is mine. Again, I give my sincerest thanks to the participants.

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Selected Bibliography

Branscomb, Lewis M., and James H. Keller, eds. *Investing in Innovation: Creating a Research and Innovation Policy That Works.* Cambridge: MIT Press, 1998.

Caws, Peter. "Scientific Method," in Paul Edwards, ed., *The Encyclopedia of Philosophy,* vol. 7. New York: Macmillan Publishing Co. and The Free Press, 1967.

Committee on Science, U.S. House of Representatives. *Unlocking Our Future: Toward a New National Science Policy.* Washington: U.S. Congress, 1998.

Committee on Science, Engineering, and Public Policy (COSEPP) of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine. *Capitalizing on Investments in Science and Technology.* Washington: National Academy Press, 1999.

Greene, Brian. *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory.* New York: W. W. Norton, 1999.

Hauger, J. Scott, and Cecilia McEnaney. *Strategies for Competitiveness in Academic Research.* Washington: American Association for the Advancement of Science, 2000.

Kirge, John and Pestre, Dominique, eds. *Science in the Twentieth Century.* Amsterdam: Harwood Academic Publishers, 1997.

National Research Council. *Harnessing Science and Technology for America's Economic Future: A Forum on National and Regional Priorities (Industry and Economics).* Washington: National Academy Press, 1999.

National Science Board. *Science and Technology Prologue.* Arlington, VA: National Science Foundation, 2000.

National Science Foundation. *Science and Engineering Indicators 2000.* Arlington, VA: National Science Foundation, 2000.

National Science Foundation Division of Science Resources Studies. *Pocket Data Book.* Arlington, VA: National Science Foundation, 2000.

Rhodes, Richard, ed. *Visions of Technology.* New York: Simon and Schuster, 1999.

Schiebinger, Londa. *Has Feminism Changed Science?* Cambridge: Harvard University Press, 1999.

Stokes, Donald. *Pasteur's Quadrant: Basic Science and Technological Innovation.* Washington: Brookings Institution Press, 1997.

Tassey, Gregory. *R&D Trends in the U.S. Economy: Strategies and Policy Implications.* Washington, DC: U.S. Department of Commerce Technology Administration, 1999.

Notes

[1] Peter Caws, "Scientific Method," in Paul Edwards, ed., *The Encyclopedia of Philosophy,* vol. 7 (New York: Macmillan Publishing Co. and The Free Press, 1967), p. 339.

[2] Donald Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation* (Washington: Brookings Institution Press, 1997), p. 6.

[3] National Science Foundation, *Science and Engineering Indicators 2000,* 6-2. The Department of Defense provides 10% of the federal obligations for academic R&D. The National Institutes of Health provides 58% and the National Science Foundation 15%.

[4] Federal organizations with major shares of the R&D budget are Department of Defense, Department of Health and Human Services, National Aeronautics and Space Administration, Department of Energy, National Science Foundation, Department of Agriculture, Department of Commerce, Department of Transportation, Department of the Interior, Environmental Protection Agency, Department of Veteran Affairs, Department of Education, Agency for International Development, Smithsonian Institution, Department of Justice and Department of the Treasury.

[5] National Science Foundation Division of Science Resources Studies, *Pocket Data Book* (Arlington, VA: National Science Foundation, 2000), p. 5

[6] Ibid, 4-3, 4-4.

[7] Ibid-p. 2-3.

[8] Ibid.

[9] *Stokes*, op cit.

[10] *Stokes,* op cit, p. 89.

[11] *Science and Engineering Indicators, Volume 1 Chap. 2.*

[12] *Science and Engineering Indicators 2000,* 6-2.

[13] *Pocket Data Book,* p. 3.

[14] See Gregory Tassey, *R&D Trends in the U.S. Economy: Strategies and Policy Implications* (Washington, DC: U.S. Department of Commerce Technology Administration, 1999).

[15] *Ibid.,* 2-28.

[16] "AOL to invest $100m in India," *Reuters,* February 21, 2001; "U.S. $100m IBM lab set up in India," *Tech News,* February 26, 2001.

[17] "Downturn? What downturn? Indian software firms rock on!" *Tech News,* February 26, 2001.

[18] *Ibid.,* 6-44.

[19] *Ibid.,* Chapter 6

[20] *Ibid.,*

[21] *Ibid.,* 5-3.

[22] Ibid., 4-4.

[23] Londa Schiebinger, *Has Feminism Changed Science?* (Cambridge: Harvard University Press, 1999), p. 195.

[24] *Science and Engineering Indicators 2000, Volume 1,* Chapter 7

[25] *Ibid,* 8-9 and 8-11.

[26] *Ibid.,* 8-8.

[27] Roper, 1996, in *Ibid.,* 8-13.

[28] National Center for Health Statistics

[29] African American men in the infamous Tuskegee syphilis experiment left many subjects purposefully untreated even when the overwhelming efficacy of penicillin treatment was noted and the disastrous effects of untreated disease was well-known. The effects of untreated syphilis were of danger not only to subject, but also to his family and the community at large.

[30] See, for example, *Capitalizing on Investments in Science and Technology*

(Washington: National Academy Press, 1999), prepared by the Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine.

[31] *Science and Engineering Indicators 2000,* 6-2.

[32] *Ibid.*, Chapter 4, "Higher Education in Science and Engineering."

[33] *Ibid*, Chapter 2, "U.S. and International Research and Development: Funds and Alliances."

[34] *Ibid.*, 2-28, 2-29.

[35] Women, African-American, Hispanics, Native Americans, Pacific Islanders, individuals from lower economic groups and rural geographic areas are under-represented in science and engineering fields as compared to their percentage of the population at large or U.S. labor force. This disparity is greater in certain fields such as mathematics, physics, and engineering and as one climbs the ladder into graduate school and postgraduate education and fellowships. Women in 1997 were 23% of the science and engineering workforce but 46% of the U.S. labor force. Blacks, Hispanics and Native American who in 1997 comprised 24% of the U.S. population, represented only 7% of the total science and engineering labor force. Ibid., Chapter 3, "Science and Engineering Workforce" and Chapter 4, "Higher Education in Science and Engineering".

[36] Kemp, Martin, *Seeing and Picturing*, from Science in the Twentieth Century, pg. 372. Eds., Kirge, John and Pestre, Dominique. Harwood Academic Publishers: Amsterdam, 1997.

[37] Ibid., Page 373.

[38] Paraphrasing Joseph Louis Lagrange.

[39] Star Trek: Deep Space Nine, 1993

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