A Foundation for the 21st Century:

A Progressive Framework for the National Science Foundation

Report of the National Science Board Commission on the Future of the National Science Foundation

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Letter of Transmittal

Dr. James J. Duderstadt
Chairman, National Science Board

Dear Dr. Duderstadt:

On behalf of the Commission on the Future of the National Science Foundation, we are pleased to present the attached report.

We call the attention of the Board to the extraordinary outpouring of very thoughtful letters from individual scientists and from institutions large and small elicited by its charge to this Commission. Many of these letters are the result of serious drafting by very well informed people. The Board should not only study this material but should be mindful of the opportunities in the future to use this method for an extended dialogue on matters of great moment to the nation.

We are also grateful to those who have spoken with us formally and informally. The report could not have been completed in a timely manner without the support of you, Dr. Walter E. Massey, Dr. Charles Brownstein, and many others on the staff of the Foundation.

We hope that our recommendations may lead to a better understanding of the role of science and engineering in meeting national goals and a better linking of scientific results with those goals.

We are honored to have been given this responsibility and to have worked with the distinguished members of the Commission.

William H. Danforth
Washington University

Robert Galvin
Motorola, Inc.

Co-chairpersons

November 20, 1992

NATIONAL SCIENCE BOARD COMMISSION ON THE FUTURE OF THE NATIONAL SCIENCE FOUNDATION

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National Science Foundation

Preface

James J. Duderstadt
Chairman, National Science Board

The establishment of an external commission by the National Science Board is a remarkable event. Over the past 40 years the Board has established external commissions on only a handful of occasions when circumstances suggested the need for an impartial and expert consideration of significant issues of national science policy.

In the context of long range planning discussions with the National Science Board, the Director of the National Science Foundation, Walter E. Massey, explored with the Board the challenges facing NSF in the future and the Foundation's appropriate responses. Accordingly, he recommended and the Board established the Commission on the Future of the National Science Foundation.

As the Commission notes at the outset of its report, the transformation of the political, economic, and social context occurring both domestically and abroad is changing how we as a society view and support science and engineering research. The Commission stresses the fundamental importance of continuing the National Science Foundation's basic mission of supporting first-rate research, identified and defined by the best researchers within the academic research community. At the same time the Commission also underscores the importance of supporting key strategic research areas in response to scientific opportunities to meet national goals.

The report notes that the challenges the National Science Foundation faces go to the core of our assumptions about the role of science in our society. In the context of enhanced public confidence in and support of science and engineering research the Foundation must better position itself to respond to strategic research opportunities. Strong linkages between research and education will be critical to this endeavor, as will more effective partnerships between the academic research community and other sectors of our society such as industry and government.

Throughout the report, the commission identifies challenging issues that will require NSF attention. These include evolving research fields, interdisciplinary opportunities, increasing dependencies among stages in technology development, grant size, student support, improved science education, knowledge diffusion and facility needs. Yet the Commission also acknowledges that the NSF budget is inadequate to support even its present responsibilities and programs and that the National Science Foundation will find it difficult to respond to these new challenges without an increase in resources.

From this perspective, the Commission strongly recommends that the NSF's responsibilities and opportunities—both present and proposed—and its budgetary needs be examined within the context of a newly conceived Federal R&D budget capable of responding to national needs. To this end, the Commission urges that its recommendations be considered by the National Science Board in the context of the Board's own responsibility to develop and carry out national policy for science and engineering research and education more broadly.

The Commission report affirms the importance of the NSF's historical mission, provides an excellent starting point for assessing the new environment for research and education, and offers recommendations for meeting the needs imposed by these changes. The wisdom contained in the pages that follow will inform discussions within the Board and the broader scientific community on issues important to both the National Science Foundation and to the nation.

Contents

Background

THE UNITED STATES is preeminent in science thanks to public support for patient and judicious investment, private as well as public, since World War II. As a result of the government's reliance on universities for much of the nation's basic research, American graduate education in the sciences and engineering leads the world.

The National Science Board (NSB) and the Director of the National Science Foundation (NSF), in a spirit of self examination, have asked this Commission to stimulate thinking on long range strategies for the Foundation.

The task is important:

- ❖ despite having only about three percent of the total federal R&D budget, the NSF has for over 40 years played an essential role in the scientific primacy of the United States;

- ❖ the NSF serves as a major source of new scientific and engineering ideas and skilled people underpinning broad sectors of our economy and our society.

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And timely:

- ❖ expectations for benefits from scientific and engineering research, including economic growth, are growing and changing;

- ❖ the U.S. is competing in an expanding global market place;

- ❖ there is realization that scientific leadership does not translate automatically into economic success for American industry;

- ❖ corporate research is becoming more sharply focussed on market-related issues, with fewer companies supporting long term research;

- ❖ there are calls for greater accountability.

Key to the success of the National Science Foundation in building American science has been:

- its broad mandate to strengthen American science and engineering;
- a partnership of trust built with America's scientists, engineers, and academic institutions;
- investigator initiated proposals and selection of the best of these proposals on the basis of merit;
- strong educational programs;
- the flexibility to pursue new ideas.

Today, America's hopes for benefits from science focus additionally on:

- greater economic success;
- better health and less expensive health care;
- protection of the environment;
- continuing military security in a changing world;
- other improvements in the quality of life, including communications, transportation, housing, efficient use of resources, and better education of young people.

With shifts in emphasis from defense to civilian concerns, the private sector is an increasingly important consumer of new scientific knowledge. Changes in American businesses and universities hold promise of a more receptive adoption and practical application of the knowledge born of research and advanced education. These include:

- more progressive quality processes, and operations standards and systems;

- a realization that longer term versus shorter term thinking and planning is necessary;

- an increase in shared funding of research and engineering by industry and state and local governments;

- academic scientists working more closely with industry.

Changes in American businesses and universities hold promise of a more receptive adoption and practical application of the knowledge born of research and advanced education.

An important national priority is to improve the relative industrial strength of the United States. The National Science Foundation can make contributions to economic success, but developing a plan to do so must begin with an understanding of the system and of the reasons for failure of some industries in world markets.

Failures in the market place have not been the result of slow transfer of academic science to industry. In fact, American firms have been the first to commercialize virtually all innovative products, but have lost market share to competitors with shorter product cycles, lower costs, and superior quality. All manner of other more prominent factors, including the stewardship by American business, far outweigh whatever could be traced to the technology itself or the technologists.

Success requires: an enlightened federal science and technology policy that touches all relevant agencies, a determination by industry to reach out for talent and knowledge, and the development of appropriate links. The universities and the NSF should complement rather than replace the roles of those engaged in technology development.

Redirecting the NSF's activities from research and education would have little or no effect on the U.S. competitive position in the near term, but would severely restrict prospects for the long term. Research and education activities offer ample opportunity to increase the potential contribution of scientists and engineers to society.

We therefore commend to the National Science Board the following recommendations.

Findings and Recommendations

CHANGE IS PART of the national agenda. NSF, and the colleges and universities it supports, are in a position to help create a new vision of and value from the role of science and engineering for society.

To realize these benefits more fully, the Commission commends to the National Science Board and the broader scientific community these:

General Recommendations

1. The United States should have a stronger and more coherent policy wherein science and engineering can contribute more fully to America's strength.

   The Board is encouraged to work with the President, his Science Advisor, and the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) to assess the health of science and engineering broadly and to generate a stronger policy into which the NSF mission fits. This thesis is amplified in the conclusion of the report.

2. Society's voice is welcome and needed.

   Society's support for the NSF and for university research is based on the confident expectation that the generation of new knowledge and the education of a skilled workforce are necessary (though not sufficient) investments to achieve our national goals of a high quality of life in a productive and growing economy. In accepting society's support, the scientific community naturally assumes an obligation to be both responsive to national needs voiced by society as well as the intellectual priorities solely initiated by the scientist or engineer.

Concern over technology application and competitiveness sometimes conjures a choice that budgeting is decided on either the criteria to please the scientists or to serve the public need. In reality these criteria and interests are congruent.

The history of science and its uses suggests that the NSF should have two goals in the allocation of its resources. One is to support first-rate research at many points on the frontiers of knowledge, identified and defined by the best researchers. The second goal is a balanced allocation of resources in strategic research areas in response to scientific opportunities to meet national goals.

It is in the national interest to pursue both goals with vigor and in a balanced way. The allocation of resources should be reviewed regularly with these two goals in mind. Positive responses to both will enhance the standing of science.

NSF should have two goals.... One is to support first-rate research at many points on the frontiers of knowledge, identified and defined by the best researchers. The second goal is a balanced allocation of resources in strategic research areas....

3. The Commission strongly supports the initiation of proposals by investigators and selection of those to be funded by merit review carried out by experts. This method has proved to be the best way of tapping into the creativity of research scientists and engineers. Periodic examination of how to improve the functioning of the system is in order. The system, of course, must assure the selection of work of the highest quality and promise.

4. The NSB, the NSF, and the science and engineering community must better come to grips with the reality that many fields not covered by traditional disciplines offer challenges for new knowledge and opportunities for creative, investigative research worthy of the most gifted scholar. These fields should be valid candidates for support and may both yield key knowledge and enable timely response to national goals.

5. Since the private sector plays the major role in the translation of knowledge into new products and services, and since the speed and efficiency of this process is an important factor in a productive and growing economy, it is appropriate that the NSB involve the private sector more fully than heretofore in the decisions which affect the classes of

research allocation as well as some evaluation of the effectiveness of the expenditures. It is more than incidentally significant that scientific advances are as likely to be driven by advances in technology as the reverse, and the interplay between parties who are conversant in both fields holds promise of synergy.

Research Recommendations

Nature knows nothing about disciplinary boundaries.

1. The Board and Foundation's key role in the support of research in science and engineering should be strongly reaffirmed.

2. The NSB and the NSF should encourage interdisciplinary work and cooperation among sectors. Nature knows nothing about disciplinary boundaries.

3. There is a convergence between science and technology arising from technology today having a stronger basis in theory and data, which creates increased demand for research at every stage of the innovation process. Goals for science are, for the most part, necessarily long-term. However, new knowledge from fundamental research is important early-on, to the technical community, as a guide for anticipating future progress in technology and in the selection of strategies for future developments.

   Commercial technology is to a significant degree the result of the work of the NSF, although it is not what the NSF does. NSF and its research and education programs do have much to do with making possible new technologies.

4. It is urged that the size of NSF grants be examined. Many believe that on average, NSF individual research grants are too small. Examination of separate fields and wide consultation within the community would help in understanding the issues. We favor research grants sufficient to do the work for which the grant is awarded.

5. The management of NSF should from time to time review the make up and combinations of Directorates to maintain the most effective focus and management of the selection process, taking into account the evaluation of research, the desirability of interdisciplinary research, the needs of different types of research and efficiency of operation.

6. The diffusion and dissemination of the knowledge and skills derivable from scientific and engineering discoveries are important. Although complex, the system is working better than many presume. It works particularly well when university trained researchers and professionals move from position to position in academia or in industry.

   Dissemination is improvable by:

   a) further encouragement of cross-disciplinary collaboration;

   b) facilitating exchanges of people between universities, industry, and government;

   c) utilizing the collective advice of the scientists and engineers in industry, universities, and government agencies;

   d) support of research with active industrial participation;

   e) more effective circulation of scientific discoveries through publications, conferences and networking;

   f) continuing funding for the maintenance of and access to large scale data bases;

   g) development of information infrastructure, such as NSFNET, to facilitate communications, research collaboration, and remote access to shared resources and facilities.

7. The Foundation should more aggressively lead in communicating the "case" for science and engineering, which deserve a high priority in the mind of public officials and citizens alike.

   There is a widespread lack of appreciation of the complex interconnected processes by which new knowledge eventually leads to societal

benefits. This exists in the university and scientific communities as well as in the halls of government. The NSF should take the lead in interpreting this process to all of its publics.

8. The NSF should both set an example and work with others in fostering international cooperation and agreements for the most effective exchange of research results and for research collaboration. To do so is beneficial to all parties, as important discoveries can be made anywhere.

Undergraduate education is enriched by faculty participating in research.

9. Undergraduate education is enriched by faculty participating in research. Research is essential to preparing graduate students for scientific careers in academia, government, and industry.

   We endorse graduate fellowships and traineeships. Students are quite responsive to perceived national needs in their selection of fields of research. The involvement of underrepresented groups should continue to be vigorously encouraged.

10. Successful research requires increasingly sophisticated instrumentation and facilities. We urge the NSB to maintain surveillance over the state of these national resources and to work for a national plan to keep them adequate for the conduct of pioneering science and engineering.

Education Recommendations

1. A major priority for the NSB and the NSF should continue to be education in science and engineering.

   NSF's support of education has a cascading influence. The Foundation should be at the leading edge of ever-emerging improvements in curricula, and methodologies of teaching and training for research.

2. The NSF should encourage further development of joint science, engineering, and management education programs.

This recommendation complements our previous research recommendations, which call for recognizing the importance and equivalence of scholarly research in a broader range of fields.

3. The Foundation is chartered to support improved education in mathematics and science throughout all the school years, from kindergarten through graduate and post doctoral studies. The two most critical areas needing improvement are K-12 education and undergraduate education.

   K-12 education, which prepares both the workforce and pre-professional students, must continue to receive the Foundation's serious attention and be pursued in collaboration with the Department of Education and other involved parties.

   The Commission urges the NSF to persuade the scientific community to expand its commitments to improving the quality of undergraduate education in mathematics, science and engineering. Introductory courses, especially, need improvement.

   We take note of the fact that the system has no one single weakness. No single grade or class can be neglected, for students fall away from science at all stages of the educational process. As we work any stage of the system, we must appreciate consequences throughout the system.

Structural Recommendations

1. Measurement of systems generates improved quality of operations. We speak here of something more than accounting and accountability. All reasonable measurements of the quality of the output of research, the quality of research allocation and the other principal functions of the Foundation should be subject to rigorous and common sense metrics for the evaluation and increase in the quality of its activities.

   Enlightened universities are beginning to teach and apply such measurement systems and both of these should be encouraged openly by the Board of the Foundation.

2. NSF should continue to support shared, common use facilities that cannot be built and maintained by individual institutions. Such facilities make economic sense and are an essential part of the research infrastructure for many individual investigators.

The Stronger National Policy

THE COMMISSION URGES that the role of the NSF be further clarified within an overall national policy, the goal of which should be to maintain the premier position of U.S. science and engineering while regaining America's lead in the commercialization of technology.

The first general recommendation reads: "The United States should have a stronger and more coherent policy wherein science and engineering can contribute more fully to America's strength." A call of this nature is not new. The strategy has been voiced in many terms—national science policy, national technology policy, and others. We do not emphasize a title. But, we do advocate a broad national policy going beyond science and engineering and including technology and its applications. The policy should be responsive to the voice and needs of society. NSF, with its emphasis on research in science and engineering and its complementary emphasis on education for science and engineering, will play a major, direct, and cascading role in fulfilling the overall policy.

The NSB, in helping to develop a national science and technology policy, should move quickly to propose a role for the NSF based on its past mission and a vision of what is needed today. In this plan the NSF should build on its accomplishments and strengths, specifically its partnership with the scientists and engineers of the nation's colleges and universities in developing outstanding research and strong science education; its partnership with the Department of Education and state and local governments working to strengthen science education in grades K-12; and its role in maintaining the

nation's scientific infrastructure. The plan should include a response to the recommendations of this Commission in order to strengthen and make more effective the work of the NSF in meeting national goals.

We urge that the Board and those involved in the planning resist any pressures to strip the NSF of its full spectrum of research goals and linkage mechanisms, from engineering research centers, to computer networks, to pure science and mathematics. The great strength of American science and of American universities is the absence of rigid cultural barriers between science and engineering and between pure research and its applications.

The great strength of American science and of American universities is the absence of rigid cultural barriers between science and engineering and between pure research and its applications.

Throughout the report we have identified new challenges, evolving research fields, interdisciplinary opportunities, increasing dependencies among stages in technology development, grant size, student support, improved science education, knowledge diffusion and facility needs. The NSF will find it difficult to respond to these new challenges without an increase in resources, for the budget of the NSF already is inadequate to support its present responsibilities and programs.

Nevertheless, each recommendation is soberly, seriously and confidently proposed as being in the nation's best interest.

We are not unmindful that adoption of most of our individual proposals will increase the funds needed by NSF. We are equally mindful that controlled growth in federal funding and even deceleration of federal expenditures are options that must be considered by governmental officials and that policies to control spending need the support of the citizenry.

Yet, we do not equivocate in recommending each and the aggregate to the Board and through the Board to Congress, to scientists, to business constituencies, and to the broader public. Our recommendations are made in the spirit of continual improvement of a fine existing system.

Moreover, we are aware that the value of the output of the system can be multiplied within a "system of the whole" which would better make the essential linkages of education—discovery—development—application—competitiveness—quality of life.

To address this issue we urge that the NSF's responsibilities, as spelled out in its mission statement, and its budgetary needs be examined in the context of a newly conceived federal R&D budget that supports the stronger, broader policy. Reallocation of funds could achieve an energizing result that stimulates academic scientists and engineers, government officials, and people from industry to serve better the U.S. public. For we are convinced that ever improving universities and colleges and an ever more quality minded private sector working together can:

- ❖ lower the cost of improving the quality of life;
- ❖ add value throughout our society;
- ❖ create true wealth and opportunity for the country.

The hidden costs of not doing so may never be accounted for but would swamp the apparent cost of what is an energizing investment. So, we must get on with it.

However, all roads need not lead just to the public treasury. We have one additional suggestion—expanded contributions by business to complement public funding for selected science, engineering and technology programs.

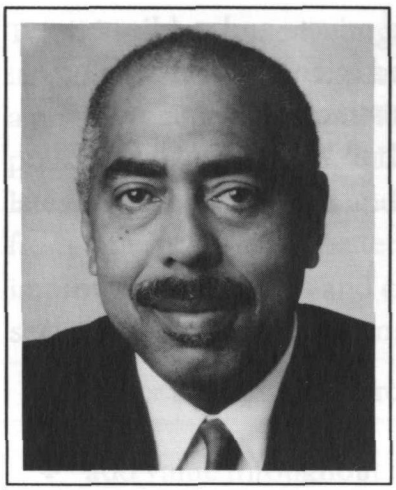
The Board and the National Science Foundation are today the lead organizations representing the interests of broad science and engineering in the United States.

It has been noted in other public documents that industry's basic research spending has lessened. Yet industry's spending for what is generally called R&D is substantial. Further, industry is moving to more affiliations—alliances, joint ventures, and consortia. Led and attracted by the visibility of a better integrated and more adequately funded government-university partnership, we see promise of a more willing contributing partner from among the progressive businesses of all sizes, including the smaller, higher growth companies where shared cost in programs with reasonable potential of eventual use would be welcomed.

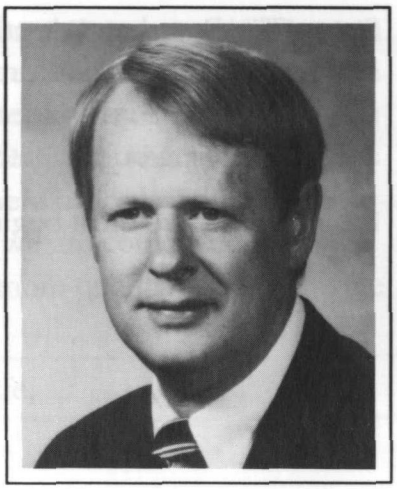
Finally, the Commission returns to the role of the Board in influencing a stronger science and engineering and technology policy for the Nation. The Board and the National Science Foundation are today the lead organizations representing the interests of broad science and engineering in the United

States. The Board must work with its peers in the private and public sectors so that the nation might formulate a much needed science and technology roadmap. We are convinced that students, scientists, engineers, industry, and the public would join together to build and build on that roadway.

It is a journey we must begin.



Walter E. Massey
Director
National Science Foundation



James J. Duderstadt
Chairman
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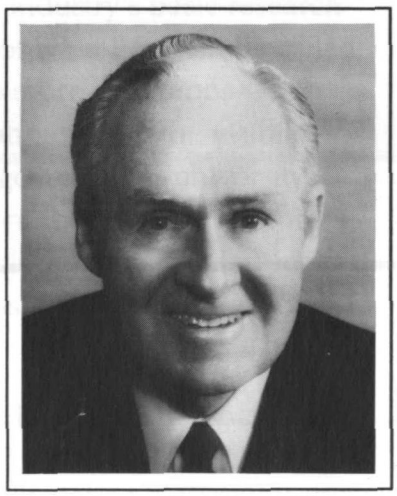

Robert Galvin
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