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ABSTRACT

The purpose of this volume is to provide or identify the major sources of information used by the National Science Board Committee in preparing its report: Four public hearings were conducted and testimony received from knowledgeable leaders in higher education, the scientific community, industry, and government. This volume is principally a compendium of the materials received. Sections include: (1) "Executive Summary"; (2) "Testimony Presented to the Committee at Public Hearings"; (3) "Additional Testimony Submitted to the Committee"; (4) "Correspondence from Federal Agencies"; and (5) "Bibliography and Sources of Information." (YP)

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Undergraduate Science, Mathematics and Engineering Education

Volume II
SOURCE MATERIALS

Role for the National Science Foundation and Recommendations for Action by Other Sectors to Strengthen Collegiate Education and Pursue Excellence in the Next Generation of U.S. Leadership in Science and Technology

National Science Board
NSB Task Committee on
Undergraduate Science and Engineering Education
November 1987

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Undergraduate Science, Mathematics and Engineering Education

Volume II
SOURCE MATERIALS

National Science Board
NSB Task Committee on
Undergraduate Science and Engineering Education
November 1987

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FOREWORD

The purpose of this volume is to provide or identify the major sources of information used by the National Science Board Committee on Undergraduate Science and Engineering Education in preparing its report, *Undergraduate Science, Mathematics and Engineering Education* The Committee was established in May 1985, and conducted its study from then until March 1986, when the report was accepted by the full National Science Board. The report itself (NSB 86-100) is available from National Science Foundation Publications, 1800 G Street, NW, Washington, D.C. 20550.

During its study, the Committee received information from many sources on the status and needs of U.S. undergraduate science, mathematics, and engineering education. Four public hearings were conducted and testimony received from knowledgeable leaders in higher education, the scientific community, industry, and government. The Committee studied a wide range of published reports and also received additional solicited and unsolicited material from numerous concerned individuals and organizations.

This volume is principally a compendium of the materials received. However, it should also be noted that many less formal but useful inputs were also received in the form of letters, telephone calls, and personal contacts. The Committee is most appreciative of the time and efforts expended by so many people in contributing to the report

The views and opinions expressed in these materials do not necessarily reflect those of the Committee, the National Science Board, or the National Science Foundation. However, it is the feeling of the Committee that these materials contain much useful information and reflect a broad cross-section of persons knowledgeable about undergraduate science, mathematics, and engineering education in the United States. It is hoped that this material not only will serve to establish documentation of the Committee's final report, but will be of assistance to others actively concerned with the quality of the nation's colleges and universities.

For the reader's further information, the report's Executive Summary is reprinted in this volume immediately following this foreword.

I. EXECUTIVE SUMMARY

Serious problems, especially problems of quality, have developed during the past decade in the infrastructure of college-level education in the United States in mathematics, engineering, and the sciences. Problems are occurring to a significant degree in all types of institutions, two-year and four-year colleges and universities, and in all regions of the country. Minority institutions continue to have serious difficulties. The broad areas of engineering, mathematics, and the sciences share many of these concerns, but each has some of its own. The problems of the engineering disciplines are especially severe. The impacts and the challenges and opportunities of the new technologies pervade all the disciplines.

The most striking and pervasive change of the 1980s—one that is fundamental and irreversible—is the shift to a global economy. The only way that we can continue to stay ahead of other countries is to keep new ideas flowing through research; to have the best technically trained, most inventive, and adaptable workforce of any nation, and to have a citizenry able to make intelligent judgments about technically based issues. Thus, the deterioration of collegiate science, mathematics, and engineering education is a grave long term threat to the Nation's scientific and technical capacity, its industrial and economic competitiveness, and the strength of its national defense.

The major objectives of the study reported here were assessment of the present character and condition of undergraduate education in mathematics, engineering, and the sciences, and determination of an appropriate role for the National Science Foundation in regard to its strength and improvement.

The Committee has concluded that the Foundation's role must be strong leadership of a nationwide effort, an effort that will require participation by public and private bodies at all levels. The Foundation must use its leadership and high-leverage programs to catalyze significant efforts in the states and local governments and in the academic institutions where ultimate responsibility lies. The recommendations of this report make renewed demands on the academic community—especially that its best scholarship be applied to the manifold activities needed to strengthen undergraduate science, engineering, and mathematics education in the United States.

The Condition of Undergraduate Education in Science, Mathematics, and Engineering

The United States has developed the most varied and extensive network of colleges and universities in the world.

In the fall of 1984, 10,700,000 undergraduates out of a total enrollment of over 12,300,000 students attended some 3,300 U.S. institutions of higher learning. Annual expenditures for higher education nationwide total $101 billion, of this, $42 billion are spent at the undergraduate level.

There are great institutions of higher education throughout the country. An inexpensive community college is within easy commuting distance of most citizens. Highly developed regional and state public universities are not much farther removed. Doctoral universities and private colleges are to be found in virtually every state in the Union. Taken together, these constitute a peerless system of higher education, affording opportunities to students with virtually every kind of academic interest.

It is in these institutions that the talents and values of future scientists, engineers, business leaders, doctors, lawyers, and politicians are developed. From them will emerge much of our future leadership at local, state, and national levels. The Nation depends in large part upon the graduates of collegiate institutions to assure its competitive edge in the world's economy and the strength of its national defense.

In 1983, the National Science Board Commission on Precollege Education in Mathematics, Science, and Technology reported on the character and condition of teaching and learning in those subjects in the Nation's schools. Partly in consequence of the Commission's findings and its report, states and municipalities have taken many steps in the intervening three years to correct the effects of previous neglect and to restore strength and vigor to school programs in science, mathematics, and technology. The Congress has approved and initiated several responses, including funding of a leadership role for the National Science Foundation in these improvement efforts.

The same concerns that led to these efforts to improve precollege education have caused steps to be taken to strengthen the flow of science and engineering research results from colleges, universities, and other research laboratories to the production and marketing sectors of the economy. **But attention has not yet been focused on the essential bridge between the schools and the national apparatus for research and development; that bridge is undergraduate education in mathematics, engineering, and the sciences.**

A few states have taken significant steps to improve the quality of instruction in the colleges and universities they support. Industry has given increased attention to science and engineering research and to graduate education, but private sector support of undergraduate education has not increased similarly.

Although the National Science Foundation for many years supported a number of substantial undergraduate programs, including both curriculum development and faculty enhancement, its present role in that area is very small and limited. There are fewer opportunities and incentives for faculty to contribute and compete on a national basis for support of scholarly and creative activities related to teaching than there are for research.

The evidence considered by the Committee and the observations of its members indicate clearly that the most serious deficiencies in undergraduate science, mathematics, and engineering education are in three areas. It is these three areas that require attention of the highest priority at this time—by the National Science Foundation and other federal agencies, by the several states, and by the private sector:

- *Laboratory instruction*, which is at the heart of science and engineering education, has deteriorated to the point where it is often uninspired, tedious, and dull. Too frequently it is conducted in facilities and with instruments that are obsolete and inadequate. (The needs for new instruments alone are estimated at \$2-4 billion.) It is being eliminated from many introductory courses. Much too little funding is available to support faculty with creative ideas for laboratory redevelopment.
- *Faculty members* are often unable to update their disciplinary knowledge continuously or maintain their pedagogical skills, and are largely unable to make skilled use of computers and other advanced technologies. In some fields there are serious shortages of qualified faculty.
- *Courses and curricula* are frequently out-of-date in content, unimaginative, poorly organized for students with different interests, and fail to reflect recent advances in the understanding of teaching and learning; the same is true of instructional materials now in use. Insufficient faculty energies are devoted to improving the quality of instruction and its appeal to any others than those enrolled as majors in their field.

These deficiencies contribute to trends in student performance and behavior that are adverse to the national interest: fewer students are choosing careers in science and engineering; certain specialties are not attracting the number or quality of entrants they need; enrollment in teacher education curricula in mathematics and the sciences is critically low; and the supply of well-qualified teachers for the schools is short.

The size of the 18- to 19-year-old age group will decline significantly in the next decade. Unless education in mathematics, engineering, and the sciences is made more effective for all students and more attractive to potential faculty members, and especially to the presently underrepresented (women, minorities, and the physically handicapped), both the quality and number of newly educated professionals in these important fields will fall well below the Nation's needs—with predictable harm to its economy and security.

There has been for a decade a steadily worsening shortage of qualified faculty in engineering schools. Mathematics began to experience the same disparity between collegiate faculty demand and supply over five years ago. More recently, a downturn in the rate at which science doctorates choose academic careers has been observed, suggesting that faculty shortages will soon characterize most of the fields in which the Foundation plays a role. These shortages will be exacerbated by the already discernible increase in retirement of faculty who were appointed initially during the enrollment expansions of the 1950s and 1960s. Those retirements are expected to intensify the general shortages of college and university faculty members projected for 1995-2010. **Since it takes at least nine years for a freshman student to become an appointable doctorate in most science and engineering fields, only immediate and sustained efforts to attract the brightest young people to the rigorous process of preparing for a faculty career can reduce the shortages that are sure to come.**

The Support of Undergraduate Education in Science, Mathematics, and Engineering

It is estimated that education in the United States at all levels will cost \$260 billion in 1985-86. Higher education will account for \$101 billion of that total; of that sum, \$42 billion will be expended on undergraduate education—\$12.4 billion in private institutions, \$29.5 billion in public colleges and universities. About one-half of the latter amounts will be devoted to science, mathematics, and engineering education.

Sources of support:

- *State funding* of higher education during the last decade has not kept up with cost inflation. Some states have established review bodies for education in mathematics, science, and technology education (as recommended in 1983 by the National Science Board Commission), but only in a few instances have statewide surveys been completed, needs determined, and new funding recommended.
- *Industrial and other corporate gifts* to education have increased in the past 15 years from 0.45 percent to 0.68 percent of pretax net income; they aggregated \$1.6 billion in 1984. The higher education share of this total is substantial, as is that of the technical fields, but industries have concentrated their support on graduate education and research linked closely to their interests.
- *Mission-oriented federal agencies* expend large sums in higher education, but primarily in direct support of basic research and graduate education. The *Depart-*

ment of Education with minor exceptions is mandated to concentrate its resources on entitlements, assistance to individuals, and formula-based distributions. Very little of its funds can be expended on flexible programming to improve undergraduate education in mathematics, engineering, and the sciences, and the agency does not have a history of strong linkages with the academic scientific and engineering communities.

- The bulk of the $1,500 million annual budget of the *National Science Foundation* is for the support of basic research at both doctoral and non-doctoral academic institutions. Some of this research involves undergraduate students, and affects their education directly. At present, two programs that specifically support undergraduate education in science, mathematics, and engineering are located in the Directorate for Science and Engineering Education. They are the College Science Instrumentation Program, budgeted at $5.5 million annually, and a teacher preparation program for future school teachers of mathematics and science, budgeted at $6 million per year.

The support from all sectors for undergraduate education in mathematics, engineering, and the sciences is inadequately responsive to either its worsening condition or the national need for its revitalization and improvement.

Recommendations to the States, Academic Institutions, the Private Sector, and Mission-Oriented Federal Agencies

The evidence before it leads the Committee to make recommendations beyond its original charge, which was to define an appropriate role for the National Science Foundation in undergraduate education in engineering, mathematics, and the sciences. The Committee believes that, realistically:

- *Responsibility for the academic health of undergraduate education resides primarily in the Nation's colleges and universities and their governing bodies. Responsibility for the financial health of the educational institutions lies primarily with states, municipalities, and the host of supporters of private higher education.*

  Most of the direct effort to reverse the downtrends of quality in undergraduate mathematics, engineering, and science education must be made at the state and local levels of government and in the private sector. Those are the places where educational policy is made and the basic financial support for higher education is marshalled.

- *The National Science Foundation cannot assume responsibility for the financial health of higher education, even in the sciences and engineering. But, the Foundation can and should expand and establish programs that assist the restoration of academic health to undergraduate education in the fields within the domain assigned to it.*

  The Foundation's leadership should emphasize provision of incentives, quickening of motivation, and the partnership of the states, educational institutions, and many private sector entities in the extensive and sustained efforts that will be required.

The Committee recommends:

To states:

1. Establishment of undergraduate science, mathematics, and engineering education as a high priority of essential importance to the economic, social, and cultural well-being of their citizens.
2. Timely and responsive consideration by legislatures of recommendations for improvement of undergraduate mathematics, engineering, and science education in two-year and four-year colleges and in universities.
3. Enactment of special legislation aimed at achieving national norms for a minimum level of support for laboratory instrumentation (amounting to $2,000 per engineering or science graduate per year, as recommended by bodies such as the National Society for Professional Engineers).
4. Careful long-range planning for the renewal of facilities, equipment, and other physical resources
5. The creation of special educational commissions or review bodies (if they have not already been appointed) to determine conditions and needs in undergraduate education in science, mathematics, and engineering in their states, to help set goals and objectives, and to recommend ways and means.

To academic institutions:

1. Achievement of the investments of faculty, physical facilities, and financial resources per student necessary for high-quality undergraduate education in science, engineering, and mathematics through internal prioritization and allocation.
2. Development of both short-range and long-range plans for modernization of undergraduate instructional and research equipment.
3. Careful long-range planning for the renewal of facilities, equipment, and faculties.
4. Strong support of faculty efforts to update and upgrade courses and curricula designed to meet the needs of both majors and non-majors.
5. Increased participation by all faculty, including research faculty, in the instruction of undergraduates and in other efforts to raise the quality of their educational experience.

6. Joint efforts with other institutions to improve the school-to-college, two-year to four-year college, and undergraduate-to-graduate transitions.
7. Expansion of partnerships in education with industries and other organizations in the private sector.

To the private sector:

1. Greater and more stable support for undergraduate education in mathematics, engineering, and the sciences.
2. Expanded partnerships with colleges and universities in efforts to improve preprofessional education.
3. Increased corporate efforts to improve the public understanding of science and technology.

To mission-oriented federal agencies:

1. Those federal agencies with strong basic and applied research components (e.g., NASA, DOD, DOE, and NIH) should continue their graduate-level programming and expand their efforts to involve undergraduate faculty and students in their research activities.
2. Those agencies also should consider providing incentives to contractors and grantees for appropriate inclusion of undergraduate components in their work.
3. The Department of Education and the National Science Foundation should collaborate in a major effort to correct the causes in schools of the steadily increasing demand for remedial mathematics and science instruction in colleges and universities.
4. The Department of Education and the Foundation should develop jointly, for college-level instruction in engineering, mathematics, and the sciences, data collection and analyses that will reveal trends in student achievement nationwide.

Recommendations to the National Science Foundation

Current national policy and federal strategy recognize that education in science, engineering, and mathematics is critical to the economic vitality and security of the Nation. Accordingly, heavy investments are being made in graduate education and research, and strong programs have been initiated to improve the effectiveness of precollege education. Now, sound national policy requires that the strategy be made complete by supporting the revitalization and improvement of *undergraduate* education in science, mathematics, and engineering.

The enabling legislation for the National Science Foundation obligates it to take leadership of efforts to revitalize and improve undergraduate mathematics, engineering, and science education in the United States.

In support of these objectives, the Foundation should concentrate on key undergraduate programs that emphasize motivation and initiative for needed change, leverage its resources, and make use of its historic relationships with the science and engineering research communities. These programs should build upon the Foundation's present activities to improve precollege science and mathematics education.

The Committee anticipates that by no later than 1989 implementation of its recommendations will have established a permanent Foundation presence in undergraduate mathematics, engineering, and science education comprising:

- *A comprehensive set of programs to catalyze and stimulate national efforts to assure a vital faculty, maintain engaging and high-quality curricula, develop effective laboratories, and attract an increasing fraction of the Nation's most talented students to careers in engineering, mathematics, and the sciences; and*
- *A mechanism to systematically inform the Nation of conditions, trends, needs, and opportunities in these important areas of education.*

The Committee's specific recommendations for action by the National Science Foundation fall into two categories: leadership and leveraged program support.

Leadership. *The National Science Foundation should take bold steps to establish itself in a position of leadership to advance and maintain the quality of undergraduate education in engineering, mathematics, and the sciences.*

The Foundation should:

1. Stimulate the states and the components of the private sector to increase their investments in the improvement of undergraduate science, engineering, and mathematics education and provide a forum for consideration of current issues related to such efforts.
2. Implement new programs and expand existing ones for the ultimate benefit of students in all types of institutions.
3. Actuate cooperative projects among two-year and four-year colleges and universities to improve their educational efficiency and effectiveness.
4. Stimulate and support a variety of efforts to improve public understanding of science and technology.
5. Stimulate creative and productive activity in teaching and learning (and research on them), just as it does in basic disciplinary research. New funding will be required, but intrinsic cost differences are such that this result can be obtained with a smaller investment than is presently being made in basic research.
6. Bring its programming in the undergraduate education area into balance with its activities in the precollege and graduate areas as quickly as possible.
7. Expand its efforts to increase the participation of women, minorities, and the physically handicapped

in professional science, mathematics, and engineering.

8. Design and implement an appropriate database activity concerning the qualitative and quantitative aspects of undergraduate education in mathematics, engineering, and the sciences to assure flexibility in its response to changing national and disciplinary needs.
9. Develop quickly an appropriate administrative structure and mechanisms for the implementation of these and the following recommendations. The focal point should be the Directorate for Science and Engineering Education; it should foster collaboration among *all* parts of the Foundation to achieve excellence in science, mathematics, and engineering education.

Leveraged Program Support. *The Committee recommends that National Science Foundation annual expenditures at the undergraduate level in science, mathematics, and engineering education be increased by $100 million.* Such an enhanced level of expenditure would be consistent with the funding goals recommended for NSF precollege activities by the NSB Commission on Precollege Education in Mathematics, Science and Technology ($175 million), and with the level of present Foundation support of research ($1,300 million).

The Committee intends that the programs it recommends be highly leveraged. Initially, "upstream" participation in financial support—e.g., through matching—will be required in many areas. This kind of leveraging is specific and quantifiable; for example, the College Science Instrumentation Program generated in 1985 contributions from awardee organizations that exceeded the federal funds made available. The Committee fully expects these programs will exhibit strong leverage "downstream"—that their influence on the quality and scope of education will be very great. An example of downstream leveraging is the computer language BASIC, developed under an award from NSF.

The following items list the program areas of highest priority and indicate the distribution of funds appropriate to their complementary and interactive character:

1. Laboratory Development .... $20 million
   (supporting development projects to improve the laboratory component of science and engineering instruction)
2. Instructional Instrumentation and Equipment .... $30 million
   (encouraging and supporting joint efforts to remedy the serious deficiencies of instructional instrumentation and equipment)
3. Faculty Professional Enhancement .... $13 million
   (stimulating new ways and sharing the support of the best new and traditional ways of improving the professional qualifications of college and university faculty members)
4. Course and Curriculum Development .... $13 million
   (encouraging and supporting efforts to improve the ways in which technical knowledge is selected, organized, and presented)
5. Comprehensive Improvement Projects .... $10 million
   (addressing several of the above priorities simultaneously in a single institution, or across a given discipline, or in a combination of these through consortial efforts)
6. Undergraduate Research Participation .... $ 8 million
   (stimulating and supporting the involvement of advanced undergraduate students in research in their colleges and in other places with programs of technical investigation)
7. Minority Institutions Program .... $ 5 million
   (strengthening the capability of minority institutions to increase the participation of minorities in professional science, mathematics, and engineering)
8. Information for Long-Range Planning .... $ 1 million
   (collecting, studying, and analyzing information and data on undergraduate education in science, engineering, and mathematics to assist long-range Foundation planning; this funding would include an appropriate level of collaborative work with the Department of Education and other major data sources)

This increase of $100 million, although insufficient to solve all of the problems of undergraduate science engineering, and mathematics education in the United States, can cause truly significant, positive changes. In constant dollars, the proposed programming is not far short of the level of the Foundation's undergraduate activities in the late 1960s. Review of these programs indicated that many of them had strong positive influence on the quality of undergraduate education, and *that* experience provides assurance that this proposed level of activity can be effective.

The levels of funding described above assume that other federal agencies will continue and expand their present support of undergraduate education, that the Foundation's efforts will stimulate the very much larger necessary expenditures by states and municipalities, and that the private sector will make an appropriate response to the national needs described in this report. We believe that a proper response to this effort by the National Science Foundation will require additional annual expenditures of sums aggregating $1,000 million by states, municipalities, other agencies of the U.S. Government, industry, and other parts of the private sector.

The Committee recommends that this comprehensive program at the undergraduate level be funded and implemented as quickly as possible. Because the program elements are complementary and interactive, their implementation will have the greatest beneficial impact if done in parallel.

We are recommending additional funding of $100 million a year. In addition to the $13 million support included in the Foundation's *FY 1987 Budget Estimate to Congress*, a viable set of program activities requires $50 **million in new funds for fiscal year 1988; attainment of a total of $100 million in new funds by fiscal year 1989** will permit a frontal attack to be made on the problems that the Committee has identified.

We make these recommendations of funding levels in full knowledge of the current federal budget exigencies, including the possible effect of the Gramm-Rudman-Hollings Act. The Committee believes the mix and balance of programs described above to be sufficiently important that they should be initiated within the existing Foundation resources rather than wait until incremental funds are made available.

The following brief tabulation summarizes the Committee's proposals for the distribution of new funds. The entries in the table show the phasing in of specific program funding and reflect the priorities of the Committee.

Examination of this table in the light of the findings and conclusions of this report reveals the imbalance and lack of synergism even at the $50 million level of additional funds. Nevertheless, the effects of built-in leveraging will permit a reasonable attack to be made on certain problems. But, it is only at the recommended $100 million level of additional expenditure that this leveraging from state and local, public and private sources results in a strong *nationwide* effort that can *solve* these problems.

NSF Budget Estimate FY 1987 $13	Program (short title)	Recommended Funding Above FY 1987 Budget Estimate: FY 1988 $50	FY 1989 $100
—	Laboratory development	10	20
2	Instrumentation	10	30
7	Faculty enhancement	10	13
—	Course and curriculum	7	13
—	Comprehensive improvement	—	10
4	Undergraduate research	8	8
—	Minority institutions	5	5
—	Planning	—	1

Dollars in millions

The Committee considered carefully, within its charge, a number of educational needs to which it does not at this time assign high priority for NSF funding. Among such needs are: construction and remodeling of facilities; student loans and scholarships; and programs to assist faculty members to earn advanced degrees. All of these (and many others considered by the Committee) are meritorious and would assist progress toward the principal objective addressed in this report—improvement of undergraduate education in science, mathematics, and engineering. However, they all have the character of capital—not catalytic—investments. The Foundation must limit its role to leadership and catalysis; basic capital expenditures in pursuit of these national educational goals must be made by state and local governments and by the components of the private sector.

The Committee carefully considered groups and institutions with special needs in arriving at its recommendations for programs and funding. We recommend that special needs be met within the programs described above, utilizing NSF's Review Criterion IV as is done in the other regular support programs. With these considerations in view, we stress the following three recommendations that cut across the areas just described:

1. *Increased participation of women, minorities, and physically handicapped.* NSF should actively seek this goal in implementing the above recommendations, including program management and proposal review, and in the projects that are supported.

2. *Institutional diversity.* The Committee believes that the diversity of institutional types in the United States is a strength to be nurtured. Care should be exercised to assure that high-quality projects are supported at all types of institutions. It is important to utilize and motivate the best and most talented faculty at all institutions to strengthen the instructional component of higher education.

3. *Engineering education and new technologies.* The Committee recognizes the current extraordinary levels of concern and need in the various fields of engineering. The impact of the new technologies (e.g., computerization and biotechnology) on all fields is great also. Accordingly, it recommends that the programs initially target their support heavily in these areas.

Review of the appropriateness of support distribution across the disciplines and in the other areas of special need should be a continuing concern of the Directorate for Science and Engineering Education.

The Committee emphasizes the importance of educational and scientific merit as established by the peer review process in the selection of projects for support under programs developed in response to these recommendations. Such projects must meet the traditional standards of quality and excellence demanded by the Foundation.

The Committee recommends that the Director of the National Science Foundation move to implement the program and action recommendations contained herein. A detailed plan for both the leadership and the program activities, including an administrative structure, within

the Directorate for Science and Engineering Education, program descriptions, guidelines, etc., should be completed in time to permit the program to be initiated during fiscal year 1987.

Finally, the Committee recommends that responsibility for monitoring the implementation of this report be assigned to the National Science Board's Committee on Education and Human Resources.

Conclusion

The principal charge given to the Committee by the Chairman of the National Science Board was ". . . to consider the role of the National Science Foundation in undergraduate science and engineering education." This report defines a role that is both appropriate to NSF's mission and responsive to the Nation's needs. It also urges needed actions by other sectors, both public and private.

The Committee believes that NSF should be a significant presence in undergraduate science, mathematics, and engineering education. But the greatest efforts must come from the people directly responsible for the health of colleges and universities. The Federal Government, in general, and the National Science Foundation, in particular, cannot and should not be looked to for the substantial continuing infusions of resources that are needed.

Undergraduate education occupies a strategically critical position in U.S. education, touching vitally both the schools and postgraduate education. We hope that this report will contribute to the resurgence of quality throughout higher education that is essential to the wellbeing of all U.S. citizens.

II. TESTIMONY PRESENTED TO THE COMMITTEE AT PUBLIC HEARINGS

The Committee conducted four public hearings from September to December 1985. The following individuals presented testimony at those hearings:

September 26, 1985

- Joseph M. Ballantyne, Vice President for Research and Advanced Studies, Cornell University
- Thomas W. Cole, Jr., President, West Virginia State College
- Richard J. Gowen, President, Dakota State College
- Bernard J. Luskin, Executive Vice President, American Association of Community and Junior Colleges
- S. Frederick Starr, President, Oberlin College
- Jon C. Strauss, President, Worcester Polytechnic Institute

October 16, 1985

- John P. Crecine, Senior Vice President for Academic Affairs, Carnegie-Mellon University
- M. Richard Rose, President, Rochester Institute of Technology
- David P. Sheetz, Vice President and Director of Research and Development, Dow Chemical Company
- John S. Toll, President, University of Maryland
- Paul R. Verkuil, President, College of William and Mary
- Betty M. Vetter, Executive Director, Scientific Manpower Commission

November 20, 1985

- Jean E. Brenchley, President-Elect, American Society for Microbiology
- Edward E. David, Member, White House Science Council
- Anthony P. French, President, American Association of Physics Teachers
- Fred W. Garry, Vice President for Corporate Engineering and Manufacturing General Electric Company
- Andrew M. Gleason, Professor of Mathematics, Harvard University
- David T. McLaughlin, President, Dartmouth College
- William G. Simeral, Executive Vice President, E. I. du Pont de Nemours and Company
- Lynn A. Steen, President, Mathematical Association of America
- Robert R. Wilson, President, American Physical Society

December 20, 1985

- Terry L. Gildea, Technical Training Manager, Hewlett-Packard
- Samuel Goldberg, Program Officer, Alfred P. Sloan Foundation
- Frederick Humphries, President, Florida A&M University
- Philip H. Jordan, Jr., President, Kenyon College
- Timothy O'Meara, Provost, University of Notre Dame
- Kenneth Starr, Director, Milwaukee Public Museum

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UNDERGRADUATE SCIENCE AND ENGINEERING EDUCATION IN A LARGE PRIVATE RESEARCH UNIVERSITY

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A number of strong factors for change have had major impacts on undergraduate education at Cornell and similar institutions during the last 20 years. These factors include:

- Curtailment of federal support for construction of research buildings;
- Shifting enrollment trends among disciplines, especially engineering;
- A push toward excellence in research;
- The phase-out of several National Science Foundation programs for support of undergraduate education in science and engineering;
- The general acceleration of technological change occurring in the country, including the availability of computers and an increase in interdisciplinary studies; and
- The relatively more austere climate for research funding at universities in the seventies as compared to the sixties.

I will discuss some of the above issues as they relate to the three major needs we at Cornell see for undergraduate education in the sciences and engineering: improved facilities, curriculum improvements, and increased numbers of faculty.

In this discussion, I will take the point of view that is most familiar to me, which stems from the environment of Cornell University. In doing so, I anticipate that other universities with characteristics similar to Cornell may be facing similar problems.

Cornell is a comprehensive, major research university of the first rank which offers the Ph.D. degree in 88 different fields and includes the following academic colleges: Agriculture and Life Sciences, Human Ecology, Veterinary Medicine, Industrial and Labor Relations, Arts and Sciences, Engineering, Architecture, Art and Planning, Hotel Administration, Johnson Graduate School of Management, Law, and Medicine. The University enrolls about 12,000 undergraduate students and 5,000 graduate students, and has a faculty of 1,500. The first four colleges enumerated are part of the State University of New York and, hence, have characteristics similar to those possessed by state universities, the other colleges enumerated are privately endowed. With the exception of the biological sciences, which are spread among the statutory and private colleges, the other physical sciences, mathematics, and engineering all reside in the endowed side. In its selection of students, Cornell also resembles more a private university than a public one. The enrollment of 12,000 undergraduate students has been essentially constant for the last 20 years. The Graduate School enrollment and the faculty size have shown an overall modest increase of one or two percent per year, with larger increases in selected fields.

The University is one of the major research institutions in the country, with research expenditures exceeding $200 million in the 1984–1985 fiscal year. It also has an emphasis on quality undergraduate education, and it is among the most selective undergraduate institutions in the country. The basic sciences at Cornell—biology, chemistry, physics, and mathematics—have been excellent throughout recent history. On the other hand, the Engineering College, which is among the three or four largest private colleges of engineering in the country in terms of student enrollment, has returned to a position of national prominence and excellence in research only recently. At the end of World War II, the Engineering College was primarily an undergraduate college. Since that time, it has developed into a major research college while maintaining a large undergraduate student body and a strong emphasis on quality undergraduate education.

Against the foregoing background, I will discuss the three needs that we see for improved undergraduate education in the sciences and engineering at our institution. While these needs for facilities, curriculum improvement, and faculty are common to both the sciences and engineering, the relative priorities are substantially different between the sciences and engineering.

Facilities

From the point of view of the entire University, improved facilities are our greatest need for improved undergraduate education. However the types of facilities needed vary with the discipline. In engineering, the greatest need is for more instructional space, particularly teaching laboratories. This is a consequence of the strong growth in research that has occurred in the Engineering College over the past three decades. The Engineering College occupies a physical plant that was, for the most part, constructed in the mid-1950s. When constructed, this plant was an excellent one for undergraduate instruction, but it did not contemplate any major research activity. The strong growth in research that occurred in the college has resulted in the conversion of what were formerly teaching labs into research laboratories. In addition, student enrollments on both the undergraduate and graduate levels have soared while faculty size has remained fairly constant. The combined forces of increased pressure on faculty (from both increased research and more undergraduate instruction) and space pressures due to expansion of research have resulted in the demise of laboratories formerly used for teaching purposes.

I will use the School of Electrical Engineering as an example of the most critical problems in the college. In the last two decades, four major teaching laboratories were discontinued: the communications laboratory, the senior projects laboratory, the master of engineering design laboratory, and the plasma laboratory. These laboratories constituted roughly one-third of all the undergraduate teaching laboratories in Electrical Engineering. In addition, the required junior laboratory now occupies less than one-half of the space it did originally, yet services triple the enrollment. The amount of laboratory instruction per week in this course was reduced from five hours to three hours to help accommodate the increased load.

The School of Electrical Engineering occupies roughly the same physical space today as it did when it moved into its new building in 1955. During this period, the undergraduate enrollment has increased by a factor of three, the master of science enrollment has increased by a factor of three, the Ph.D. enrollment has increased from two or three to over 100, the amount of research funding has increased by orders of magnitude in real terms, and the faculty size has increased about 10 percent.

A major reason for the crowded facilities in Electrical Engineering was the phase-out of federal support for construction of research facilities in the late sixties. This has had a severe impact on engineering, but a less severe one in the physical sciences. New research buildings in the physical sciences were constructed at Cornell in the sixties while federal funding was still available, but this source of funding was not available in the late seventies when it became painfully apparent that a major research plant was needed for the College of Engineering. Hence, federal funds for the construction of research facilities would serve in a major way to upgrade the quality of undergraduate instruction by freeing badly needed space for teaching laboratories.

Another category of facilities need is brought about by the emergence of new technologies including computer-aided teaching and video. An example is the recent experience of Professor Hubbard in our Department of Mathematics who has been a pioneer in developing new "experimental" techniques for teaching undergraduate mathematics using computers. The faculties in mathematics, engineering, and the physical sciences at Cornell are excited about the innovative techniques Professor Hubbard has developed. A major publisher is interested in handling a book that he is preparing to describe his new methods. However, the publishers have indicated that he should not waste his time developing modules for computer-aided instruction to go along with the new book, since the availability of Macintosh personal computers in the academic world is so minimal as to constitute a negligible market for any such educational material. While Professor Hubbard has been able to implement his computer-aided teaching methods at Cornell due to generous corporate donations of equipment, other institutions have apparently been less fortunate and are not able to utilize such teaching methods in their mathematics courses. Federal support for such teaching facilities is sorely needed throughout the country.

The final category of needed facilities is laboratory equipment. In this area, the sciences and engineering share common needs. Because of its stature, Cornell has probably been relatively more fortunate in attracting corporate gifts of laboratory equipment than have many other schools. One of the departments that has greatly benefited from such corporate gifts is our School of Electrical Engineering. Gifts of new instructional equipment worth several hundred thousand dollars per year have not been uncommon in recent years. These gifts have been stimulated by the tax incentives offered to equipment manufacturers. Even so, the teaching labs in Electrical Engineering still make regular use of instruments manufactured in 1920, oscillators manufactured in 1940, microwave equipment manufactured in 1955, oscilloscopes manufactured in 1962, and computers manufactured in 1970. It is evident that the corporate generosity has not been sufficient to fill the full need for modern teaching laboratory instrumentation. Because the major source of new teaching equipment has been corporate gifts, and there is no regular university budget to the College of Engineering for equipment in undergraduate teaching laboratories, strong equipment needs remain. This shows up most particularly in courses such as the discontinued senior projects laboratory, which had as one objective the provision of a flexible environment where students could design their own experiments. In this type of laboratory, a wide variety of equipment is needed, quite a bit of which is made by small companies. These small companies have not been active in giving donations since their profits and taxes are not large and the tax incentives are not substantial. There is, therefore, a great need for a federally funded program to supply instructional equipment for undergraduate teaching laboratories. Such a program would encourage substantially more innovation in the design and construction of new laboratory courses than presently exists.

Curriculum Improvement

Since the phase-out of NSF programs to support innovation in undergraduate science and engineering teaching, there has been a marked decline at Cornell in the number of such programs. The normal avenues of change are small amounts of released time for faculty to prepare new courses and texts and a sabbatical every seventh year for college and university faculty to renew themselves. These avenues were sufficient in a period without exponential growth rates in research and knowledge, but are insufficient to renew the teaching of science and mathematics in engineering at present. In the 1960s, "after Sputnik," the National Science Foundation issued grants providing released time for research university faculty members for preparation of new course materials. NSF also gave grants to universities for retraining teachers. Universities selected these teachers by open advertised competitions. Similar efforts are needed now. Funded released time is required for those faculty in research universities willing to prepare new course material. Money for programming aid is needed for preparation of new computer modules that go with them. Since the phase-out of NSF programs, we have seen a decrease in the flow of new educational materials from the research universities.

Funded non-sabbatical leave is needed to allow undergraduate science, engineering, and mathematics teachers to return to research university environments long enough to pick up needed subjects that they never had in school, now necessary to be introduced into their own undergraduate curricula. One model is provided by a Dana Foundation grant to the Cornell Department of Mathematics. Under this grant, professors of undergraduate mathematics at liberal arts colleges come to Cornell and teach two freshman calculus courses per term. In return, the University allows them to take courses in applied mathematics, statistics, and computer science to upgrade their teaching skills in these areas. The Dana Foundation pays a half salary for each participant, and the University grants tuition relief. This has allowed Cornell to change its calculus program from large lectures to small sections, each enrolling about 20 students, with the Dana fellows as teachers. In addition, the Dana fellows obtain the new knowledge they need. In the case of the present six fellows, two who have Ph.D.'s in mathematics will receive Master of Engineering degrees in Computer Science as a result of participation in this program.

Some of the burden for curriculum improvement that NSF formerly assumed has, therefore, been assumed by foundations like the Dana Foundation and also by corporate initiatives such as the IBM-sponsored Project EZRA at Cornell. Under the latter, IBM donated 500 personal computers to the University. These were given on a competitive basis to departments in response to proposals for their use in innovative ways to develop new undergraduate educational materials. They are used broadly throughout the University and are not restricted to the sciences and engineering.

However, foundation and corporate support is not enough. One element that is missing is a competitive focus for individual professors to seek funds for new teaching ideas. Also missing is the visibility provided by the competitive process. At a place like Cornell, the worth of a faculty member is often judged by his or her success in the competitive process of seeking research grants A national competitive process for seeking funds for innovative teaching and curriculum improvements would also give young faculty visibility and "credit" in the tenure process. Without this visibility and credit, there is less incentive for faculty at institutions like Cornell to participate in innovative teaching activities. Another element that is missing when a competitive federal program leaves is the general requirement for some institutional matching. Matching is an effective lever to pry funds away from other priorities. In its absence, funds that might be used for innovative teaching get diverted to match programs in other areas such as research.

Faculty

Shortage of faculty makes a critical impact on the quality of undergraduate teaching in engineering, but is less of a problem in the sciences. This is due to two kinds of shifts involved in engineering: (1) shifts of undergraduate student majors from other fields into engineering and (2) shifts of students from one engineering field to another.

In the first case, statistics show that on a nationwide basis, undergraduate enrollments in engineering have nearly doubled since 1965. In the period from 1976 to 1982, the number of undergraduate students in engineering increased by over 50 percent in 51 large engineering schools, while, during the same period, the engineering faculties increased less than 10 percent. This is a problem for most universities. It has not been a problem at Cornell because each college has a strict quota on its undergraduate enrollment, and the number of undergraduates in engineering at Cornell has not changed materially over that six-year period.

The second type of shift, however, the shift of students from one field of engineering to another, did occur in the College of Engineering at Cornell, recreating severe problems. Cornell has maintained the flexibility of an admitted student to choose freely his area of major within the Engineering College. This has resulted in massive shifts of students into electrical engineering. As an example, the School of Electrical Engineering currently awards about five bachelor of science degrees each year per faculty member. The School of Civil Engineering currently awards about one bachelor's degree per faculty member per year. In the School of Electrical Engineering, there are

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no multiple sections taught of any class with an enrollment under 250 students. Most senior electives enroll over 100 students, and required courses enroll 200 students. Graduate courses in popular fields enroll 75 to 100 students. In the sub-area of computer engineering, all graduate courses are larger than 50 students. The large class sizes are ameliorated somewhat by a policy of having recitation sections enrolling about 30 students each for such large undergraduate classes. Each recitation section is taught by a faculty member. However, there is no doubt that the large class sizes have caused a deterioration in the quality of the undergraduate instruction and have led to an absolute halt on acceptance of transfer students into the School of Electrical Engineering at Cornell.

Such a situation poses difficulties for the Dean of the College. It is not possible to shift tenured faculty from the School of Civil Engineering into the School of Electrical Engineering, yet major infusions of faculty are needed in fields such as electrical engineering and computer science. One solution to this problem may be to recruit qualified engineers in industry to teach for short periods at universities. A federal program to pay the salaries of such short-term teachers from industry would be a major help in alleviating the faculty shortage in a few critical fields. Other programs already in place such as the Presidential Young Investigator awards should be preserved and strengthened, since they materially enhance the attractiveness of an academic career to young faculty members.

While the faculty shortage in the sciences and mathematics is not as severe as that indicated above, a program like the one funded at Cornell in mathematics by the Dana Foundation should be instituted on the national level in the sciences. This would have the effect of increasing the quality of undergraduate instruction in the research universities by allowing either small class sizes or faculty released time to prepare innovative teaching materials. It improves the quality of undergraduate education at the smaller schools by upgrading the skills of their faculty.

Summary and Recommendations

There has been a reduction in the amount of innovative educational material for undergraduate instruction coming from first rank research universities. This is probably due in part to the removal of the competitive incentive and recognition inherent in federally sponsored programs for curriculum improvement and by the loss of "leverage" that such programs provide. A relatively small amount of federal funding could have a marked effect in this regard. For example, at Cornell University, I estimate that federal funding of the order of $500,000 per year for curricular improvements would have a very substantial effect on the production of new teaching materials and on the visibility accorded to curricular innovation at the undergraduate level in engineering and science.

I recommend the following:

1. Federal programs to provide funding for construction of science and engineering buildings should be strengthened. These would strengthen undergraduate education by relieving pressure on such facilities created by research expansion and by providing modern teaching facilities that incorporate video, computer aids, and so forth.
2. Federal programs to support innovative curriculum development by paying faculty salaries for released time (and other costs such as program support and publication costs) should be developed. Programs that fund the salary of undergraduate science teachers to work for a one-year period at a research institution should be instituted. These programs would improve the quality of undergraduate instruction at both the research universities and the primarily undergraduate institutions.
3. The federal program to provide equipment for teaching laboratories in science and engineering should be reinstituted, and it should include equipment for computer-aided teaching in classrooms.
4. A federal program of paid leaves to support engineers in industry while they teach in engineering fields that are suffering critical faculty shortages should be instituted.

The reinstitution or creation of the above federal programs to support undergraduate education in science and engineering would have a major salutary effect on the health and vitality of the educational function in these fields. The annual costs need not be great, and would probably not exceed the price of one or two large airplanes for the Department of Defense. Such a modest redirection of funding would have a major qualitative impact on future generations of engineers and scientists.

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Conditions and Trends in U.S. Undergraduate Science and Engineering Education: Perspective of Academic Institutions

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I am a graduate of Wiley College, a historically Black private liberal arts college in Texas, and I received the Ph.D. in organic chemistry from the University of Chicago. I was a member of the faculty at Atlanta University for 16 years with intervening appointments as visiting professor at the University of Illinois (Urbana-Champaign) and the Massachusetts Institute of Technology. At Atlanta University, I served as Vice President for Academic Affairs and Provost and Director of the first Resource Center for Science and Engineering established by the National Science Foundation before assuming the presidency of West Virginia State College in March 1982. I am also a member of the NSF Committee on Equal Opportunities in Science and Technology (CEOST). I am here today, however, in my capacity as college president. The views I express do not represent the position of NSF CEOST or any particular group or organization. They are a reflection of my own experience as an undergraduate chemistry major, a faculty member who has taught at the undergraduate and graduate levels, and a president of an undergraduate college that is one of four Historically Black Institutions (HBIs) that now has a predominantly white student body.

I want first to commend the National Science Board for convening these public hearings to assess the condition of undergraduate science and engineering education in the nation's colleges and universities. I have long felt that National Science Foundation support programs at the undergraduate level have not kept pace with the attention given to the precollege and graduate levels, and the quality of undergraduate education has suffered as a consequence.

I am impressed by the array of questions raised by this Committee. I am tempted to respond to most of those in which I have a particular interest. However, I will confine my remarks to two broad areas and respond to other issues if time permits.

Frank Newman, in yet another report on American higher education, states:

> ". . .the American system of higher education is the best in the world . . . . American higher education must be even more effective if it is to meet the needs of this country in the decade ahead . . . The most critical demand is to restore to higher education its original purpose of preparing graduates for a life of involved and committed citizenship. It is a need which arises from the unfolding array of societal issues of enormous complexity and seriousness—issues such as, how to accelerate the integration of growing and diverse minorities, how to control the continuing proliferation of nuclear arms, how to reduce the dangers of toxic wastes . . . and fashion solutions acceptable to the community. Colleges and universities must be willing to examine how successful each is in meeting the goals espoused for truly effective liberal education, for active involvement of students in their own learning, for the development of research and technology that is at the cutting edge of world scholarship . . . . At stake is the fundamental issue of the place of the United States in the world."

I cite this report, not because it uniquely presents all the issues of importance in a national debate on American higher education, but because it does raise questions of interest to this Committee in its deliberations on undergraduate science and engineering education. The Newman report cites several assumptions about higher education that need to be refocused, two of which are relevant to my remarks. The first is access.

> "Many assume that the great gains in broadening access to higher education made in the 1960s and 1970s have done the job. But concern for access must include concern for outcomes as well. Both economic development and civic integration require the full participation of more than just an elite, particularly just a white elite. The enduring and honorable American tradition of opportunity must function for the whole of the population. This requires higher education to do a better job of drawing people from all segments of society into those programs that lead to positions of leadership in the life of the country."

The second is expertise:

> "The economic times have changed. Ours is a more technological, more international, but most of all

more dynamic world. This country's ability to compete and to lead is dependent on the nature and quality of higher education. Much of the focus until now has been on the needs for greater expertise but it is clear that technical expertise alone is not enough The graduates of American colleges and universities must be more entrepreneurial, more creative, more flexible, and they must be more internationally minded."

It is time to teach science in our classrooms and laboratories in relation to international problems. Given the technological bent our society is taking, college graduates must be produced who understand the issues. The liberal arts colleges present the best opportunity to integrate scientific principles with the humanistic values that can bring a human perspective to problems of global concerns. And, thus, I think that there is a need for improvements in the undergraduate curricula for science majors and non-majors, and NSF has a responsibility to provide leadership in this area.

Let me now turn to one of the important issues already identified by this Committee: minority participation in science. Numerous data sources have documented the fact that American Indians, Blacks, Mexican-Americans, and Puerto Ricans are seriously underrepresented in science and engineering fields, in comparison to their respective representation in the general population.

Table 1 shows the percentage composition of the general population, the science and engineering (S/E) workforce, and the doctorate S/E pool by race/ethnicity. The table shows, for example, that Blacks represented over 11 percent of the U.S. population in 1980 but accounted in that same year for less than 2 percent of the S/E workforce. Persons of Spanish origin represented more than 6 percent of the population (proportionately, about half the representation of Blacks) but less than one percent of the S/E workforce. By comparison, Whites represented 95 percent of the S/E workforce while comprising only 80 percent of the population. Asians are even more "overrepresented" in the S/E workforce (approximately 3 percent, almost twice their representation in the population). Within the S/E doctorate pool, the representation of Asians is *more than four times* their representation in the population.

Differences in attrition rates between Whites and the underrepresented minorities at various points along the educational ladder help to explain their relative representation in the S/E workforce and the doctorate S/E pool.

Table 2 shows that for every 100 Whites who enter first grade, 83 complete high school, 23 complete college, and 8 complete graduate or professional school. By contrast, for every 100 Blacks who enter first grade, 72 complete high school, 12 complete college, and only 4 finish graduate or professional school. Of every 100 Mexican-American and every 100 Puerto Rican children entering first grade, 55 will graduate from high school, 7 will complete college, and only 2 will finish graduate or professional school. Thus, Blacks, Mexican-Americans, and Puerto Ricans lag significantly behind Whites at each potential entry point into the S/E workforce.

Table 1. 1980 U.S. Population, Science/Engineering Workforce, and Doctoral Scientists and Engineers by Race/Ethnicity.

Race/Ethnicity	% in Population	% in S/E Workforce	% in Doctorate S/E
White	79 6	95 0	89.0
Black	11 5	1 9	1.1
American Indian	0 6	a	b
Asian & Pacific Islander	1 5	2.8	6.6
Spanish Origin	6 4	a	b
Other/No Response	0 4	a	b
	100 0	100 0	100.0

NOTE Categories with a total 0 3 percent of the 1980 science engineering workforce categories those with b total 3 3 percent of the doctorate science engineering pool

SOURCE National Science Foundation *U S Scientists and Engineers. 1980* NSF 82-314

Table 2. The Educational Pipeline Index.

Educational Stage	Whites	Blacks	Mexican-Americans	Puerto Ricans	American Indians
Enter First Grade	100	100	100	100	100
Graduate from School	83	72	55	55	55
Enter College	38	29	22	25	17
Complete College	23	12	7	7	6
Enter Grad Prof School	14	8	4	4	4
Complete Grad/Prof School	8	4	2	2	2

SOURCE Adapted from the Commission on the Higher Education of Minorities *Final Report of the Commission on the Higher Education of Minorities* Higher Education Research Institute Inc 1982

Table 2 also shows differences in the percentage of the various groups entering college at the time this longitudinal study was made. The rate of entry into college of at least some of the underrepresented groups actually improved significantly during the 1970s. According to a 1983 Department of Education study on the participation of Blacks in higher education, during the first half of the 1970s, there was a large increase in Black enrollment that coincided with an expansion of federal legislation and policies. *By 1975, the percent of Black high school graduates enrolling in college was the same as that for Whites*, resulting in a significant increase in the number of Blacks receiving undergraduate science degrees.

During the last half of the 1970s, however, the number of Blacks who enrolled in college remained essentially unchanged, even though the pool of Black youth in the college age group increased by 20 percent. Broadly stated, minority participation in higher education has declined at all levels in the 1980s following dramatic improvement in the 1960s and 1970s. In 1975 and 1980, the percentage of Black high school graduates enrolling in college declined from 32 percent to 28 percent, with a similar decrease for Hispanics from 35 percent to 30 percent.

An even more serious concern is that students from all minority groups tend to be disproportionately concentrated in two-year public colleges. In 1978, more than half of all Hispanic and American Indian college students were enrolled in public community colleges, compared with only 39 percent of Black students and 33 percent of White students. A subsequent study of minority students enrolled in 65 flagship universities showed that in about 75 percent of those institutions, enrollment by minority students was seriously underrepresented in comparison to the minority population in the state. Interestingly, the institutions with the greatest underenrollment of Blacks are located in the South and are all technologically oriented universities.

In 1980, two-thirds of all Black college students were enrolled in institutions whose student bodies were predominantly White; 42 percent, in two-year colleges; 27 percent, in predominantly Black institutions. In 1985, approximately one in five Black college students in the United States attended HBIs.

What is significant about these statistics is that while minority student enrollments have increased over the past decade, they are disproportionately concentrated in those institutions at the lower end of the educational hierarchical system with respect to financial resources, e.g., community colleges and HBIs. Given the great disparities in institutional resources and uneven distribution of minorities among the various types of institutions, the concept of equal opportunity should be modified to take into account the type of institution. In answer to the question posed by this Committee, "Should NSF programs differentiate between types of institutions?" I would say yes.

The impact of the type of institution is even more dramatic when one looks at degrees awarded. For example, in 1981, the majority of Black degree recipients at each level, except doctorate, earned their degree in a state where HBIs are located, primarily because of the HBI. In that year, 83 HBIs that granted bachelor's degrees produced more Black baccalaureates in the sciences, mathematics, and engineering than did the 673 non-HBIs in those states.

The point is that minority students are still very much concentrated in minority institutions, which are more effective in training minorities who receive degrees than any other group of institutions. Majority institutions, while effective for some minority students, have become a revolving door for so many minority students, where they are "the only" in the department, without a psychological and academic safety net, without faculty who can see beyond the rough to the diamond, beyond the lack of experience to the talent waiting to be nurtured and claimed. This means that if the federal government takes seriously its responsibility to increase the representation of minorities in science and engineering, one component of the solution should involve support of those institutions, where minority students are located, that have a historical track record in producing quality graduates at the undergraduate level. A similar argument could be made for support to women's colleges. There are targeted efforts to increase support to HBIs, but it is not clear that these efforts have been focused enough and been sustained long enough to have a long-term impact on science and engineering education.

Why should the National Science Foundation be involved? This is not a social problem as some would suggest. The Foundation must increase its involvement in an activity designed ultimately to increase the flow of minority students into science and engineering fields. To produce minority citizens who are better informed about scientific issues is the Foundation's historic responsibility for the health of science in the nation.

National reports speak of the dire social and economic consequences to the country of not providing minority youth with the technical skills needed for constructive and productive participation in our economy. Such a forecast is based in part on the demographic changes projected within the public school population (30 percent minority by 1990) and on the projected shifts in population in several of our major cities (53 will be predominantly minority by the year 2000). It is also projected that by 1992 there will be a substantial drop in the number of qualified students entering engineering colleges in 38 states, unless special efforts are undertaken.

Such projections compel us to focus on improving the educational preparation of minority students so that quantitatively based careers are among their options. They would justify, for reasons of national interest, the involvement of NSF in activities designed to attract more minority students into scientific and technical careers. In addition, the extent and nature of the poor preparation in science and mathematics received by minority students argue for major systematic changes.

The Outlook for Science and Technology 1985 (by the National Academy of Sciences, et al.) comments on the importance of "providing the fullest opportunities for women and minorities to contribute to the health and vigor of the research enterprise." A second report, *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future* (by the National Research Council's Committee on the Education and Utilization of the Engineer), reports on the decline in minority freshman enrollment in engineering that began in 1982 after several years of successful recruitment efforts in the 1970s. It emphasizes that "efforts must be made to reduce attrition of minorities all along the educational pipeline."

These Foundation-supported reports, as well as others, call for increased attention to the preparation of minority youth for scientific and technical careers. Also signaling the need for greater involvement of NSF in programs targeted to minorities are (1) the continued underrepresentation of minorities in the science and engineering workforce, (2) the lack of significant minority

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involvement in science decisionmaking and policy-making roles, and (3) declining minority enrollments in higher education, particularly in science and engineering fields.

HBIs are not a monolithic subset of institutions. Most are teaching institutions, just as are majority colleges, and they should not be expected to develop state-of-the-art research programs to compete with research universities. But, as a subset of institutions, they enroll 20 percent of Black college students and produce almost 40 percent of the Black baccalaureates in science and engineering. These are impressive figures, and they should be considered carefully in any funding scheme to increase minority participation in science, mathematics, and engineering. I should point out, however, that much of the success of these institutions in recent years is due to support programs of the National Institutes of Health and other federal agencies. Indeed, in fiscal year 1983, NSF awarded only $2.4 million (0.3 percent of its total awards to higher education institutions) to HBIs. Additionally, other federal agencies have incorporated some of the best elements from good, but discontinued, NSF programs, such as CAUSE, COSIP, MISIP, and RCSE, and have established focused programs at minority institutions that are yielding excellent results. For some reason, NSF initiatives in science and engineering education appear to be short-lived, and many exemplary programs have been discontinued before they had time to mature.

Let me conclude by making one specific recommendation. NSF increase its support for HBIs to the level of $10 million/year (less than one percent of the total NSF budget) by funding competitive proposals in two broad areas: (1) projects at smaller undergraduate teaching institutions to equip them with the latest teaching tools and instructional methodology in science and engineering education, including program opportunities to allow individual faculty and their students to participate in research, most of which would occur during the summer term; and (2) research and educational projects at those HBIs with graduate programs (approximately 10 institutions) that perceive their mission more broadly and are more competitive than the smaller undergraduate colleges, but are not yet part of the mainstream program of support in science and engineering education and research.

This program should not be funded indefinitely. The Foundation's commitment to each project should be at least five years with possibilities for continuation for those institutions that show significant progress.

The strategies and programs that I have presented to you can be accomplished, but not without external support beyond the current budgets committed to HBIs to bring these colleges and universities into the mainstream programs of the Foundation. It will require a commitment that supersedes short-term considerations for long-term results—one that implies a commitment to the long-term development of sciences.

It is time for the scientific establishment, and the National Science Foundation as one of the leaders of this establishment, to take the lead and make the commitment to reduce the underrepresentation of minorities in science and engineering.

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Enhancing Undergraduate Science and Engineering in Public Institutions

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Dakota State College

Representing the American Association of State Colleges and Universities

I am an engineer and a scientist concerned about the need to improve the support provided for undergraduate science and engineering education. In 1984, it was my privilege to serve as the President of the Institute of Electrical and Electronic Engineers (IEEE), an organization of engineers and scientists with over 250,000 members in 128 countries, which is the world's largest professional technical organization. In 1984, the IEEE celebrated its centennial year by reflecting on the achievements made by a century of giants, most of whom received their entire professional education in undergraduate programs.

During 1984, I was invited to serve as President of Dakota State College, an institution designated by the Legislature of South Dakota to develop new approaches to education with special emphasis on the appropriate use of computers and other technologies. I serve as a Director of ETA Systems, a new company with the goal to produce a 10 gigaflop supercomputer in the short period of only three years. I have been a research director and principal investigator of several research programs that have ranged from space medical experiments to weapons systems development.

Public institutions of higher education are concerned with the policy of the federal government for the continued development of undergraduate science and engineering education. Many of these institutions belong to the American Association of State Colleges and Universities (AASCU), an organization of more than 360 colleges and universities representing the rich and diverse heritage that is the essential spirit of higher education in America. As a representative of AASCU, I speak to you on behalf of institutions that range in size from 400 to more than 34,000 students; institutions that in many instances were founded as normal schools and now are multipurpose institutions. Most of our institutions offer programs of study in the sciences. Also, 52 engineering colleges are members of AASCU. Together, AASCU institutions annually graduate over 250,000 students with baccalaureate degrees, or approximately 31 percent of the total baccalaureate degrees graduated in this country, and we also award 27 percent of the master's degrees.

It is my belief that there is urgent need for change in the federal policy of support for the education of scientists and engineers.

A Growing Problem

Our great nation is in the midst of uncomfortable changes in its economic health. For the past several years we have become increasingly aware that our historic trade leadership in many markets has drastically eroded. The effects of such market changes in the areas of steel, shipbuilding, automobiles, consumer electronics, and heavy machinery are felt throughout every corner of the nation. Today we face a growing crisis in our agricultural economy, and for the first time in 71 years we are confronted with a growing trade deficit.

The full magnitude of the need for the nation to improve its ability to compete is difficult to judge. Yet in this age of computers and information systems, we now find that even our high-tech computer components and systems industries are joining the list of areas in which we appear to be losing our competitive edge. One need only visit with the leaders of Silicon Valley to gain a most distressing view of the growing problem of the loss of the competitiveness of the American semiconductor industry in the world marketplace.

World trade and competition are complex subjects and are receiving much attention, not only in the nation's capital, but throughout every city and town of our country. An important facet of competition in the marketplace is the development of new products. In particular, let us focus on the role of science and engineering in the development of the products that ultimately must be provided if we are to regain our leadership in the world marketplace.

Policy of Federal Support

The federal policy for the support of academic programs in science and engineering is largely determined by the policies of the National Science Board and the National Science Foundation. The other federal agencies look to NSF to guide the development of federal policy that collectively has a profound effect on the actions of state governments, industries, and professional organizations and associations.

There appears to be nothing in the current authorization of NSF that would exclude greater participation in developing undergraduate science and engineering education. The mission of NSF is broad. As stated in the preamble to the Foundation's organic legislation, its purposes are:

> ". . . to promote the progress of science; to advance the national health, prosperity and welfare; to secure the national health, prosperity and welfare; to secure the national defense. . . ."

As described by Dr. John Moore, the Deputy Director of the National Science Foundation:

> "To meet these purposes, NSF is directed to support programs of basic research in all fields and programs to strengthen the Nation's scientific potential."

The historic thrust of NSF has been the support of basic research, often in areas in which other funding, either federal or private, would be difficult to obtain. NSF has served and continues to serve the nation well in a number of areas. However, because of the changing economic conditions and the unparalleled importance of undergraduate education in preparing people to develop the technology needed to compete in the marketplace, there is an urgent need for NSF, the Administration, and the Congress to extend and broaden existing NSF programs and create badly needed new programs for the support of undergraduate education in science and engineering.

The Role of Undergraduate Education in Science and Engineering

NSF has focused on the need to develop leaders in science who have the vision and wisdom essential for the generation of new scientific knowledge. Through support to research and graduate education, NSF has helped to develop a flow of graduate-level personnel to meet national research needs. While this system seems to have worked well in some areas, perhaps it is time to address the ability of the present funding policy to prepare adequate numbers of the persons needed in the future. There is an urgent need for an in-depth review of the process by which we prepare our scientific leaders. I applaud the efforts of the National Science Board to improve funding for academic research and graduate education. We must continue to revitalize the capabilities of our research universities to prepare the best minds to develop the science and the engineering technologies essential for this nation to regain leadership in the world marketplace, but we must also address the needs of undergraduate education.

Dr. Moore, in his address to the Council of Undergraduate Research, noted:

> "This worldwide competition in manufacturing and trade is paralleled by sharply increasing competition in research, notably in fields where discoveries have clear economic implications such as materials research, computer science and biotechnology.
>
> "The competition in research is not limited to such fields as these, but can be found in others as well. High-energy physics is just one example. Furthermore, the lag between basic discoveries and their appearance in new products is decreasing rapidly. The link between basic research and economic well-being has never been clearer.
>
> "In short, the long-standing pre-eminence of the United States in research can no longer be taken for granted. It is being strongly challenged in many areas—and not just by the traditional European countries. There has been a tendency to underestimate this trend. I hardly need emphasize to this group the danger of doing so."

The urgency of this need may far surpass that brought to our attention by the 1957 beeping satellite circling the world. We have no beeping Sputniks to awaken us, we have only our eroding marketplaces!

A Need for Equity

Our current system of comprehensive support for academic research and graduate education in the sciences began in the 1950s. However, an effect of this focused funding has been the creation of the two-tiered system of colleges. Federal funding for academic research and development is approximately $2 billion annually and continues to have a substantial impact. As noted in a report of the National Academy of Engineering (NAE) on engineering education and practice:

> "Three decades of rising annual funding fostered a group of research universities or institutions—the first-tier schools—whose graduate and research programs became heavily dependent on contract research. This system of government grants and contracts has greatly benefited many engineering colleges, but its focus has been almost exclusively at the graduate level. As a result, it has been the driving force in graduate engineering education. It has produced an array of sophisticated laboratories, so that some 15 to 20 schools now have one or more unique and cutting-edge laboratory facilities for research."

A number of major corporations have recently made sizable grants to a relatively small number of institutions. However, most of these initiatives focused on the graduate research level in the same group of institutions that have been recipients of government funding. As noted in the NAE report:

> "Industrial support for academic R&D expenditures now amounts to about 4 percent of the total (although it is around 10 percent for engineering research) (National Science Board, 1982). Thus, the federal government plays a dominant role in funding academic R&D."

The NAE study goes on to note the distinct advantages that influence education at such institutions:

> "Their recruitment of faculty is enhanced because the young assistant professor can continue working in a research environment similar to that experienced in graduate school. Their policies thereby sustain and perpetuate the academic value system."
>
> "Teaching loads at research universities are relatively low, and [each] faculty member has a cadre of research assistants."
>
> "The research infrastructure includes laboratory facilities, access to modern machine shops, and extensive library holdings, along with—most recently—extensive computer equipment."
>
> "Typically, the benefits also include strong secretarial and technical support as well as ample travel funds."
>
> "Taken as a whole these benefits give a powerful impetus to academic research in graduate engineering education."
>
> "At the undergraduate level, no set of national policies or programs recognizes the important role of engineering education in contributing to the imperatives of a technology-based world economy. Because government and industry focus on research and graduate education, colleges that have as their primary focus undergraduate education in engineering have not enjoyed the advantages just described. They occupy a second tier within the engineering educational system."
>
> "Because approximately half of the B.S. engineering degrees are granted by colleges of the second tier, government, industry, and academe will continue to depend upon graduates of these primarily undergraduate colleges for at least half their engineering work force. Yet, because both government and industry focus their funding on graduate study and research, these colleges are forced to depend on other, appreciably smaller sources of funding."

Only One Science

As an engineer and scientist, I am concerned with the ability of the United States to develop the technology to compete in the world marketplace and to ensure the security and defense of our country. The development of technology requires a delicate transfer of knowledge between scientists and engineers, a process that itself is constantly changing as a result of the technologies developed. The traditional beliefs that science and engineering are fundamentally different no longer are applicable. The National Science Board, in its twelfth annual report, *Only One Science*, brought attention to the change in the relationships between scientists and engineers with the use of a quote from Louis Pasteur on the title page of the report:

> "To him who devotes his life to science, nothing can give more happiness than increasing the number of discoveries. But his cup of joy is full when the results of his studies immediately find practical application.
>
> "There are not two sciences. There is *only one science* and the application of science, and these two activities are linked as the fruit is to the tree."

This report provides dramatic documentation of the melding of distinctions between science and engineering that mark the shift in the way that research is now brought to application. The historic differences in the education of professionals in most of the fields of science and engineering are also changing, at least in part as a result of the almost incredible capabilities we now enjoy through the use of computers, new materials, biotechnology, and similar leading-edge technologies. This fundamental change in the way we practice science and engineering has had a profound effect on the educational system for preparing scientists and engineers.

A Change in Practice

The student of science or engineering today soon realizes the meaning of the information explosion. Not only must these students master traditional approaches to their chosen fields of specialization, but they must develop exceptional abilities in the use of information. Hopefully, we who are educators will continue to learn how to make better use of the great power and low cost of computers to enhance the processes through which our students learn.

Dr. Jerrier Haddad, Chairman of the Committee on the Education and Utilization of the Engineer, recently noted:

> "To deny an engineer sufficient computer capability is to guarantee poorer less effective results. This has resulted in laboratories that no longer have the same look as fifteen or twenty years ago. No longer do we have rows of oscilloscopes or machine shops with tons of precision equipment. Rather, today's laboratory is more likely to look like a set of desks with terminals or personal computers alongside. When one does see a laboratory with instruments and experiments, the chances are that small computers are

working with transducers to collect and reduce the data."

Dr. Haddad also commented on the need for greater understanding of integrated circuits throughout the practice of engineering:

"No chemical engineer, no mechanical engineer, no engineer designing appliances or automobiles or refineries or office buildings or airplanes can be ignorant of the power and effect of integrated circuits and do a proper job in his field. This is change of the highest order."

This change in the availability of technology has a far-reaching effect on the practices of science and engineering. There is a growing concern that the level of education expected of scientists and engineers to practice their professions must be accompanied by significant improvements in the level of preparation of high school graduates. Only 13 percent of high school graduates have the background that many feel is necessary to enter studies in engineering.

Support for Public Education

There is a growing awareness of the importance of excellence in education in the economic future of this nation. The sleeping giant of America is awakening to the need to prepare students better in science, mathematics, computers, and foreign languages along with perhaps the more traditional and more generally accepted requirements for excellence in English, the social sciences, and the fine arts.

This awakening awareness has had little effect at the college level. Unfortunately, the condition of the economy coupled with the need for vast improvements in our elementary and secondary schools and the requirement to teach the growing population of young students has left precious few resources for the improvement of public higher education. Our state-supported colleges and universities must compete with the growing feelings of urgency for increased funding for elementary and secondary education. Further, our science and engineering colleges must then compete within the higher education system for the increased levels of funding needed for vital curriculum improvement; funding to retain outstanding faculty while also attracting needed new faculty, and funding to provide the facilities and equipment so urgently required to support the curriculum and faculty.

In many states, our legislators seek to gain the perspective essential to choosing among the requests for funding if much needed support is to be provided to science and engineering education. The need for the development of technology, and hence the education of scientists and engineers, transcends state and regional boundaries. In my state, South Dakota, the Legislature has chosen to provide the extra support needed for science and engineering education both to meet immediate local growth needs and as an investment in future economic growth. But, it is not easy to convince legislators to provide the higher funding levels per full-time equivalent (FTE) student needed for science or engineering education for what often appears to be only a limited number of students, when the same amount of funding could be used to educate large numbers of students in other areas.

Increasing State Support

I urge that this Committee recommend to the National Science Board that it take action now to assist colleges and universities in obtaining support from legislatures for much needed improvements in science and engineering education by leading the formation of federal policy that will clearly identify the value of such increased support for undergraduate science and engineering education. While the value of local support from concerned industries and community leaders is important in developing support for public higher education, perhaps such support could be even more effective if it were possible to combine it with a federal commitment in the form of both policy and dollars. Such a visible sign of endorsement of the importance of support might serve to encourage state matching funding and would have a profound effect on the improvement of undergraduate science and engineering education.

I know from first-hand experience the importance of having our legislative decisionmakers understand the possible future impact of significant investment in public higher education. In 1984, the Legislature of South Dakota, a state in the midst of the agricultural crisis, chose to invest in its future by designating one of its public colleges to reorganize and develop its curriculum, faculty, and facilities to better prepare graduates to support new economic growth in the region. Indeed, this designation of mission change and the allocation of additional funding was a bold move for the future, taken only because the leadership of the state—the Governor, the Legislature, the Board of Regents, and the industries—believed that this investment could bring about change that would improve the economic base of the state. It is my privilege to have been invited to be President of this institution.

There are many other examples of states providing special support for science or engineering education through funding for laboratories, research facilities, and faculty support. Additionally, there have been significant programs of support provided by many corporations in the form of grants for equipment, programs, scholarships, faculty salary, and other supplemental awards. But, unfortunately, the collective impact of such support is far too restrictive for the job that must be done if we are to bring our educational programs in line with our national needs.

Restoring the Balance

We must not lose sight that these research and graduate education programs are only the finishing touches of a process that began many years earlier. A major portion of the education of the scientists and engineers needed for the economic growth of this nation occurs at the undergraduate level.

It is a well-documented fact that less than half the engineers studying in our graduate programs today are U.S. citizens. Truly, this nation continues to make a great contribution to the health, welfare, and stability of the world by providing opportunities for research and graduate education of engineers and scientists from throughout the world. Many of these outstanding scholars choose to remain in this country and have played important roles in the continued development of our technology. But, clearly, we must take steps now to prepare additional American students to enter our research and graduate education programs.

Many suggestions have been made throughout the science and engineering community for attracting more American students into our graduate programs, and I strongly urge the provision of additional graduate fellowship support so that our brightest and best minds will choose to enter these programs. However, I suggest that we must go far beyond such short-term approaches and act now to increase the number of students ready to enter graduate education. It seems to follow that if there were more American graduates from baccalaureate programs in science and engineering, and the same percentage chose to enter graduate school, then there would be more American graduate students.

It is often noted that many of our baccalaureate graduates are attracted to industry rather than graduate school to continue their education. While many who choose to pursue careers in science will continue graduate study through the Ph.D., over two-thirds of the 1.5 million baccalaureate-level engineers will enter the practice of their profession without further graduate education. There certainly is nothing wrong with many of our brightest and best engineers choosing careers in industry, but if we are to have more participants in our research and graduate programs, then we must have more students studying in our undergraduate programs.

One highly possible result of increasing the numbers of American students who are prepared to enter research and graduate study will be an increase in the numbers of future science and engineering faculty. Perhaps the most pressing problem of engineering education today is the need for additional faculty. Estimates of the shortage range from 1,567 faculty members reported in a recent survey of engineering deans to an estimated 6,700 faculty required to restore student-faculty ratios to the levels believed needed to provide high-quality education. Additionally, the retirement of an estimated 7,000 faculty over the next 15 years makes this problem a continued urgent need.

The historic feeder role of undergraduate institutions is well documented; it is now time to increase the number of baccalaureate graduates who are prepared to enter research and graduate education. The need for federal support for undergraduate education in engineering and science is critical and remains largely unheeded.

Broadening Science Education

It is time for our federal policy to recognize the role of undergraduate education at all colleges and universities in the preparation not only of engineers and scientists, but also in the preparation of all future citizens. Because of the urgent problems we face in trade, there is a growing need to modify the educational opportunities we provide to all undergraduate students in the areas of science, mathematics, and computers.

The baccalaureate graduate, whether aspiring for a career in business, education, or government, must be prepared to function in a world that is rapidly increasing in technological complexity. While it is essential that we must have new technological advances if we are to have new products, it is equally essential that our business leaders be prepared to understand fully such technologies so that they can realize the fullest competitive advantages of the marketplace. On a recent trip to China in my capacity as President of the Institute of Electrical and Electronic Engineers, I met with a large book distribution company. One of the employees of the company looked at the logo of the IEEE and said, "That's the right-hand rule." This employee was a journalist who majored in a foreign language, English. She had learned of the current-magnetic field relationship embodied in the right-hand rule in high school physics. One cannot help but consider how many employees of American marketing or other companies would equally understand either the logo or the scientific principles it represents.

The need is great! It is a need that transcends all state boundaries and all academic boundaries. We must respond to this need at the federal level. Publicly supported colleges and universities turn to our leaders at the federal level for the development of new policy direction. We request the National Science Board and the National Science Foundation to take immediate action to modify the policies of support to include more funding for the continued growth and improvement of undergraduate science and engineering education.

Action

Support for undergraduate education, whether in the areas of science, engineering, or in the broadest sense of preparing all graduates for a greater understanding of technology, can be classified into the areas of faculty, curriculum, and facilities.

Faculty. There is a need to strengthen the support provided for the continued professional development of faculty who are teaching predominantly in undergradu-

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ate programs in science and engineering. Many state-supported budgets provide only limited funding for research or other scholarly activity, for participation in major conferences or national workshops, or for travel or sabbatical leaves. In this time of a rapidly expanding technological knowledge base, it is vital that faculty have the opportunity to gain a hands-on appreciation of the new discoveries of scientists and the technology developed by engineers—information beyond that available in professional and technical publications.

I urge this Committee to recommend to the National Science Board that a coordinated federal program be formed to provide support for:

1. Science and engineering undergraduate faculty development grants, awarded for programs judged to have the greatest impact in improving the level of science and engineering education.

2. Faculty research participation, by increasing the funding available for the Research in Undergraduate Institutions (RUI) Program and by expanding the guidelines for participation to recognize that while a doctoral-level program may exist in one field of science or engineering at an institution, such a program may provide no appropriate opportunity for participation by faculty in other fields, departments, or colleges.

3. Participation by undergraduate faculty in research programs, by providing additional incentives in the funding of research centers or requests for equipment and other facilities if such proposals include provision for the inclusion of undergraduate faculty as direct participants and members of the team of investigators.

During the first of three years of extraordinary funding for the change in mission at my own institution, Dakota State, we have observed the significant effect that funding for faculty development has on the growth of undergraduate education. The faculty of this largely liberal arts-oriented institution has completely revised the curriculum and developed new strong computer science-information systems majors in English, mathematics, business, and teacher education. Additionally, they have appropriately integrated computers in over one-third of all the courses. In the teaching of English, computer programs developed by faculty now provide students with an enhanced ability to improve the grammar and technical aspects of their themes so that they now come to class to learn about the more advanced concepts of style and expression in writing. Much the same has occurred in the teaching of mathematics and science. This environment has led to nearly $500,000 of new research funding being awarded to the institution in this first year.

Curriculum. I encourage the National Science Board to support a study of curriculum innovations that have the promise of significantly improving undergraduate science and engineering education. Such a study should seek to identify those unique developments that help to prepare undergraduates better in science or engineering to integrate more fully both traditional excellence in education with the expanding science and engineering knowledge base.

There has been wide recognition of the educational value of an integrated research experience as a capstone for undergraduate science education. The Joint Board-Council Committee on Professional Training of the American Chemical Society reports:

> "In the Committee's judgment, the best indicator of the provable excellence of a baccalaureate degree program is its emphasis on undergraduate research. More than any other factor, joint participation of faculty and undergraduates in research seems to characterize excellent programs."

I urge that consideration be given to reinstating the Undergraduate Research Participation Program, which was the mainstay of many undergraduate research involvements in the sciences, but has not been funded since 1981.

Facilities. I urge the National Science Board to continue to expand the College Science Instrumentation Program. This program is of vital importance to the development of undergraduate science and engineering education and should receive increased funding.

Dr. R. D. Kersten, Professor of Engineering and Dean, University of Central Florida, reported to the Henniker 1983 Engineering Foundation Conference on the Undergraduate Engineering Laboratory that over $2 billion may be needed to return undergraduate engineering laboratories to the level of current state-of-the-art. Further, his study suggests that the period of obsolescence for much of this laboratory equipment may be as short as 10 years.

Additionally, I recommend that special consideration be given to enhancing the availability of shared large data bases and scientific and engineering information retrieval systems for undergraduate programs. Further, there is significant educational value in providing shared access to engineering data bases to support computer-aided design and the development of automated manufacturing systems. Many colleges and universities have begun activity in such areas, but consideration should be given to supporting these efforts through shared data bases that will enhance the educational value of local facilities and activities.

Summary

I urge this Committee to recommend that the National Science Board:

1. Reconsider the NSF policy for the funding of research and graduate education to provide for increased sup-

port for undergraduate science and engineering education.

2. Urge the adoption of coordinated federal funding policy that both recognizes the value of increased funding for undergraduate science and engineering education in the improvement of this nation's competitive position in the world marketplace and provides coordinated funding support across all federal agencies.

3. Urge the increase in funding and modification of programs that currently support undergraduate education in science and engineering. I recommend the addition or restoration of programs to support the enhancement of faculty, curriculum, and facilities in undergraduate science and engineering education.

The continued growth of science and engineering is vital to the growth of America. I have presented several examples of how an expanded policy that includes increased support for undergraduate science and engineering education will inspire the nation's overall capabilities in research and graduate education, while also increasing our overall ability to grow as a technologically oriented free society. I commend this Committee the NSF, and the National Science Board for addressing these questions that are so important to the continued growth, security, and prosperity of the nation.

The Role of the National Science Foundation in Undergraduate Science and Engineering Education

Bernard J. Luskin

Executive Vice President
American Association of Community and Junior Colleges

My broad concern is undergraduate science education as it relates to all of America's postsecondary institutions. The institutions whose concern I reflect specifically are the 1,222 community, junior, and technical colleges that now form the largest branch of American higher education. Figure 1 shows the geographic distribution of America's community, junior, and technical colleges.

This year, community, junior, and technical colleges enrolled almost five million credit students. They serve 52 percent of all Americans who go to college for the first time and 41 percent of all full-time freshmen and sophomores.

Our colleges are now the largest door of postsecondary access for minority students. In 1985, community colleges enrolled approximately 42 percent of all Black college students, 54 percent of all Hispanic college students, and 43 percent of all Asian college students attending higher education institutions.

While we meet the needs of large numbers of 18- to 24-year-olds, many typical community college students differ in fundamental ways from the "traditional" college student. He tends to be older. She tends to work and attend college part-time. They are commuters. He is often from a minority group or is a new immigrant. She is often the first member of her family to attend college. He is more likely to pursue an occupational than a liberal arts program.

Undergraduate science education is vital to the future of this nation. The National Science Foundation should assume a leadership role in undergraduate science education. And, since community colleges are a major provider of undergraduate science education, NSF needs to work closely with the two-year colleges to support and enhance their work in this area.

The very fact that our colleges now enroll the majority of Americans who are starting college suggests that we serve a stream of talent that, in the national interest, NSF can ill afford to ignore. The assumption that all the learners who are better suited to science and mathematics automatically take their undergraduate work at senior institutions is the kind of position that could very well undermine American leadership in global economic and technological competition.

The National Science Foundation must, in my view, be a guiding force in science education and in public understanding of science and technology transfer issues, in addition to supporting science research. We at America's community, technical, and junior colleges are eager to work with NSF to further the cause and are glad for this opportunity to contribute our perspective to this national policy discussion.

In my brief comments, I will address four imperatives that I believe are critical to the future of science education and the role of the National Science Foundation. They are population, work, equipment and technology, and technology transfer.

Population

Public Understanding of Science. During the coming years, the United States will be confronted with major policy decisions involving science and technology. These policy decisions will have far-reaching consequences for all American citizens. If citizens are to react to issues in as rational a manner as befits the world's most scientifically and technologically advanced nation, they must be able to sort out, from all the conflicting information aimed at them by self-interested parties, the unvarnished facts from which policy should be made.

The task of informing and educating the public with regard to issues involving science and technology is a formidable one, yet it is one that must be accomplished, for our democratic society rests upon the active involvement of an informed citizenry. As the issues we must grapple with become increasingly scientific and technological in nature, so must our people become more scientifically and technologically sophisticated. Community colleges, known as "Democracy's colleges," are an ideal vehicle for achieving the upgrading of scientific knowledge on the part of our citizens.

Public Support of Science. A general public receptivity to science undergirds the public's general attitude toward the importance of science. A public that does not understand space, laser, biological, telecommunications, genetic, and engineering technology cannot be expected to support programs that break new ground in these areas.

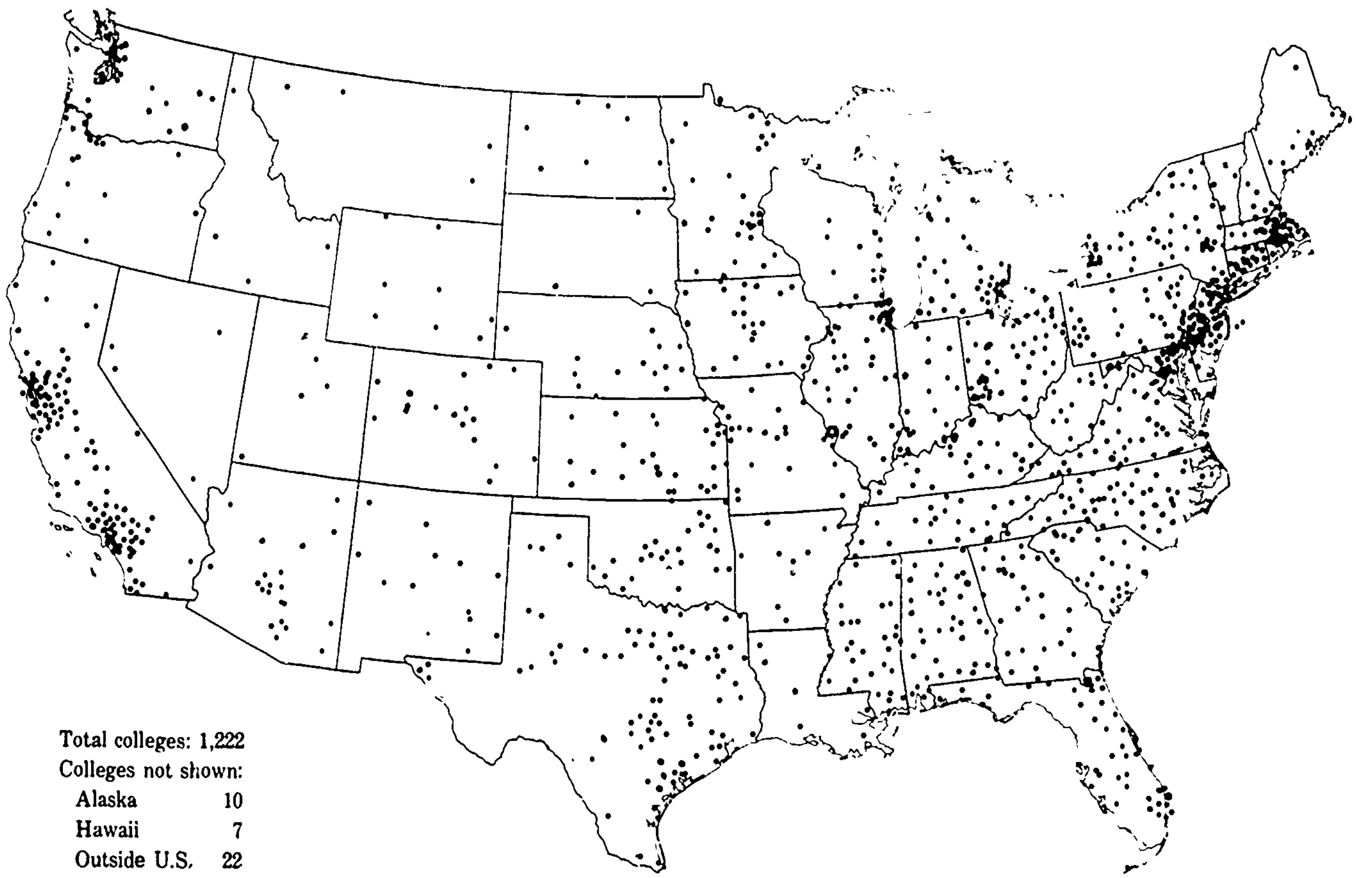

Figure 1. Distribution of America's Community, Junior, and Technical Colleges.

Minority Understanding of Science. Minority groups are a steadily increasing proportion of the population. It is estimated that by 1990 minorities will constitute approximately 25 percent of the labor pool as compared with 17 percent in 1980; women will make up about 47 percent of the workforce. In 25 major urban centers, minorities are now the majority of the community, and many of these individuals attend community colleges.

For minority groups, the growing need for understanding of science and technology has special implications. Already out of the economic and social mainstream, these population groups cannot afford to fall any further behind. Yet, will the growing numbers of minorities shy away from science-based programs because such programs are ill equipped, poorly taught, and not up-to-date?

My point here is simply that two-year colleges provide the first opportunity for postsecondary education for half of all the minority students in the country. If, as a nation, we are serious about attracting minorities into science education, we must address their needs in two-year colleges.

Work

Occupational Demands. Employees competent in the applied science fields are imperative to the well-being of this nation. The literature is replete with descriptions of the changing nature of work and the increasing demand for analysis and computation in technical fields.

If the nation's technical workforce is allowed to deteriorate, or to fall behind the skill levels of its global rivals, American prosperity can only decline, as will the revenue and resource base that sustains our leadership in science and technology.

Simply put, the welfare of our country and enlightened self-interest on the part of the science community demand leadership in science and science education. Only the National Science Foundation is in a position to respond in these areas.

Equipment and Technology

As I have demonstrated, the need for more and better science education is great, and it is clear that NSF must play a major role in improving science education in undergraduate programs. Unfortunately, many postsecondary institutions are poorly equipped to provide the increased sophistication in science education that is so badly needed.

As I am most familiar with community colleges, let me present the circumstances in which many of our schools find themselves. Most of the nation's community colleges were built during the 1950s and 1960s, in part as a result of the G.I. Bill and the influx of veterans. They have grown from one-half million students in 1955 to the five million students currently enrolled. In too many instances, the community colleges have aging science faculties, working in outdated laboratories that lack state-of-the-art equipment. The colleges desperately need new equipment, and the faculties need training and retraining.

The National Science Foundation has concentrated its support on a mere handful of institutions. The 100 institutions that receive the largest share of NSF money are all doctorate-granting institutions representing only 3 percent of the nation's universities. Not only do these 100 institutions receive 61 percent of all federal aid to education, they also receive more than 80 percent of all science money. The 353 doctorate-granting institutions receive 76 percent of all federal funding for education and 97 percent of all science money. Clearly, undergraduate institutions are underrepresented and underfunded.

There are specific, identifiable needs for science education at undergraduate institutions. These are science instruction and curriculum, faculty needs, and facilities and equipment.

The following examples of science associate degree programs in community colleges show the range of programs now offered and for which attention is needed:

- Engineering Science (Transfer)
- Biology (Transfer)
- Geology (Transfer)
- Astronomy (Transfer)
- Chemistry (Transfer)
- Mathematics (Transfer)
- Physics (Transfer)
- Aeronautical Engineering Technology
- Airframe and Power Plant Technology
- Architectural Engineering Technology
- Biomedical Electronics Technology
- Civil Engineering Technology
- Communications Technology
- Computer and Digital Technology
- Cytotechnology
- Fluid Power Technology
- Genetic Engineering Technology
- Information Systems Technology
- Laser Electro-optics Technology
- Machine Tool Technology
- Materials Engineering Technology
- Mechanical Design Technology
- Nuclear Technology
- Petroleum Technology
- Plastic Technology
- Radiologic Technology
- Robotics and Automated Manufacturing
- Telecommunications
- TV and Satellite Technology
- Viticulture

These programs are expensive and they take sophisticated, highly educated, up-to-date faculty and state-of-the-art equipment to teach them.

If the National Science Foundation does not give its weight of prestige, support, and commitment to the obvious needs I have described, who will?

Technology Transfer

In terms of instruction, computers, broadcast television, satellites, cable, instructional television fixed service (ITFS), point-to-point microwave, video disk and video cassettes, telecomputer networks, and the various subgroups encompassed by each of these technologies are creating new means of access and are changing the shape of teaching and learning through diversity. They also reflect the socialization of the exploding media technology and communications.

As their use permeates education, they provide many opportunities to do an even better job of what we already do well in education, by bringing new dimensions to the roles of teachers and students. The effectiveness of these approaches has been demonstrated in hundreds of experiments. Classroom and non-classroom-based learning systems will coexist side by side as new, accessible, and flexible educational forms emerge. In fact, broadcast courses, which enable formal learning to take place in the home, give education the potential of becoming a family affair and offer examples of both dramatic technology transfer and vehicles to strengthen both science education and public understanding of science.

Industry is investing millions of dollars into configuring the home entertainment center for movies and records. Science recently sent a rocket through the tail of a comet and computer-controlled cameras into the ocean depths to scan the decks of the *Titanic*. Science research is going to outer space and inner space with accelerating intensity. These developments all have implications for science and science education. The question we face is, "What will be the nature of the home education center and how will these developments affect instruction on campus?"

The National Science Foundation has made a significant economic and leadership contribution to these efforts and it must now be prepared to help colleges and universities stay abreast of these advances.

Some Concluding Observations

In conclusion, as obvious as some of the realities may be, several are worth reemphasizing:

1. Most science faculty members have been around for awhile. An entire generation of science teachers are reaching the last third of their careers. Fifty percent of these faculty, according to studies I have seen, indicated that they received their initial training because of both the encouragement and financial assistance of the National Science Foundation. Who will take their places? This issue should be a major concern of NSF. For many community college faculty, contact with the mainstream is non-existent. Look at the map of college locations shown earlier. Ignoring this reality deprives our educational system and country of the vast resource in talent, experience, and dedication that exists in the science faculties of these institutions. For those with experience, some genuine improvements in instruction would occur with modest funding commitments from relevant agencies. Opportunities for community college teachers to re-enter the mainstream

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via funded sabbaticals at research institutions or at research laboratories would create extremely effective paths to upgrading undergraduate education.

2. In the area of equipment, we face a constant struggle. Nationally, each year, funds are cut with the same consistency and dedication with which they were included in the budgets in the first place. In the long run this leads to an inferior level of some of the equipment. High-quality chemistry scales, computer hardware for laboratories, numerical control machines for such programs, etc., create obstacles that faculty must "teach around." Stimulating commitment and providing a catalyst for support is a responsibility that NSF should consider.

In short, there seems to be both good news and bad news.

Regardless of obstacles, including ill-prepared students, heavy teaching loads, feelings of isolation, etc., most of the science teachers in our community colleges will continue to do their jobs even if they never hear from NSF again. They love what they do and care deeply about the students in their classrooms. They are, however, eager to do better and to learn new science and new ways of communicating that science, if given the opportunity. So the good news is that people are doing the best they can in deteriorating circumstances. The bad news is that a large segment of the educational population has been long-ignored by those making funding decisions.

Perhaps that middle 50 percent of the student population who are part of the "neglected majority" will continue to be excluded from the more elite educational community either by birth or circumstances, but their dedication and talent can be as important to our national success as that of students attending large and prestigious institutions.

Recommendations

Teacher Training and Retraining. NSF should:

1. Take a leadership role in identifying and supporting areas important for the improvement of science teaching, such as attracting qualified teachers, urging teacher preparation programs to become state-of-the-art, and conducting programs for retraining and upgrading of staff. This should include:
   —Establishing and operating teacher training institutes for two-year college faculty and
   —Supporting development and dissemination of materials for training, retraining, and in-service development in mathematics, science, computer science, and technical occupation fields.
2. Establish an industry/education matching grant program to support experience opportunities for faculty through cooperative arrangements.
3. Foster a faculty exchange program between institutions of higher education.
4. Include two-year college faculty in programs for graduate fellowships.
5. Support summer institutes and workshops that provide for the improvement of science teaching and programs.
6. Fund commissions, task forces, and publications that specify and urge new developments and directions in college science teaching.

Science Equipment Programs. NSF should:

1. Support programs that provide strategic science equipment for new and emerging science education programs.
2. Fund commissions, task forces, and publications that outline the need for refurbishing science teaching equipment in colleges and that develop recommendations for improvements.

Technology Transfer. NSF should:

1. Support broad-based projects designed to foster wide use of high-technology applications in teaching.
2. Support studies and publications that foster technology transfer.

Public Understanding of Science. NSF should:

1. Provide support for special programs that help the general public understand the benefits and the problems related to technological development.

Science Education Programs in General. NSF should:

1. Support programs that encourage and improve articulation of programs and facilitate student transfer from high schools to colleges. Improve the high school/college connection.
2. Support roundtables across the nation that improve science teaching and learning in both high schools and colleges.
3. Support applied science and technical programs in emerging science-related programs.
4. Impanel a special broad-based commission to give guidance to high schools and colleges in science education and technology transfer
5. Modify the College Science Instrumentation Program to include two-year colleges. This program currently provides funds only for four-year institutions.

Funds expended to improve science faculty, equipment, and programs must be seen as an investment both to move us forward and as a form of maintenance that will prevent our programs from deteriorating.

As previously noted, these programs should include, but not be limited to, such fields as robotics, computer applications, microelectronics, laser technology, telecommunications, and biotechnology.

A Look Back and A Look Ahead

It is well known that science education has consistently been a problem area within the Foundation and should not be so, but rather should be a pacesetter for NSF.[1]

Stresses between the priorities of research and the responsibility for leadership in science education have been visible. We at the American Association of Community and Junior Colleges advocate the need for science research. But, we also support the need for leadership and support for science teaching in undergraduate science programs.

We call your attention to the two-year college as a major provider of both transfer and occupational science education to vast numbers of Americans, including those who transfer to traditional colleges. We call your attention to the neglected majority who comprise the middle 50 percent of American citizens who fix the airplanes, keep our electricity charging, man our laboratories, and run our computers.

We at AACJC believe that the needs I have expressed for support of teacher education, program planning and implementation, equipment improvement, and technology transfer should have significant priority in your deliberations.

Reference

1 The Annual Report of the Advisory Committee for Science Education, 1976

More Output from Less Input: Science Education at Leading Liberal Arts Colleges

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I warmly commend the National Science Board's interest in undergraduate science. This level, after all, is not merely an early section of the "pipeline" from which future scientists emerge; it is the chief pumping station and filtration point along that pipeline. The undergraduate years are the last point at which large numbers of students not previously oriented toward science can be drawn into the enterprise, and, conversely, the point at which the largest attrition from the ranks of future scientists occurs.

It is well known that undergraduate interest in basic science has recently plummeted. Within a decade, the percentage of American unc :rgraduates intending to major in science fell by 33 percent, with the absolute number of such intended majors dropping by almost 40 percent (the difference due to a dr ›in *total* enrollments). Only slightly more than one in twenty freshmen on American campuses intends to major in science today, down from a high of one in ten in the late 1960s. Meanwhile, of course, our graduate schools are being filled by increasingly able students from abroad.

In the face of this erosion of America's human resources in science, any institutions that have maintained a contrary trend must become the object of urgent attention. In these remarks I would like to focus on a group of four dozen or so such schools that have successfully bucked the decline of the study of science nationally, namely, some four dozen private liberal arts colleges—"colleges of the arts and sciences" would be a better name—stretching from coast to coast. Drawing on research begun last year at Oberlin and continuing at this moment, I will sketch in the contours of these institutions' strong record in basic science, offer some explanations for their achievement, and suggest means by which the National Science Foundation might help assure continued strength in this quarter.

The "Pipeline" for Scientists: Changes in Flow

The rapid and sustained national decline in interest i basic science has affected nearly all types of colleges and universities. Since 1975, public universities collectively have seen freshman intention to major in science fall a precipitous 37 percent, from 13 percent of their students to only 8 percent in 1984. Private universities have fared even worse over this period, falling from 22 percent interest in science to 12 percent, a 45 percent drop. Even the most highly selective of the private universities have experienced a 34 percent reduction in the proportion of students intending science majors (from 26 percent in 1975 to only 17 percent in 1984). And, colleges as a group, even the privates, also witnessed nearly 40 percent reductions in prospective science majors since the mid-1970s.

These trends are not limited merely to freshman intention. They translate into almost equally serious, and just as universal, declines in both proportion and absolute numbers of undergraduates being awarded baccalaureate degrees in the basic sciences. The national volume of undergraduate degrees awarded in all science fields fell fully 17 percent between 1975 and 1981, from 87,442 to 72,223. In contrast, total baccalaureate production actually rose slightly (from 931,663 to 935,410) over this period. Thus, the proportion of all baccalaureates being conferred as degrees in the sciences fell from 9.4 percent to 7.7 percent, a 23 percent drop. Again, even the best research universities were seriously affected. The 20 public and private universities with the best-rated graduate programs by the National Academy of Sciences conferred 14 percent fewer undergraduate degrees in basic science in 1980 than they had only four years earlier (8,114 down to 6,974). As a proportion, this decline translates as a drop of over 11 percent, from 16 percent to 14 percent of all baccalaureate degrees awarded by America's premier research universities.

The major liberal arts colleges have shown themselves to be virtually immune to these strong negative trends. Since 1975, their proportion of freshmen intending to major in science has remained steady at from 28 to 31 percent. This is more than four times the national average, better than twice the 12 percent proportion of the most selective public universities, and two-thirds greater than the level of interest in science at the best private research universities. Moreover, unlike these schools and the nation at large, the level in science interest at these four dozen colleges since the mid-1970s has been almost flat, that is, nearly completely resistant to the unfavorable trends at even the best universities.

Considering actual undergraduate degree production, the bottom line after attrition, the performance of these leading colleges is even stronger. Again, the proportion of all their baccalaureates awarded in the sciences has been an unflagging 24 percent since 1975, and the absolute number of science degrees conferred has actually *risen fully 16 percent*, from 4,450 to 5,150, by 1983. Thus, the colleges are uniquely able to sustain their students' interest in science.

The colleges' positive trends on all fronts in the face of downward trends nationally indicate that these select undergraduate institutions are rapidly becoming more important to America's science pipeline. In 1975, the leading colleges provided 42 per thousand of the nation's B.A.'s in science. In 1980, their share was 54 per thousand, a 27 percent growth. In contrast, the 20 top-rated public and private research universities' baccalaureate share rose barely one percent, from 92.6 per thousand to 93.5 per thousand, over this period.

The fact that these data have not been generally known until recently must be traced to the liberal arts colleges themselves, few of which appreciated their distinctive contribution to basic science in the United States. In the absence of data, it was easy to assume that the strongest undergraduate science was to be found at the same "research universities" where graduate study flourishes. This is not necessarily so.

Are liberal arts colleges enriching American science with persons of exceptional talent? The fact that the four dozen liberal arts colleges under discussion surpass all but a handful of universities in the percentage of their graduates who go on to get Ph.D.'s in science attests to the strength of their student body in these fields. It is no wonder that alumni of such schools have included such distinguished scientists as Nobel Prize laureates Arthur Compton, Robert Millikan, Roger Sperry, and Charles Townes.

Are liberal arts colleges also broadening the social base of American science? Nothing speaks more eloquently to this issue than the unparalleled recruitment of women into science at the liberal arts schools. Fully 52 percent of basic science majors at such schools are women, far higher than the corresponding figure at public or private research universities, the Ivy League, etc. Data on Blacks and other minorities is not yet at hand, but they are probably analogous, given these schools' vigorous recruiting.

Why Liberal Arts Colleges Excel at Science

The obvious explanation for the success of liberal arts colleges in science is that they are undergraduate institutions, not universities. There are no graduate students to claim professors' time nor do they substitute for seasoned professors as teachers. Faculty members in colleges are expected to devote more of their time to teaching, all of it, of course, being directed toward undergraduates. As a result, the actual classroom ratio of permanent faculty and undergraduate students is far higher at these schools than at even the finest universities.

This affects all levels of teaching. One-third to one-half of all science courses at liberal arts colleges are at the introductory levels, thus stimulating the recruitment of majors. Of these introductory courses, half are taught by tenured members of the faculty, people with at least six years of classroom experience and a proven professional commitment to undergraduate education. Of course, top undergraduate scientists receive excellent training at the leading universities and colleges alike. Only at the liberal arts colleges, however, are they so likely to be drawn into advanced research in any numbers, and only at these schools are they so likely to be placed in the relationship of apprentice to their professors. The very practical reason for this is that faculty researchers at these colleges have no graduate students to employ in their laboratories. Lacking them, professors have no choice but to train undergraduates to fill such assignments. To assure continuity, professors generally identify promising freshmen and sophomores, who thus become collaborators over a period of three or four years. It is not surprising, therefore, that nearly one-third of all journal articles published by liberal arts college faculty during the past five years are co-authored with undergraduates, a rate far higher than for research universities on which data are available.

But do professors at liberal arts colleges really conduct research? Most definitely. Some 350 books, 6,961 journal articles, and 4,478 conference papers were authored by scientists from the four dozen leading colleges over the past five years. Sixty to 65 percent of all college faculty publish regularly, most of these being in the younger ranks. To be sure, the more modest scale of laboratories and instrumentation at such schools distorts somewhat the subfields in which such research is concentrated. Moreover, the fact that college-based research is viewed in part in its relationship to undergraduate teaching also influences the research agenda to some degree. But the overall emphasis upon research at such institutions is firmly rooted. They can with justice be termed America's "research colleges." Recently, the Committee on Professional Training of the American Chemical Society declared:

> "In the Committee's judgment, the best indicator of the probable excellence of a baccalaureate degree program is the emphasis on undergraduate research . . . . [Undergraduate research] is the best education we can offer the younger generation in preparation for service to society as chemists."

By this measure, liberal arts colleges are a central component of American science.

The Funding of Science at Liberal Arts Colleges

Roland W. Schmitt, Chairman of the National Science Board, has observed that "no systematic federal leadership or support exists for science...at the undergraduate level." Since World War II, the United States has built up several hundred "multiversities" as centers for advanced research and graduate study in science. We are all indebted to this investment, which has established America's global leadership in many fields. Meanwhile, however, the top liberal arts colleges were neglected. In 1982, the 100 principal research universities garnered 86 percent of all NSF grants to higher education and 91 percent of all federal grants for facilities and instrumentation for instruction. Of all federal support for research and development to academia, 98 percent goes to universities.

In spite of their small base, liberal arts colleges are seeing a rapid decline in federal support. All federal support to the four dozen colleges between 1978 and 1982 dropped by 28 percent in real value, while their NSF support in real dollars plummeted fully 65 percent during those years. Fewer than half of the four dozen institutions received any help at all for facilities and teaching instrumentation in 1978. In 1982, none of them did.

Let me restate this point: *Those institutions with some of the strongest records in educating undergraduate scientists have dramatically improved their share of the prospective science market in recent years, in the face of grave erosion nationally; they have also improved their absolute number and share of U.S. total B.A. production in basic sciences. Neither of these records can be claimed by public or private research universities. These same institutions, however, have received only a trivial amount of federal help in such crucial areas as research instrumentation grants since the establishment of the National Science Foundation, and even that amount has recently fallen precipitously. In short, top liberal arts colleges are accomplishing far more with far less.*

Is this not an ideal situation? After all, such schools have avoided any unwholesome dependence upon federal support. They have sustained a remarkable record with their own resources, remaining free not only from federal entanglements but also from corporate sponsors, which have also concentrated their giving overwhelmingly on multiversities, both public and private.

Unfortunately, the picture has a darker side. To paraphrase Voltaire, the colleges have been living off the capital of another era. None can compete successfully with even minor universities in such areas as start-up costs and summer research stipends for young scientists, let alone salaries and instrumentation. Of course, the college-based researcher expects to have less time for his own work, but is it reasonable that the percentage of his research time that is externally funded is only half the amount for colleagues at *all* universities? Nor is the college scientist's basic salary secure. The endowment dollars per student at major private universities far surpass the figures for leading colleges, and the gap is widening. This means that basic costs for the scientific enterprise on college campuses are increasingly dependent upon tuition payments, and at a time when all institutions of higher education are facing the so-called "baby bust." Finally, it must be noted that many laboratories at liberal arts colleges were built up during periods of affluence. Without external assistance, there is absolutely no way that comparable laboratories for instruction and research can be maintained on these campuses in the future.

What Is the Appropriate Role for the National Science Foundation?

Liberal arts colleges have no interest in weakening support for science at leading universities. The two categories of institutions are linked in a common enterprise, and they benefit one another in numerous ways. What is called for is not some wholesale shift in funding (which would not occur under any circumstances) but an adjustment of emphasis that would benefit undergraduate science everywhere.

What would this shift in emphasis involve? The 48 liberal arts colleges of which I have been speaking are devoting the present year to further research on this point. They are evaluating their future investment needs and comparing them with possible sources of support. Fuller recommendations will be in hand by June 1986. Meanwhile, the following steps appear desirable:

1. Recognize the leading "research colleges" as being as distinctive a subset within American science as the leading "research universities," and enhance support of undergraduate science on these campuses in the same way that graduate education has been supported at leading universities. The group of colleges should be defined solely on the basis of student and faculty performance and institutional commitment and not by some undesirable form of entitlement. Obviously, institutions listed with this group would change from time to time, as happens among universities.

2. Assure that qualified scientists from such institutions are included on all the relevant boards, councils, and panels of the National Science Foundation, beginning with the National Science Board, and, conversely, that senior university-based scientists serve on all councils and panels dealing with undergraduate science.

3. Strengthen existing undergraduate science and instrumentation programs within NSF and establish a special fund within them for the most productive liberal arts and science colleges. This fund could provide one-time grants to defray set-up costs, summer stipends for junior faculty, grants for research leaves, etc.

4. Restore the program of faculty research leaves that previously brought great benefits to liberal arts college scientists but was subsequently dropped.

5. Link scientists on liberal arts undergraduate campuses with major NSF-sponsored projects at universities and national research centers through paid leaves of absence. This could be accomplished by providing bonuses for including professors at undergraduate institutions in large research grants.

6. Most important, NSF should explore the possibility of substantial one-time grants in endowment to underwrite distinguished professorships in science at leading undergraduate campuses. The National Endowment for the Humanities has a similar program that could serve as a model. One-time major instrumentation grants should also be considered, on a matching basis.

This list is meant to be suggestive, not exhaustive. It does indicate, however, that no serious progress will occur until NSF acknowledges the centrality of colleges of the liberal arts and sciences to the scientific enterprise in the United States. It has acknowledged the special role of the leading research universities, concentrating more than four-fifths of its general academic support and nine-tenths of its facilities and instrumentation support in a mere 100 institutions. In other words, the principle of focusing NSF support on institutions of proven quality has long been established in the case of universities. This should now be done for undergraduate colleges as well.

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U.S. Undergraduate Science and Engineering Education: A Worcester Polytechnic Institute Perspective

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To appreciate the Worcester Polytechnic Institute (WPI) perspective, it is important to understand something of the origins of WPI's innovative approach to undergraduate education in science and engineering—the "WPI Plan."

Worcester Polytechnic Institute was found in 1865 as the Worcester County Free Institute of Industrial Science, primarily through the efforts of John Boynton, a prosperous tinware manufacturer. Ichabod Washburn, the community's leading industrialist, soon lent his support to the Institute by organizing practical work in modern industrial shops. This combination of scientific and theoretical study with practical project experience became the foundation for WPI's continuing "Two Towers" approach to education.

In the last several decades, WPI has made the transition from a traditional engineering college to a modern technological university. The increasing sophistication of technology has diminished the need for practical shop work. However, the WPI Plan, which arose from widespread discussions within the whole academic community in the late 1960s, places major emphasis upon each student demonstrating professional competence through state-of-the-art project work in both a major and an interdisciplinary area. The plan offers students vastly increased opportunities to develop educational programs suited to their individual career objectives, in the context of becoming a "humane technologist."

WPI has awarded graduate degrees since 1898. New programs have been added regularly in response to the changing needs of the professions. Currently, the master's degree is offered in 18 disciplines and the doctorate in 10.

The current student body of some 4,000 students includes about 1,000 full- and part-time graduate students. Women have been admitted regularly as undergraduates since 1968 and now comprise approximately 20 percent of the student body. Currently, students attend WPI from 36 states and 50 foreign countries.

WPI received significant assistance from the National Science Foundation through the former RULE (Restructuring Undergraduate Learning Environments) and CAUSE (Comprehensive Assistance to Undergraduate Science Education) programs during the mid 1970s to help implement the WPI Plan. Without this financial assistance and the intellectual encouragement of the peer reviewers, this extraordinarily effective approach to undergraduate engineering education would have been virtually impossible to implement. It is interesting to note for purposes of this presentation that both these NSF programs, as well as LOCI (Local Course Improvement), ISEP (Institutional Scientific Equipment Program), and URP (Undergraduate Research Participation), were discontinued in the late 1970s, much to the detriment of undergraduate science and engineering education.

Overview

We understand that the Committee seeks recommendations on its identified overarching concerns in the context of the importance of undergraduate science and engineering. These overarching concerns include:

- Excellence in teaching;
- Competition in recruiting outstanding faculty;
- Faculty renewal;
- Curriculum, facility, and equipment modernization;
- Precollege science and mathematics teacher preparation; and
- Participation of women and minorities.

Importance of Undergraduate Science and Engineering Education

Given the background of the Committee, it is truly "preaching to the converted" to comment at length on the importance of undergraduate science and engineering education. It strikes us, however, that three major issues deserve brief mention.

1. *International economic competitiveness.* One needs only to look to basic industries such as steel and textiles, where the battle with foreign competition has been lost for all intents and purposes, to realize the importance of maintaining and enhancing our competitiveness in the presently threatened automotive, computer, and microelectronics industries. To do this will

require superbly educated and trained engineers imbued with a sense of mission and significant investment in the science and technology of manufacturing automation and computer and information sciences.

2. *Infrastructure integrity.* In addition to the obvious foreign competition referred to above, we need properly trained engineers to maintain and enhance the integrity of our industrial systems to preserve our future competitiveness, to say nothing of the integrity of our national support systems in roads, bridges, transportation, waste disposal, energy production and distribution, cities, etc.

3. *National security.* Given both the rhetoric and demonstrated support of the Administration, there seems to be little need to belabor this issue further here.

Recommendations Regarding NSF's Response to the Overarching Concerns

Excellence in Teaching. This is the sine qua non of excellent undergraduate education in science and engineering, particularly at those institutions, such as WPI, that have historically emphasized undergraduate programs.

To encourage excellence in teaching, NSF should:

1. Fund national engineering competitions, perhaps to be administered by the American Society for Engineering Education (ASEE) or the National Society of Professional Engineers (NSPE), where faculty-student teams can participate in real engineering problem-solving experiences (examples include the recent NASA Space Glove competition or the infamous concrete canoe competition);

2. Fund grants to institutions, such as those formerly provided by the URP program, to sponsor undergraduate student involvement in research and scholarship;

3. Fund additional studies into the standards for, and the measurement of, excellence in teaching;

4. Renew the former LOCI program to encourage the updating of courses and development and introduction of new educational technologies in undergraduate science and engineering instruction; and

5. Fund programs to encourage the development of faculty scholarship, a necessary—but not sufficient—condition for excellence in teaching.

Competition in Recruiting Outstanding Faculty. Next to dealing with competition in recruiting quality graduate students, this represents the single biggest impediment today to excellence in science and engineering education. Undoubtedly, this is the biggest impediment for predominantly undergraduate institutions.

To help resolve competition in recruiting outstanding faculty, NSF should:

1. Fund more competitive fellowship/loan programs for graduate education in engineering and science that would have explicit forgiveness provisions for the individuals who engage in teaching careers,

2. Provide more funds for research initiation grants and presidential young investigators that will facilitate the career start-up for young faculty members; and

3. Fund programs in conjunction with NSPE and ASEE to improve the status and recognition of undergraduate science and engineering teaching.

Faculty Renewal. With the accelerating pace of technological change (the half-life of the factual basis for an engineering education is now estimated to be less than five years), it is imperative that effective mechanisms be found to encourage faculty renewal.

To encourage faculty renewal, NSF should:

1. Develop and fund programs for six-month to one-year renewal leaves for faculty, perhaps to participate in planned research/refresher programs offered by acknowledged centers of excellence in engineering education such as MIT, CMU, Illinois, or UC-Berkeley; and

2. Fund the development of self-study programs and supporting materials.

Curriculum, Facility, and Equipment Modernization. President Donald Kennedy of Stanford University has been a vocal proponent of the need for enhanced federal support to arrest the deterioration of the capital plants of the major research universities during the last 15 years. If the "research plant" of higher education has been deteriorating, the "instruction plant" of undergraduate science and engineering has been collapsing. A recent study by NSPE indicates that the average laboratory equipment inventory of the 250 accredited engineering schools declined in value from $5,810,000 to $856,000 during the period 1972–1981. To bring the equipment of these schools back to the 1972 level would cost some $1.25 billion in today's dollars, and adjusting for the doubling of enrollments would require an additional $.95 billion. This problem is compounded by the fact that laboratory equipment has undergone a revolution during the past 20 years, shifting from all analog to largely digital with significantly higher maintenance costs.

To help deal with the mammoth problems in this area, NSF should reinstitute at significant funding levels the RULE, CAUSE, LOCI, and ISEP programs formerly conducted by the agency. Emphasis here should be on matching grants to serve as incentives for fundraising to refurbish entire laboratories.

Precollege Science and Mathematics Teacher Preparation. Interestingly, a study being conducted by the National Research Council's Commission on Engineering and Technical Systems suggests that the single most important factor for encouraging the participation of women and minorities in science and engineering is their appropriate exposure to, and counseling in, these areas while in high school.

In our view, NSF's involvement in this area should focus on acquainting precollege science and mathematics teachers with the excellent prospects for success of women and minorities in engineering and science. We believe, in general, that resources are more effective in direct support of undergraduate science and engineering than in precollege programs.

Participation of Women and Minorities. The previously referenced NRC Commission study suggests that the single biggest deterrent to increased participation of women and minorities in science and engineering is a lack of peer role models in professional practice and in engineering and science faculties.

To help address this issue, NSF should develop and fund programs to encourage both basic and advanced study of engineering and science by women and minorities.

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Undergraduate Science and Engineering Education

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On the surface, the status of engineering and science education at elite, private research institutions is "good" to "excellent." Enrollments in engineering and science are up at such institutions, and graduates are increasingly well trained and are probably more advanced, technically, than corresponding cohorts of university graduates at any time in the past.[1] To the degree that there are perceived major problems, they relate principally to manpower shortages and perennial labor market distortions—concerns as to whether the rush to electrical engineering and computer science will lead to oversupplies in these areas and shortages in, say, civil engineering and physics later on.

Given the apparent health of engineering and science education in private research universities, it is important to note that these institutions do not constitute the only or even the major source of engineers and scientists in the country[2]—even if, traditionally, they are the most influential in shaping education and the research agenda in academic science and engineering. In spite of the apparent health of engineering and science education in these institutions, I argue that there are serious long-term problems that private research universities must themselves face up to, and that there is an important, continuing role for enlightened federal government participation in engineering and science education in these universities.

I shall not attempt a comprehensive statement on the status of engineering and science education in American higher education. Rather, my remarks are confined to a few issues that have not yet been fully covered by others appearing before the Committee, and issues that seem to me to be of sufficient long-run importance so as to be of interest.

Briefly, two sets of problems seem particularly important at this juncture. Both stem from the success of academic science and engineering as measured in conventional terms—the intellectual progress made by the engineering and science disciplines, their continued ability to attract excellent young minds to the field, and the quality and depth of education provided by the various elements of higher education in scientific and technical areas. The first set of issues and problems relates to the explosion of knowledge, skills, and techniques that comprise engineering and science as academic disciplines. Stated simply, the natural response to the increase in potential topics that could be covered in an undergraduate curriculum has been to cram more engineering and science into the same four-year program. The second set of issues is more complicated and applies more directly to private universities. It involves the classic tensions between education and research, but with a different twist: the increasingly capital-intensive nature of education and research in engineering and science, the difficulty private universities currently face in securing certain kinds of capital funds, and the distorting effects this combination of circumstances has on internal resource allocation processes within a private research university. These distortions, in the long run and indirectly, create severe problems for education in engineering and science.[3]

Overspecialization in Engineering and Science Education

Science and technology play increasingly important roles in American society. Partly because of its increased role in society and partly because the body of knowledge, methods, and perspectives that comprise "engineering and science" has grown so rapidly, the temptation to pack more science and technology into undergraduate engineering and science degree programs is great. It is a temptation few institutions have resisted. The result is more narrowly educated graduates, and students under greater stress while in school.

If one seriously compares the transcript of a 1960 engineering or science graduate with that of his/her 1985 counterpart, one is struck by the degree to which undergraduate programs in these areas have accelerated and escalated—more topics are covered per unit time and graduates have gone considerably further into their disciplines. The typical B.S. degree holder in engineering or science at Carnegie-Mellon in 1985 resembles a precocious M.S. degree holder, circa 1960, and there is greater specialization within the discipline. There are at least two significant educational implications of this trend toward greater depth and specialization at the undergraduate level.

First, greater depth and specialization among engineering and science majors comes at the expense of breadth. The seemingly better professional and technical education comes at the expense of a broader, liberal edu-

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cational perspective. Although most engineering and science programs have "distribution requirements" requiring a certain number of courses in the humanities, social and behavioral sciences, and the fine arts, it is the rare faculty advisor who equates coursework outside the major with the importance of the more technical courses found in the major. Often, coursework in the liberal arts is seen as a form of leisure activity, not intellectually demanding, and generally as a safety valve for the high pressure of a modern engineering and science degree program.

At my own institution, there is a long, rich history supporting the notion that the best professional education is broadly based, or liberal. My purpose here is not to advertise the Carnegie-Mellon approach to professional education,[4] of which we are justifiably proud, but rather to indicate that even in an environment where tradition provides strong support for a broadly based engineering and science education, the forces of narrow professionalism are present and strong.

The maintenance of a proper intellectual balance in the education of engineers and scientists requires a firm, philosophical conviction and continued attention to the evidence that intellectual breadth is the prime prerequisite for success and leadership in any profession—technical or non-technical—and that work outside of one's major is not diversionary but makes for more adaptable and more creative professionals. Countering the forces of narrow professionalism is the primary responsibility of institutions of higher education, not the federal government.[5] Nevertheless, federal programs aimed at strengthening engineering and science education in the United States have a special responsibility to give prominence to intellectual breadth, to a liberal approach to professional education, as a dominant curricular design criterion.

The increasing importance of engineering and science in all aspects of contemporary American society implies that our society will be better served if the political, social, and economic leadership can comprehend issues with a significant technological dimension and be intellectually equipped to share in the leadership of technology and science. Stated somewhat differently, if the best scientific and technical education is liberal, the best liberal education includes science and technology.

Unfortunately, the most narrow and parochial educational programs in the United States today are to be found in the humanities, social sciences, and fine arts disciplines. I submit that the explosion of knowledge in engineering and science, leading to increasingly sophisticated curricula in engineering and science, is a prime culprit in helping create a scientific and technologically illiterate class of "educated" Americans in the liberal and fine arts.

Traditional arts and science colleges have generally not abandoned the notion that the physical sciences and mathematics are important components to a liberal education. Often, the price for inclusion is a "physics for poets" approach to the physical sciences—an approach far better than excluding the sciences from a liberal arts curriculum. The physical sciences and mathematics seem quite comfortable with their general education role in American universities.

The engineering disciplines have been far less interested and far less successful in providing "technological literacy" to students in the liberal or fine arts. Engineering is a consumer of general education, not a provider. The Alfred P. Sloan Foundation, with its "New Liberal Arts" program designed to add engineering and technology to the traditional list of the liberal arts, has provided an important and innovative approach to the general problem. They have focused their earlier efforts on the small, elite liberal arts colleges. These colleges are excellent, early targets for "new" liberal arts curricula, given their intellectually talented student bodies and commitment to undergraduate education.[6] Other promising institutions for introducing engineering and technology into the intellectual portfolio of liberal arts students are relatively small institutions with both strong engineering and liberal arts programs[7] and a commitment to quality undergraduate education. The major point to be made is that when one thinks of the strength of engineering and science education in the United States, the concern should be broader than just those educational activities designed to provide students with degrees in engineering and science. Monitoring the results of the Sloan Foundation experiments would seem like a most sensible way for the federal government to design a constructive role for itself in strengthening this aspect of engineering and science education in the country.

Research, Graduate Education, and Undergraduate Education

Education and research are not truly separable activities. Especially in engineering, those faculty who provide undergraduate education are almost always active researchers as well. Certainly in private research universities—and, to a somewhat lesser degree, in liberal arts colleges[8]—science faculty are also active researchers. In a real sense, a faculty member's personal time budget makes education and research inseparable. Similarly, graduate students are not only factors in faculty time budgets, but are also an integral part of research and teaching programs. Undergraduates at most large research universities are painfully aware of the fact that the need for graduate students to staff an active program of research, coupled with a scarcity of English-speaking applicants for graduate study,[9] often translates into unintelligible graduate student instructors for undergraduates.

The interrelationships between education and research are many, and most are positive. It is, after all, the products and process of research that provide the raw material for education. This is especially important in academic fields as actively evolving as those in engineering and science. Research generates much of what is to be taught. The justification for research productivity as an important criterion for tenure in American universities is partly based on the observation that productive scholars represent the best long-run prospects as productive teachers. The products and processes of laboratory research also help specify what the appropriate educational laboratory experiences should be and the sort of professional tools undergraduate students should be exposed to.

It is not the "research-as-model-for-education" or the "faculty-time-budget" tensions that I want to address here in examining the research-education relationships. Rather, it is the more subtle relationships between research and education as parts of the same institutional resource allocation processes in American universities. I would like to examine the research-education interrelationship from a resource allocation perspective. There are some important contextual components of this interrelationship that are different for private research universities than for, say, large public institutions.

Capitalization of Engineering and Science Research: An Inadvertent Enemy of Engineering and Science Education

The realities of internal university resource allocation are such as to cause problems for engineering and science—research or education—to be exported to other areas of the university. Often, these problems are amplified along the way so that a "solution" to a pressing engineering and science problem translates into a catastrophe for other parts of the university—the liberal arts, for example.

Most simply stated, the high costs of doing research in engineering and science—especially the high capital costs—translate into more severe resource squeezes for engineering and science *education*, and into even more severe resource difficulties for non-technical parts of a university.

University-based engineering and science education is expensive. This is partly because faculty who teach in these areas are more highly paid than faculty in, say, the humanities, social sciences, fine arts, or in many of the other professions. Mostly, however, engineering and science education is expensive because it is an inherently capital-intensive activity. Special equipment, instruments, computers, and dedicated facilities are required to a degree that is unheard of in other areas of academia. With the possible exception of computing, equipment and facility costs have been rising at rates faster than traditional university revenue streams—research grants, tuition, and donations.

Competition for Faculty. For some time now, the competition for top people in disciplines requiring "wet" laboratories (biology, chemistry, chemical engineering, and other forms of medical research), supercomputers, special electronic or production facilities, and the like has resembled the free agency markets in major league baseball more than traditional academic markets. It is not uncommon to see a $1 million or more "signing bonus" requirement attached to even the most standard academic appointments in many disciplines. When one adds up the costs of creating a new laboratory, of paying for equipment set-up costs, and of providing for graduate student support costs for new appointments, the out-of-pocket costs can be astronomical. Such faculty are nearly always sold, internally, as "paying their own way" when the always-promised research contracts begin to roll in. Only a fraction really seem to "pay their own way," but to challenge the assumed, long-run financial viability of such an appointment is to declare the field the appointment is in to be unimportant. There is a limited supply of credible academic researchers, and all too often the competition for those talented few seems only to drive up their price, much in the form of capital devoted to research. This is not to say the equipment and laboratories required by star faculty are unimportant for science or engineering or that the sizable investments required are unwise in the abstract, merely that the costs of remaining competitive in many areas of engineering and science research are far greater than the already formidable direct costs. The opportunity costs may exceed the direct costs.

Side-Effects of Capital-Intensive Research. To remain competitive in particular areas, universities are faced with some very unpleasant choices. Somewhat ironic is the fact that capital invested in engineering and science research facilities leaves less capital available for capital-intensive educational facilities in the same capital budgets. A capital commitment to research in engineering and science leads to a greater demand for similar facilities in the corresponding educational programs of research universities and less in the way of resources (in the short run) to pay for those facilities. For example, consider the demand for sophisticated instruments and powerful computers in electrical engineering undergraduate laboratories originating from recent research advances and modern research facilities in electrical engineering. "Research-as-model-for-education" creates a very vicious circle of capital needs and expenditures.

The difficulties faced by private universities are particularly acute. Whereas many public universities obtain regular capital funds from state legislatures, where such things are considered to be an integral part of a state's annual capital budget, private universities have seen major sources of capital funds entirely disappear. The past decade has seen the federal government eliminate its contributions for bricks and mortar expenditures in universities and the trends to require even greater university matching funds for federal equipment grants. Foundations have virtually eliminated all programs aimed at providing necessary capital—equipment, instruments, or bricks and mortar. Corporations have been reasonably generous in providing equipment and instrumentation grants—which, in turn, imply other, unfunded, renovation and maintenance expenses—but not bricks and mortar.

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Private universities have seen nearly all of their traditional sources of capital funds in all areas—academic and non-academic, research labs and dormitories—disappear in the last 10 years, precisely as the needs for capital items in engineering and science education and in non-technical areas have expanded. Compounding an already severe problem is the fact that these trends are occurring when the capital plants created in many universities during the late 1950s through mid-1960s, in a period where federal funds and foundation funds for such purposes were relatively plentiful, are in great need of replacement or major renovation.

Without access to capital funds—public or private—private universities have several choices: (1) compete with other universities by diverting considerable amounts of operating income into capital, (2) not compete, letting existing plant and facilities deteriorate and become obsolete, (3) reduce the number of areas in which the university attempts to mount serious teaching or research activities, or (4) launch fundraising campaigns to raise, from private donors, resources not available elsewhere. My own university, for example, has been devoting 15-20 percent of its operating incomes[10] to capital expenditures. For the past several years, most of this has gone into capital facilities and equipment in the engineering and science areas, nearly all for research activities. This, I submit, is an extraordinary reinvestment strategy and one that places severe strains on other parts of the university budget. Nowhere is the stress greater than on undergraduate education, in all areas, and on undergraduate student life.

It is no longer the case that only education in the technical areas is capital intensive. At Carnegie-Mellon, we are experiencing and are helping to lead a revolution in higher education through the use of computing technology. Educational applications software being developed at Carnegie-Mellon is at least as prevalent in the liberal and fine arts as in engineering and science. If anything, the use of computing technology in normal classroom settings in non-technical areas is greater than in engineering and science. Equipment grants are encouraged by the federal government through existing tax policies; unfortunately, this encouragement is explicitly confined to engineering and science and can have a detrimental effect on equipment and capital available in non-technical areas of the university. Although competent university administrations can ensure that tax-benefit-stimulated equipment grants to engineering and science will have an indirect, positive effect on other areas, those effects are necessarily much less than if the engineering and science restrictions did not apply.

Private research universities have been fortunate in receiving substantial outside help in acquiring modern equipment and instrumentation grants for both teaching and research. Even these grants—financial subsidies, direct equipment grants, or in-kind contributions— represent a double-edged sword to a university. Federal equipment grants increasingly require substantial university matching funds. Direct grants of equipment almost never provide for the increased operating costs, for maintenance, or for the cost of peripherals and other equipment expenses necessary to make effective use of equipment or instruments. Almost all such equipment grants or subsidies, regardless of source, imply substantial additional expenditures on the part of the university, which, in turn, translate into financial pressure in other areas.

Nowhere is the pressure on private university capital budgets more severe than on "bricks and mortar" items. For private universities, the need for monies for buildings to house new facilities or to renovate existing ones can only be met through diversions from operating budgets or from private individual donors. No help can be expected from foundations, corporations, or government agencies. Consider, for example, the recent experience at my own university in accepting the grant of a large number of personal computers for educational uses. The placing of these personal workstations in public clusters implies a capital outlay of roughly $2,500 per workstation simply to pump more power in and to pull it back out in those areas occupied by the public clusters—to redo electrical wiring to accommodate the increased power load and to air condition the area to remove the excess heat caused by increased power usage. The renovation costs—often invested largely in upgrading the mechanical infrastructure of older buildings, not in creating additional space—routinely exceed the equipment costs in most areas. There is no such thing as free equipment for a university.[11] Increasingly, universities must choose between "slipping a little" in the most capital-intensive areas of education and research and "slipping a great deal" in those less costly, largely non-technical areas for which there is no money left when engineering and science opportunities are taken.

Federal policy helps create distortions in university operations. In attempting to address severe needs for equipment and instrumentation in engineering and science, generous tax credits are given to donors of such equipment. Through budgetary mechanisms discussed briefly above, this is often translated into relatively severe pressures on other, non-technical areas. Reacting to perceived declines in enrollment, the federal government and most private foundations have decided not to provide private institutions with "bricks and mortar" grants or subsidies leaving private universities at a severe competitive disadvantage relative to corresponding state research universities with access to legislatively provided capital programs. Federal tax policies and equipment grants are targeted to engineering and science fields and almost never provide for full-cost support of expensive programs. Universities, unable or unwilling to say "no," come up with the unsubsidized portion of program costs, leaving little or no monies left for non-technical areas. At least at the margin, universities are better off, but, in the long run, there is a resulting flow of resources away from non-technical areas of the university to engineering and science programs that does not necessarily reflect university priorities. The opportunity costs for bolstering engineering and science education can be severe.

To summarize, academic science and engineering research is an increasingly expensive business. To remain competitive—whether one views the competition as other societies or other universities—academic institutions are required to spend large amounts of capital on dedicated research facilities. The federal government does not provide significant sources of monies, except in a few areas, for equipment, and almost no resources for renovation of facilities or for new construction to house research activities. With the exception of state legislative appropriations for public universities, there are no other significant sources of capital funds for universities, other than private, individual donors. In-kind grants and sizable discounts of equipment are available in certain areas, but seldom are full costs considered. The major increases in the demands for capital funds for research, coming largely from engineering and science areas, coupled with a diminished supply create severe pressures and corresponding distortions in academic priorities. Ironically, universities, in addressing research needs for faculty in engineering and science, inadvertently undercut educational programs in engineering and science. The inadvertent effects on other, capital-intensive areas of scholarship and education can be catastrophic. The offending mechanism is a university capital budget with a limited supply of capital.

Policy Recommendations: A Comprehensive Approach for the Federal Government

Federal policies and programs designed to strengthen engineering and science education in the United States, if they are to be effective and if they are to avoid significant negative side effects in other educational areas, must be comprehensive in approach.

Programmatically, federal programs need to recognize the importance of non-technical disciplines to engineering and science education.

Programmatically, federal programs need to explicitly address the role of engineering and science education in non-engineering and science degree programs.

Federal programs must recognize the full relationship between academic research and education in engineering and science. In particular, policies and programs designed to address laboratory, computing, and instrumentation equipment needs in undergraduate education must reflect the fact that engineering and science capital needs for academic research are a major cause of the capital deficiencies in education.

Federal programs designed to strengthen undergraduate education in engineering and science, particularly those addressing capital needs, must either fully fund those programs or realize that failure to do so is an explicit decision to harm education in other, non-technical areas of a university. Although it is beyond the scope of this Committee, one would hope that National Science Foundation educational policies and programs aimed at science and engineering would be crafted in the context of a broader, comprehensive educational policy position for all of higher education.

Federal policy and programs need to address explicitly the immediate and pressing needs for capital funds for institutions of higher education. A major contributor to the current problem for all aspects of university operations is the high demand for and cost of capital facilities needed for modern engineering and science research. Just as the current situation translates engineering and science research needs into a severe financial squeeze for engineering and science education and for all other areas of a university, relief through full-cost support of major portions of engineering and science research capital needs would provide relief to engineering and science education and to other areas of the university.

References

1 National Research Council *Engineering Education and Practice in the United States* Washington, D C.: National Academy Press, 1985. See especially Chapter 4, "Current Status of Engineering Education," where the principal problems cited are current or anticipated shortages of graduate students and faculty due to high starting salaries of B.S. degree holders.

2 See statement by S. Frederick Starr, President of Oberlin College, before this Committee, "More Output from Less Input: Science Education at Leading Liberal Arts Colleges," September 26, 1985.

3. Some of the more obvious problems created directly by the high cost of research and education in engineering and science involve higher tuition payments with a corresponding impact on the number of students attracted to engineering and science (necessarily less) and the socio-economic backgrounds of those students (tendency to exclude minorities, for example) I merely note these as among the more important direct implications of high costs

4. Established in the 1940s, the Carnegie Plan for professional education was based on the notion that engineers, to be effective professionals and leaders, needed the breadth or perspective and intellectual skills found in the humanities and social sciences The result was one of the first engineering programs in the nation to require that a quarter of an engineering student's coursework be in the liberal arts. The modern version of this philosophy of education, of the symbiotic relationship between liberal and professional education, is the core curriculum in the Carnegie-Mellon liberal arts college, requiring a year or more of coursework in one of the physical sciences, and in mathematics, computer science, and statistics It is also the basis for our new, university-wide core curriculum, encompassing all students in engineering, science, humanities and social sciences, and the fine arts

5 The viable, long-term solution to the problem of handling the explosion of things to be covered in an undergraduate engineering education, while providing requisite breadth to an undergraduate education, is likely to involve either. (1) moving the standard engineering degree program to five years, or (2) changing the concept of the terminal professional engineering degree from better engineering programs from a four-year B.S. to a one-year M S following a more liberally based B.S. degree. Because it adds a degree of freedom to the overall educational system, I prefer the "M.S solution."

6. In addition, they have an excellent track record in undergraduate science education.

7. For example, MIT, RPI, Carnegie-Mellon, Princeton

8. See Starr, op. cit

9. Due partly to high starting salaries for B S engineers and scientists and a paucity of graduate fellowships

10. "Operating income" includes tuition and fees, indirect research costs recovered, unrestricted gifts and grants, endowment income, and other miscellaneous income

11. Clearly, the federal government could decide to play an even more constructive role than it currently does by providing full-cost funding for *research* equipment grants—including necessary building renovation and mechanical infrastructure expenses, operating and maintenance costs, etc.

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The Future of Undergraduate Science and Engineering Education

M. Richard Rose

President
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It is my pleasure to have this opportunity to speak with you today about the critical challenges facing undergraduate science and engineering colleges. I would submit that these are challenges for the nation as a whole because of the central importance of a strong educational foundation to our national ingenuity and productivity and our ability to compete effectively in international markets. With this theme in mind, I would like to present a perspective on the future of undergraduate science and engineering education that I hope will be helpful to you in your deliberations.

Webster defines the word challenge as "a summons that is often threatening, provocative, stimulating, or inciting." In the case of the future of science and engineering education in the United States today, I would suggest that all of the above characteristics apply:

- That the National Science Board, as the policymaking authority of the National Science Foundation, is sufficiently concerned with the subject to commission a comprehensive report and recommendations is evidence of the fact that the quality of education in these critical disciplines is threatened by internal and external forces, and that the economic future of our nation could hinge in the balance.

- It is a provocative situation in that it has served to evoke comments and proposed solutions from a wide range of sources, including those in the industrial sector as well as government and academia.

- It has stimulated almost unilateral recognition that some concerned, proactive measures must be taken to address the roots of the problem and to look for new and innovative approaches for effectively distributing limited resources.

- And, finally, it has incited action not only through forums such as these, but, also, through the implementation of new programs that have begun to address the critical needs of undergraduate science and engineering education for faculty, facilities, and instrumentation, both in the private and the government sectors.

Much, however, remains to be done. The initiatives that the National Science Foundation has taken in support of in umentation and research at undergraduate institutions are to be applauded. The Rochester Institute of Technology (RIT) was fortunate to receive two instrumentation grants last year in chemistry and computer science, as well as a sizable grant in support of our program of workshops for high school math and science teachers. These grants will have a direct benefit on the communities we serve, and we were pleased to have been successful in obtaining them.

For the moment, in order to lay the foundation for my subsequent remarks and recommendations, I would like to describe briefly the institution that I represent here today.

The Rochester Institute of Technology is a comprehensive, predominantly undergraduate institution which enrolls nearly 15,000 women and men in a wide range of technical and scientific disciplines. The Institute is comprised of nine colleges, among them the National Technical Institute for the Deaf (NTID), one of four special institutions funded by the federal government through the Department of Education.

The range of program options within the colleges reflects the diversity of the Institute and the impact of technological advancements on college curricula. NTID is the only technological institute in the world expressly designed to meet the needs of the hearing impaired. In our College of Science, for example, traditional programs in biology, mathematics, physics, and chemistry have been joined by majors in biomedical computing, biotechnology, nuclear medicine technology, and ultrasound technology, some of which have been initiated within the last two to three years. Similarly, our College of Engineering last spring graduated its first majors in microelectronic engineering, a program begun in 1982 to meet a specific industrial demand due to the lack of any undergraduate programs in this emerging field.

Our College of Graphic Arts and Photography, which has a long-s. nding international reputation for its expertise in printing and photography, is also at the forefront of scientific development. Its education and research programs include imaging and photographic science, a rapidly developing technology with inexhaustible potential for application in fields ranging from artificial intelligence to robotics.

The College of Applied Science and Technology at RIT is the location for programs in computer science, engineering technology, and packaging science, among others. As with science and engineering, these programs represent an integral part of the technological educational infrastructure in our nation and, with respect to federal policy, merit consideration.

Integral to RIT's fundamental mission to prepare students for successful careers is the cooperative work experience. Co-op is an opportunity for our students to gain hands-on experience in their chosen fields and to put into practice what they have learned in the classroom. Since co-op "blocks" are typically alternated with quarters "on campus," the resulting synergism benefits the students, faculty, and other classmates alike by helping to bring new theories and ideas into classroom discussion.

Although I have described RIT in more detail than is perhaps necessary in this forum, I have done so to illustrate the foundation for an educational philosophy that has begun to emerge at our institution and that reflects the continuing evolution of the Institute. RIT's growth and development have historically paralleled the changing nature and needs of industry. In looking to the future, we see a divergence from the traditional focus on single disciplinary specialties to an emphasis on individuals with a broad range of scientific and technical skills. In short, the complex needs of our nation will be addressed in the future by an interdisciplinary approach to problem-solving and scientific investigation.

As a case in point, our microelectronic engineering program, the only undergraduate program of its kind in the nation, was made possible through the integration of faculty expertise in physics, chemistry, photographic science, and electrical engineering. Similarly, the means to address the future development of our manufacturing systems will require collective wisdom that cuts across several disciplines. Hence, I would urge the National Science Board and the National Science Foundation, first and foremost, to encourage innovation and creativity in undergraduate science and engineering education with an emphasis on interdisciplinary curricula, which will meet the diverse needs of our nation and enable us to be best prepared to meet new challenges.

Such an approach parallels the need for innovation and creativity in supporting the task ahead of us, a task that will require cooperation—a partnership if you will—among government, industry, and academia. The needs are enormous and, by traditional means, may be, indeed, insurmountable. Fortunately, there are, I believe, viable possibilities achievable within the context of such a partnership.

Moreover, this partnership, in order to succeed, must focus on a common goal—the economic future of our nation.

As I mentioned earlier, the National Science Board, through these hearings and its intent to study the needs of undergraduate science and engineering education, is helping to confirm the central importance of undergraduate education to the quantity and caliber of our nation's future cadre of scientists and engineers. That in itself is a significant step toward solutions that can best position our educational infrastructure to meet the challenges ahead. As Ray Stata, Chairman of Analog Devices, stated in a 1982 address to the Semiconductor Industry Association:

> "...the size and quality of the [electrical engineering] workforce will have the greatest impact on the growth and development of the electronics industry in the 1980s and 1990s. Computer science is also becoming increasingly important...."

Data on the makeup of the engineering workforce further affirm the importance of high-quality undergraduate instruction. A recent report by the National Research Council noted that approximately half of the bachelor of science degrees in engineering are granted by predominantly undergraduate institutions—in other words, the government and industrial sectors are all dependent upon those institutions for half of their engineering employment.

As I am sure you will hear as a consistent message throughout these hearings, the most immediate concerns for undergraduate science and engineering relate to the urgent needs for faculty and for facilities and instrumentation. Two other major issues are the need to find effective means of encouraging more women and minorities to pursue science and engineering careers, and the continuing educational needs of the science and engineering workplace. I will concentrate my remarks on these four issues and offer some suggestions as to how we might develop a national strategy to deal with them.

Faculty

A recent survey of engineering deans found a total of 1,567 unfilled faculty positions. The "vacancy rate" in engineering today, calculated as a percentage of budgeted faculty positions, is 8.5 percent, which is two to three times the expected national norm.

At RIT, although we have, as a matter of necessity, made a concerted effort to keep our salaries competitive, we have experienced similar difficulty in recruiting faculty in our College of Engineering. Nationwide, it has been estimated that to restore faculty/student ratios to their peak levels (last realized in 1975–76) would require some 6,700 new faculty members.

Undergraduate institutions are hit hardest by this critical shortage of engineering faculty, not only because of salary expectations, but because the teaching requirements of these positions currently leave relatively little time for the kinds of research and professional development opportunities that are so vital in enabling faculty members to keep abreast of new technological and scientific developments. There is no question as to the dedication of faculty to science and to their students at these predominantly undergraduate institutions. However, the allure of significantly better salaries and greater opportunities for research, postdoctoral study, and other professional development opportunities is all too often a temptation that cannot long be resisted by some. As the gap continues to grow, retention of faculty in these disciplines will become increasingly difficult for undergraduate institutions.

Obviously, there are no pat answers or simple solutions to this dilemma. Colleges and universities, particularly in the independent sector, will not be able to offer salaries to scientists and engineers that would match those available to them in industry. What is needed, then, are creative approaches that recognize the mutual interests at stake and that provide for a realistic and reasonable level of support as an investment in our nation's economic future.

That we must increase the pool of capable faculty is an inescapable conclusion. To do so, we must make faculty careers more attractive to recent graduates and current students alike.

A related issue is the relatively high percentage (42 percent in 1983) of foreign nationals who are pursuing graduate study in the United States on temporary visas. Many of these foreign nationals have assumed faculty positions in colleges and universities and have made an invaluable contribution; without them, our engineering faculty shortage would be even more severe. However, for the long term, we need to address the issue of increasing the numbers of native-born Americans in advanced studies, since the temporary visas of many current and potential faculty will eventually expire. We as a nation must be prepared for these circumstances, and, as the National Research Council recommends in its report, *Engineering Education and Practice in the United States*, emphasis should be placed on increasing the proportion of U.S. residents in our doctoral programs.

To address the need, funds should be made available for graduate fellowships and stipends so that recent graduates will have an incentive to continue their studies. To assure that these funds will indeed be targeted to the problem at hand, the fellowships might be contingent upon a commitment to teach for a certain period of time; failure to live up to the commitment might require a repayment of the fellowship amount.

To help provide a more attractive climate to potential faculty in an undergraduate setting, several opportunities should be considered seriously. The NSF Research at Undergraduate Institutions program is a welcome opportunity for faculty members to compete for scarce research dollars. As further recognition of the significance of research being accomplished in undergraduate settings, the Presidential Young Investigators program should also be accessible to faculty at these institutions. Currently, nominations for these prestigious awards are limited to faculty at Ph.D.-granting institutions or to individuals with industrial experience. This relatively arbitrary restriction should be lifted.

The Undergraduate Research Participation program should be reinstituted. This program could provide opportunities for faculty and students to participate in productive research and also serve to whet the appetite of undergraduate students for careers in academic research and teaching.

Collaborative research opportunities in federal research laboratories and major academic research centers for undergraduate faculty would begin to develop the partnerships suggested earlier. The National Science Foundation should take the initiative in funding support of professional development leaves for undergraduate science and engineering faculty, particularly for summer periods. The former Science Faculty Professional Development program administered by the Foundation was very helpful in this regard. Such leaves might support a faculty member's individual professional pursuits or provide opportunities for collaborative research projects.

Finally, given the realities of salary competition and other factors, we will not begin to address the faculty shortage issue adequately without developing creative means to tap the potential pool of adjunct faculty in industrial settings. Incentives to encourage formalization of exchange programs, tax relief opportunities for businesses who "lend" their talent to educational institutions, and funding to develop and implement new technology for delivery of educational programs offer a wide range of options with potential for significant mutual benefit.

Facilities and Instrumentation

Equally critical to the foundation of a quality education is the ability for students and faculty to have access to state-of-the-art instrumentation and laboratory facilities. An important note is that the need for basic laboratory equipment is equally as critical as that for specialized instruments. Donations of specialized, highly sophisticated instruments by business and industry have been especially helpful to RIT, for example, in enabling us to equip the laboratories in our new microelectronic engineering program. Since 1982, we have received equipment valued at over $2.7 million for this program alone. However, in this and other high-technology programs, we have an ongoing need for basic laboratory equipment that is becoming increasingly difficult to come by through industrial donations. The conventional wisdom in the educational and scientific community calculates a useful lifespan of laboratory equipment of approximately 10 years. However, a 1982 survey of the National Society of Professional Engineers found the average age of lab equipment in engineering schools to be 20 to 30 years. It is generally acknowledged that the median age of instrumentation in colleges and universities is twice that of industry.

The implications of these phenomena are abundantly clear. State-of-the-art instrumentation, particularly in the sciences and engineering, is directly related to the ty of the educational experience that can be provided and, subsequently, to the productivity of our graduates immediately upon graduation if they must require additional on-the-job training with unfamiliar equipment.

At RIT, we are particularly proud of the fact that employers who have hired our graduates consistently report that the graduates are not only well educated, but also are able to immediately fit into their work settings with a high degree of initiative and seriousness of purpose. We believe that our students graduate with a high degree of confidence in their abilities, engendered by their classroom and laboratory work on campus as well as their cooperative work experiences. Because of their cooperative work, our students are also unusually knowledgeable about the state-of-the-art instrumentation in their chosen fields. Hence, we need to be particularly concerned about the quality of our own facilities if our students are to continue to appreciate the value of their RIT education. Moreover, the level of instrumentation in the academic setting is a significant factor in attracting and maintaining faculty who would have access to such equipment in the major research centers or in an industrial setting.

In terms of federal policy, the College Science Instrumentation Program is a wise investment and should be continued and expanded.

Cost-conscious businesses and industry want to ensure that their corporate contributions have a high degree of leverage power. To help stimulate donations of equipment to college campuses, the National Science Foundation should advocate tax relief opportunities and other efforts to stimulate matching grants.

Finally, the Foundation might consider a challenge grant program, similar to those in other agencies of the federal government, aimed at comprehensive support for academic facilities, equipment, and program development. The program might indeed focus on interdisciplinary initiatives that can demonstrate a significant correlation with national economic priorities and industrial support.

Enrollment of Women and Minorities

Women and minorities are still significantly underrepresented in science and engineering programs and the professional ranks as well.

Ultimately, if we are to raise these numbers successfully and to increase the representation of women and minorities systematically at all the steps along the science and engineering continuum, we must address the need for effective intervention at the junior and senior high school levels. It is at those levels where many students, consciously or otherwise, begin to make the decisions that will ultimately affect their career paths. Junior and senior high school students who fail to pursue anything beyond the minimum requirements in mathematics and science are automatically restricting their options. As technology becomes even more pervasive throughout our society and the workplace, the chasm between their limited options and their future career opportunities will continue to grow.

The sequential requirements of these disciplines, particularly in such fields as mathematics, underscore the need to ensure that the path to a scientific career is not broken prematurely. Steps must be taken not only to encourage women and minority students to continue to study these subjects, but also to provide secondary school teachers with appropriate materials and information about potential careers which they can share with students who may become discouraged or who have questions about applying what they learn. Enrichment programs, in-service activities for high school teachers, and student mentoring are among the mechanisms that must be brought to bear on this fundamental problem.

Continuing Education

Technology by definition is a dynamic, ever-changing phenomenon. The rapid growth in recent years of "in-house" education programs at many large corporations attests to the ongoing need of professional employees, including scientists and engineers, to keep abreast of new knowledge and its applications. Technology itself has opened new vistas for the delivery of continuing education, as remote locations have the increasing potential to be brought "closer" to the campus via telecommunications. It is not a question of whether continuing education is necessary—rather, the issues are cost and accessibility, and how these services can be delivered most cost effectively.

The changing nature of our economy also points to the need for lifelong learning and accessible educational opportunities. The Rochester region is a case in point. Rochester industry has historically had a very strong manufacturing base, with a particular emphasis on high-technology products and processes, such as photographic materials and optics. As our industrial leaders look to the future, they project a changing workforce in our community which will be based on skilled technical personnel and technicians. Some have gone so far as to predict that there will be *no* unskilled labor in the manufacturing workforce within 10 years.

Appreciation of this startling phenomenon underscores the dynamic state of technology throughout science and engineering, a phenomenon that we must be prepared to address quickly and effectively, for failure to do so will directly and negatively affect our international competitive position. Key to the solution of this need are the development of new teaching materials responsive to the needs of this contingent of highly sophisticated learners and the use of innovative delivery systems. Industries and academic institutions will need to develop effective linkages to address the issues of when, where, and how continuing education programs can be delivered.

To help disseminate information about the most successful of such models, the National Science Foundation might consider a program of achievement awards, which would give national recognition to particularly successful linkages and provide support for dissemination of knowledge to assist other interested organizations.

The challenge is before us, as are the opportunities for innovation and creativity. We at RIT will continue to develop our programs to meet the needs of industry within the resources available to us and, we hope, with the support of those industries. We look to the National Science Board to continue to exercise leadership in recommending federal policy for engineering and science education and welcome any opportunity to contribute to your deliberations.

Dow's Need for Technically Trained People in the 1990s

David P. Sheetz

Vice President and Director of Research and Development
Dow Chemical Company

I will leave discussions on the *quality* of science and engineering undergraduate education to others. In short, I am satisfied that the quality of students graduating from American colleges and universities today is pretty good. In other words, we are not suffering from a serious breakdown in the actual education of our students, as far as I can tell.

Instead, the message I have come to deliver today is straightforward, and it concerns *quantity*—specifically, the declining number of American science and engineering undergraduates and the corresponding reductions in Ph.D. candidates.

This is of particular concern to the Dow Chemical Company because, while the supply curve seems to be falling, our demand for technical people, particularly in the chemical and related sciences, is on the rise, and it will continue to increase into the 1990s. Perhaps more important, Dow is not alone in this trend. In general, the demand for engineers and scientists is increasing to the point where a significant shortage in this country is indeed a possibility.

Why is demand for technical skills increasing in the United States? In what areas is that demand the greatest? What effect will dwindling high school enrollments have on the future number of undergraduate and Ph.D.-level chemical engineers, chemists, and other technical professionals? In turn, how will that affect U.S. industry?

To answer these questions, I will rely on information related specifically to Dow Chemical employees in the United States. But my experience tells me that much of what I say may be applied in a similar manner to other companies and other industries as well.

At Dow, our demand for technical skills is increasing because the nature of our business has changed. International competition has tightened, and the commodity chemicals business is no longer the profit-generator that it was in the 1960s and early 1970s.

Today, in order to survive and prosper in the future, we continue to shift a large share of our resources toward a growth and diversification effort that includes basic research, development, and marketing of specialties, e g., new specialty chemicals, pharmaceuticals, agricultural chemicals, and consumer products (Table 1). Over the next few years, the largest portions of our global sales growth will come from these specialty areas, which, incidentally, require a considerably higher level of technical support per dollar of sales than do commodity chemicals.

Table 1. Dow Chemical Company: Projected Sales Growth in Ten Years.

Specialty Areas	% Growth
Industrial raw materials	+50
Specialty products	+87
Human health	+200
Agricultural chemicals	+150
Consumer products	+200
Total	+90

About half of our total sales will come from the United States, where our 1992 goal is to have specialties account for 60 percent of our sales and better than 60 percent of our profits. Today, both figures hover a little above the 40 percent mark.

To achieve those goals, we will be placing more technically trained people in some of these specialty areas—coatings and resins, human health products, agricultural chemicals, and specialty plastics, while our employee needs will fall slightly in the commodity segments of our business—inorganic and organic chemicals and hydrocarbons (Table 2).

Table 2 Projected Growth of Technical Manpower by Selected Product Segments in Dow U.S.A.

Product Segment	% Growth
Inorganic chemicals	−10
Organic chemicals	−10
Hydrocarbons	−20
Coatings and resins	+60
Specialty plastics	+40
Agricultural chemicals	+35
Human health	+50

That is how we are going to deploy our additional technical employees, but more important to this Committee is from what academic areas we plan to pull these people. Where specifically is our demand going to increase?

Before I can explain how our employee mix is going to change, it is necessary to understand where we are today.

Table 3 shows actual 1984 figures representing the number of technical Dow employees working in the United States. There are about 7,000 employees with technical degrees of all sorts. This includes employees working in research, manufacturing, sales, and administration. Two-thirds of the total have bachelor's degrees, and nearly 900 have doctorates.

Table 3. Dow in the U.S.A.: Degree Level of Full-Time Exempt Technical.

Degree Levels	Technical
Under 4 years	294
Bachelor's	4,638
Master's	1,077
Doctorate	885
Total	6,894

Better than half of the overall total are engineers, and together, engineering, chemistry, and life science graduates make up nearly all of our technical population (Table 4). We also employ a number of physical science and math/computer graduates.

Table 4. Dow in the U.S.A.: Exempt Count by Technical Discipline Group.

Discipline Group	Exempt Count	%
Engineering	3,778	55
Chemistry	2,157	31
Physical sciences	129	2
Math/computers	137	2
Life sciences	693	10
Total	6,894	100

The degree levels within each of these categories are about what you would expect (Table 5). Most of our engineers have B.S. degrees, while a significantly higher percentage of chemists and life scientists hold doctoral degrees.

Table 5. Dow in the U.S.A.: Full-Time Exempt Degree Levels of Technical Discipline Groups (All Functions).

Technical Discipline Groups	Technical Degree Level					
	To 3 Yr	Bach.	Mast.	Doct.	Total	%
Engineering	187	2,987	488	116	3,778	54 8
Chemistry	42	1,073	428	614	2,157	31 3
Physical sciences	12	80	24	13	129	1 9
Math/computers	17	101	16	3	137	2 0
Life sciences	36	397	121	139	693	10 0
Total	294	4,638	1,077	885	6,894	100 0

Table 6 gives you some idea of the variety of disciplines from which we seek employees and the magnitude of each. Chemical engineers are obviously the largest single segment, and although the list is shortened here, we certainly employ a variety of different chemistry specialists. This listing does not include every discipline, but it does touch on our two primary areas of concern—engineering and chemistry.

Table 6. Dow in the U.S.A.: Full-Time Exempt Degree Levels of Specific Technical Disciplines (All Functions).

Discipline Group	BS/MS	Doctorate	Total
Chemical engineer	2,135	89	2,224
Mechanical engineer	609	5	614
Electrical engineer	270	5	275
Civil engineer	149	0	149
Other engineers	312	17	329
Totals	3,475	116	3,591
General chemist	1,318	150	1,468
Organic chemist	61	225	286
Physical chemist	22	95	117
Analytical chemist	32	57	89
Inorganic chemist	30	43	73
Polymer chemist	18	29	47
Other chemists	20	15	35
Total	1,501	614	2,115

From this actual 1984 data, you get a feel for our current use and need for technical people. It is a benchmark for talking about our future needs in these same disciplines. If we were merely to maintain these levels, natural attrition would require us to seek a significant number of new employees each year. In fact, since 1980, technical recruiting has averaged about 400 new employees annually in the United States, and our overall number of technical people has stayed about constant over that period. That is going to change.

To estimate our needs for the future, we surveyed a representative number of middle managers from every major function. The survey was conducted at the end of last year, when the managers were asked to list their 1984 employee figures and their estimated needs for 1992.

We have also calculated our future employee needs by taking our economic forecasts and calculating increased R&D needs as a percent of sales. This macro approach is in general agreement with the data to be presented here and, therefore, enhances our confidence in their validity.

Table 7 shows the results of our survey. In total, our need for technical employees will increase 40 percent stretched over the next few years. The numbers in the top half of the table are the results of the sample survey and the corresponding percentages. At the bottom, the percentage increases are applied to the actual 1984 employee totals to project the survey's implications for Dow in the United States.

Table 7. 1992 Technical Disciplines: Dow in the U.S.A.

Survey Results/1,000 in 1984			
Degree levels	1984	1992	Δ %
BS/MS	785	1,093	+39
PhD	215	312	+45
Total	1,000	1,405	+41

Survey Implications: Dow in the U.S.A.			
Degree Levels	1984	1992	Δ Total
BS/MS	5,715	7,959	+2,244
PhD	885	1,283	+398
Total	6,600	9,242	+2,642

The increases are, in my opinion, large enough to be labeled significant across the board. Of particular importance is the substantial expected increase in Ph.D.'s. I will address that need specifically in a few minutes; but first, Tables 8 through 12 show how the survey results apply to our five major academic groups.

Note two things. First, these are results of a representative survey, and, as such, the percentages are the most important figures. Second, in these tables, no distinction is made between graduate and undergraduate degrees.

Table 8 shows that in our three main areas—engineering, chemistry, and life sciences—the percentage increases are all around that 40 percent figure.

Table 8. Survey Results/1,000 in 1984—Technical Discipline Groups (BS/MS/PhD).

Discipline Group	1984	1992	Δ %
Engineering	463	629	+36
Chemistry	367	523	+43
Physical sciences	25	29	+16
Math/computers	18	36	+100
Life sciences	127	188	+48
Total	1,000	1,405	+41

Specifically, by 1992, our need for engineers will be up about 35 percent (Table 9). In real numbers, the largest increases will be for chemical engineers and mechanical engineers, whose percentages translate across the United States to an increase of a few hundred employees in each area. Ceramics will still be a relatively small field in 1992, but its growing importance is reflected in a doubling of manpower.

We expect a sizable increased need for people from several particular chemistry disciplines (Table 10), most notably, polymer chemists and material scientists, where our increases are 250 and 320 percent, respectively. There will be modest increases in our need for organic, inorganic, physical, and general chemists. Again, the small, but growing importance of ceramics technology to Dow Chemical is apparent.

Table 9. Survey Results/1,000 Engineers in 1984—Engineering Disciplines (BS/MS/PhD).

Discipline Group	1984	1992	Δ %
Chemical	687	897	+31
Mechanical	154	261	+70
Electrical	72	97	+35
Agricultural	3	2	−33
Ceramic	2	5	+150
All others	82	96	+17
Total	1,000	1,358	+36

Table 10. Survey Results/1,000 Chemists in 1984—Chemistry Disciplines (BS/MS/PhD).

Discipline Group	1984	1992	Δ %
General chemistry	520	687	+32
Organic	229	280	+22
Inorganic	50	60	+20
Material science	14	59	+321
Physical chemistry	74	99	+34
Ceramics	3	15	+400
Polymer	32	114	+256
Analytical	60	94	+57
Pharmaceutical	2	6	+200
Agricultural	1	1	0
Electrochemical	7	10	+43
All others	8	2	−75
Total	1,000	1,427	+43

In the life sciences (Table 11), Dow's projected needs will grow about 50 percent with significant percentage increases in biology, medical science, agricultural science, zoology, and botany.

Table 11. Survey Results/1,000—Life Science Disciplines (BS/MS/PhD).

Discipline Group	1984	1992	Significant Changes
Biology	371	557	+50%
Medical science	228	380	+67%
Agricultural science	96	122	+27%
Entomology	55	66	+20%
Zoology	49	64	+31%
Botany	43	55	+28%
Other life science	158	240	+52%
Total	1,000	1,484	+48%

Finally, in other science disciplines (Table 12), we will continue to increase our use of computer technology as indicated by the large increase in demand for computer science graduates.

Table 12. Survey Results/1,000 in 1984—Other Science Disciplines (BS/MS/PhD).

Discipline Group	1984	1992	Δ %
Physics	264	327	+24
Math	164	182	+11
Computers	264	641	+143
Other sciences	308	334	+8
Total	1,000	1,484	+48

As mentioned previously, I am most concerned about meeting our increased demand for scientists with doctorate degrees. Obviously, these are our most advanced scientists, and with an increasing emphasis on specialty products, their specialized expertise is more critical than ever. By 1992, we will need about 200 additional chemists with Ph.D.'s, 130 more people with doctorate degrees in the life sciences, and 50 additional Ph.D.-level engineers (Table 13).

Table 13. Technical Discipline Doctorates.

Discipline Group	1984	1992	Δ %
Engineering	84	135	+61
Chemistry	587	795	+35
Physical sciences	7	13	+86
Math/computers	2	6	+200
Life sciences	205	334	+63
Total	885	1,283	+45

As we get more specific (Table 14), you can see exactly where our biggest needs are, in order—polymer chemists, chemical engineers, biochemists, etc. By 1992, we will require somewhere between 350 and 400 more Ph.D.-level scientists than we employ today. That is a 45 percent increase over a seven-year period.

Table 14. Specific Technical Doctorates.

Discipline Group	1984	1992	Additions
Polymer chemistry	32	91	+59
Chemical engineering	73	112	+39
Biochemistry	38	72	+34
Organic chemistry	287	315	+28
Analytical chemistry	56	84	+28
Material science chemistry	20	48	+28
Physical chemistry	99	126	+27
Pharmacology	28	44	+16
Inorganic chemistry	62	77	+15
Ceramics	3	17	+14
Medicine	17	26	+9
Mechanical engineering	1	10	+9
Medicinal chemistry	11	19	+8
Veterinary medicine	13	20	+7
Electrochemistry	9	16	+7
Physics	7	13	+6
Entomology	14	20	+6
Pharmacy	10	16	+6
Plant physiology	12	17	5
Microbiology	16	20	+4
Agronomy	6	9	+3
All others	71	111	+40
Total	885	1,283	+398

We are worried about filling these and all of our technical employee needs for two reasons. First, over the next 10 years, nationwide demand for people from technical areas is going to rise, according to the Bureau of Labor Statistics. Table 15 shows a sampling of that demand. Like Dow Chemical, others will be looking for additional chemists, chemical and mechanical engineers, and computer scientists, among other disciplines.

Table 15. Job Outlook: Total U.S. Demand 1982–1995.

Chemical engineers	+43%
Electrical engineers	+65%
Mechanical engineers	+52%
Computer engineers	+85%
Petroleum engineers	+22%
Chemists	+22%

The second reason that we are concerned is that at the same time demand is going up, supply apparently will be coming down (Figure 1). The estimated number of high school graduates will drop in the coming years and will remain low well into the next decade. This decline will have a sizable corresponding impact on the future supply of science and engineering undergraduates and Ph.D. candidates.

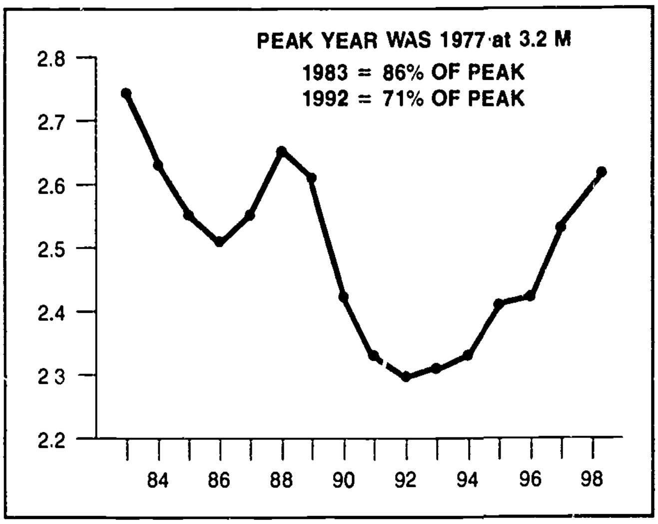

Figure 1. Projected Number of High School Graduates: 1983-1998 (Millions).

Based on current high school enrollment figures and the traditional percentage of those who pursue technical degrees in college (Table 16), it is estimated that the decline in science and engineering bachelor's and doctoral degrees will continue through the end of the 1980s. This is of particular concern when you consider that an increasingly large percentage of the graduates are foreign nationals, many of whom will return to their country of origin.

Table 16. 1980 Projection of Science and Engineering Degrees* (Thousands).

	Bachelor's	Doctoral
1981	191.3	10.8
1982	202.5	10.6
1983	203.8	10 3
1984	202.0	10 1
1985	198 8	9 8
1986	196.3	9 6
1987	192.5	9.4
1988	191.1	9.3
1989	191.1	9.0

*Physical sciences, engineering, math sciences, and life sciences Social sciences are excluded

I feel as if to this point I have inundated you with numbers. Please realize that the figures are merely reinforcement. As a scientist, I need facts and figures to support my conclusions. But all of those numbers can be boiled down to a simple message: I am concerned that the number of students graduating with bachelor's and doctorate degrees in science and engineering from American colleges and universities will not meet the growing future needs of Dow Chemical, and American industry in general.

As I have discussed, Dow has established specific sales and profit goals necessary to remain a viable company competitive within the chemical industry. Simultaneously, we have estimated from what disciplines we need employees and how many from each are necessary to achieve those business goals. Our projections indicate that by 1992 we will need to have increased our number of technical employees by 40 percent, a net compounded annual growth rate over attrition of about 5 percent per year. Should we fall significantly short of meeting these needs, our ability to achieve the sales and profit objectives that we have set will be jeopardized.

There are several things Dow Chemical and the National Science Foundation can do today to ensure that our technical personnel needs are met in the future.

Our efforts should begin at the grassroots—in elementary and junior and senior high schools—promoting interest in science and engineering, because it is here that we can have some impact. We cannot really expect to change high school enrollments, but we can change the traditional percentage of graduates who pursue technical degrees in college. As Table 17 indicates, there is certainly room for improvement. For every 2,000 seventh grade boys and 2,000 seventh grade girls, there will emerge 63 scientists and engineers with bachelor's degrees and 6 with Ph.D.'s. At the precollege level, we can do several things to help raise these percentages. For example, we can help sponsor local, state, or national science fairs, coordinate activities around and support the National Science Foundation's National Science Week, produce films that are written specifically to interest kids in science, or encourage our scientists to go to schools and talk in general about what they do.

Table 17. Potential Scientists and Engineers in Quantitative Fields.*

	Boys		Girls	
	Total	S/E Pool	Total	S/E Pool
Seventh grade	2,000	1,000	2,000	1,000
High school graduates	1,400	283	1,560	217
College freshmen	900	143	830	45
Bachelor's	480	44	440	19
Master's	140	14	150	4
PhD's	20	5	10	1

*Physical sciences, math sciences, computer sciences, biological sciences, economics, and engineering

At the college level, we should continue and expand our support of science and engineering undergraduate programs. We should, for example, work closely with university faculty so they are aware of our needs, encourage qualified students to pursue graduate studies and offer them incentives to do so, and promote co-op education and internship programs that give students and companies a better understanding of each other.

I would encourage the National Science Foundation to get involved specifically in support of undergraduate science and engineering education. As I said at the beginning, in many ways graduates of American universities set the quality standard for the rest of the world, but that quality could be threatened without proper federal support.

Modern science requires sophisticated and increasingly expensive equipment and scientists versed in current technology. As advances are made, it is imperative that both undergraduate and graduate education keep up with the improved technology. This will not be possible without proper guidance and funding at the federal level.

I think the challenge is clear. We must all work to maintain the quality of American science and engineering education while at the same time increasing the quantity. If we fail in this purpose, the implications for the future competitiveness of our society are ominous indeed.

Undergraduate Science and Engineering Education

John S. Toll

President

University of Maryland

It is a special pleasure to be invited to present my thoughts on the role of the National Science Foundation in undergraduate science and engineering education. I am especially impressed by the distinguished character of this Committee, most of whose members I have known in one way or another for many years. I am confident that your report can have a major effect in stimulating improvement of national programs for science and engineering education.

It is reasonable to separate the consideration of undergraduate science and engineering education into two parts: First, programs for students whose undergraduate major will be in some field of science or engineering as preparation for a probable career in one of these fields; second, courses of general education that should be recommended or required for all undergraduate students to give them a basic understanding of science and engineering.

I expect that most of your attention will focus on the first category. It is important, however, that the National Science Foundation should also be concerned with the understanding of science and engineering by all college students. This is particularly important in the United States, since we devote much less time and attention to science and engineering education in our secondary schools than do many other nations. Indeed, if the term "liberal arts" is to be anything more than a quaint anachronism in our time, its meaning must encompass a decent level of literacy in the mathematical foundations of science and technology, plus direct experience in the actual processes of at least one science. I fear that we may be further away from this goal in our undergraduate institutions today than we were a decade ago, with fewer non-science majors electing science courses than heretofore.

The best remedy, I believe, is for universities and colleges to require of all students a basic level of mathematical understanding and skill and at least one sound science course. Exciting electives well beyond the basic level would then be more feasible, and would attract more students and thus further increase appreciation of science and mathematics among general students. Colleges and universities must set standards of basic mathematical competence that place particular stress on problem-solving. For many institutions, this standard should be raised above current levels to include understanding of basic elements of the calculus and of foundations of computer logic and programming, since these will be increasingly important skills. All degree recipients should be expected to meet minimal levels as fixed by these standard requirements, but many students should be encouraged to go further in science, and institutions should give much more emphasis to the creation of good elective courses in the sciences.

In this connection it might be useful to note the phenomenon of computer games. Many of our students spend hours playing computer games, presumably hooked on the sheer intellectual fun of interacting with the machine. The field of computer-assisted learning exploits this fact. Through direct interaction with the student, the computer can give problem-solving hints, adjust assignments to individual student needs, and help to assure mastery of each successive level in a sequence. Can we capture our students' enthusiasm for computer games in behalf of learning? We need much more effort by our faculties nationally to use computer-assisted learning imaginatively in teaching college-level mathematics, science, and engineering principles and problem-solving techniques. This use of computers in teaching problem-solving does not imply that computers can solve all of our teaching problems, and it is given only as one example of the general goal: courses that excite the general student and are adjusted to each student's pace and needs. Such approaches may also prove effective in making efficient use of limited laboratory space and equipment in our institutions. Faced with the escalating cost and complexity of laboratory facilities, many institutions have greatly reduced or eliminated the laboratory component of science courses.

Laboratory teaching *is* expensive, but it is essential if we are to teach science, and not merely teach about science. The National Science Foundation can, and I believe must, help with grants to assist institutions with equipment and laboratory construction in efficient arrangements.

The substantial increase I contemplate in national efforts to ensure basic mathematical and scientific literacy for *all* our college graduates would also help to make a start on the issue that I expect will be the primary focus of this Committee's work, namely, the critical matter of

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attracting more able students to careers in science and engineering, and then providing them with the best academic preparation our educational institutions can devise.

For these fledgling scientists and engineers, our efforts should focus on:

1. Curriculum development, to assure that the content and methods of teaching mathematics and science keep pace with current developments in scientific practice and interests.

2. Facilities renewal, to assure that laboratory facilities and equipment for teaching stay abreast of research in the natural sciences and engineering.

3. Articulation between undergraduate and graduate programs, to assure that our undergraduate science majors are in fact consistently and effectively prepared to pursue challenging work at the graduate level. This could help, for example, to encourage well-planned undergraduate research opportunities.

All three of these concerns offer opportunities for the National Science Foundation to provide leadership and substantive help. NSF deserves high praise for its outstanding support of curriculum development in the past, and I believe these groundbreaking programs point the way toward meeting current needs. The national programs of curriculum development—in biology, under Bentley Glass; in physics, under Jerrold Zacharias; and in chemistry, under Glenn Seaborg—all benefited enormously from the leadership of those distinguished scientists and from the economic and organizational support of NSF. While they were aimed at the secondary schools, their influence quickly extended to college teaching as well, and they were followed by some efforts at the college level. I was personally acquainted with the Commission on College Physics, since for a time it was headquartered at the University of Maryland, and it did excellent work.

It must be noted with great regret, however, that all of these useful and effective projects have been terminated. Presumably on the assumption that they had completed their work and accomplished their purpose, they passed from the educational scene. I believe their demise reflects a fundamental error in understanding both science and teaching Neither is static. Both are always evolving and by definition exploring new fields of knowledge and technology. It is simply wrong to believe that science teaching can be brought up-to-date by a "quick fix" or even by more substantial, but one-time-only efforts. Even as the devoted committees and task forces of scientists and teachers in the sixties were hard at work on new curricula for high schools and colleges, some of their new approaches were already being rendered obsolete by rapid advances in science and technology. Science teaching is inevitably rather like the White Queen in *Alice in Wonderland*, who said we must run very fast just to stay where we are!

So, as my major overall recommendation, I urge that continuity be the hallmark of all NSF programs in the teaching of science and engineering. The assurance of continuity is essential to attract the best people to the task and to avoid the great loss in effectiveness of groups that are set up only to be knocked down. Although NSF funding for teaching will probably never exceed 25 percent of the amount the Foundation invests in research, teaching must have the same long-term continuity of effort and support that is provided to research.

Organizations like the former Commission on College Physics should be set up, along with parallel groups in other fields of science, in forms adapted to the needs of the current era. The experience of the earlier efforts suggests that this may best be done through close collaboration with national groups, such as the American Association of Physics Teachers, to involve the whole teaching profession and to provide for effective interplay between the colleges and the schools in improving teaching. Only by mounting anew these efforts, by giving urgent attention to the problem of modern facilities and equipment for teaching, and by improving the mechanisms for articulation of all levels of science and engineering education—and only by approaching all of these concerns from a long-term and continuing standpoint—can we say with confidence that America is doing what it must do to ensure our country's progress in science and technology.

I have been speaking about what I believe must be done if we are to teach good science to good students. But so far I have left out a crucial element. Obviously we cannot teach good science to good students without good teachers. Good teachers—and enough of them—are not only necessary, but fundamental, and closely related to attracting better students to better courses.

So, as my second recommendation, I urge that NSF consider the training of science teachers as a matter of high priority. According to all available current information, we will face a serious shortage of science teachers in the near future, a shortage that already exists among qualified engineering faculty. It is a matter of *both* quantity and quality. NSF alone cannot solve this problem, but its leadership in assessing needs and in mobilizing resources and directing attention, as well as its essential economic support, can make a major difference. We are still living on the residual benefits of post-World War II support for teacher training, first through the G.I. Bill, then through NSF, NDEA, and other fellowship programs. But that earlier intellectual capital is running out and must be renewed. I urge that NSF establish programs of scholarships and fellowships. I also urge that NSF introduce loan programs in which loans may be repaid by service, on a one-for-one basis: for each year of subsequent service in full-time teaching in school or college, one year's loan would be forgiven.

Such programs, at a substantial and continuing level of commitment, would help to attract some of the nation's ablest students to careers in science teaching. To retain such teachers and to keep them abreast of new develop-

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ments in science and in teaching, NSF should also rebuild its former system of summer institutes for both high school and college teachers. These institutes were very effective in the past, and the Japanese have also demonstrated their value. NSF should give priority to this important element of improving teaching in science and engineering.

Can it all be done? Can America focus its attention and its resources on the urgent task of providing for the base of competence in science and engineering on which our future as a nation will in part depend?

I answer that it must be done. And I take heart from the example of leadership, energy, and resources that NSF has provided in the past and, I am confident, can provide again.

I am especially encouraged by the seriousness and scope of these hearings, and I am grateful indeed to have had the opportunity to contribute in a small way to the important deliberations of this Committee.

Undergraduate Science and Engineering Education

Paul R. Verkuil

President
College of William and Mary

It is an honor to be asked to share with you some thoughts on science education at the undergraduate level from our perspective at the College of William and Mary.

The College of William and Mary is about to inaugurate the 25th president in its 292-year history. In its Royal Charter of 1693, natural philosophy, that is science, was one of six original chairs directed by the Crown to be established to serve the Virginia Colony at this "place of universal learning" to be founded on the "southside of the York River." This Sunday in my inaugural address I will quote the first professor of chemistry at William and Mary, the Reverend James Madison, our eighth president and the cousin of his namesake who was to become the fourth president of the United States. After the Declaration of Independence and the severing of ties between William and Mary and the Anglican Church, the Reverend Madison, as a loyal republican, changed allusions in his sermons to the "kingdom of heaven" into the "republic of heaven." The point of this digression is that "science" has been integral to William and Mary's mission throughout its 300-year history, and it has been taught continuously during that time. The sciences are as integral a part of William and Mary's mission today as they were nearly 300 years ago.

We take great pride in the quality of our students and in the baccalaureate degree we award. In a recent book, we were named a "public Ivy" and called "the most selective public institution in the United States." Interestingly, we are the smallest "public Ivy" in Richard Moll's list, and we were also listed recently as one of the "best buys" in American higher education by *Newsweek*. Our enrollment of 6,500 has about 4,500 undergraduate and 2,000 graduate students. Most of the graduate students are in the professional schools—Business, Law, Education—but over 300 are in the Arts and Sciences and in our School of Marine Science located at the mouth of the York River on the Chesapeake Bay.

In 1985, about 1 in 5 of the bachelor's degrees awarded at William and Mary were in the sciences. In comparison, only about 1 in 20 undergraduates major in science nationwide. Of our graduates, about 20 major in physics, 40 each year in chemistry, 100 each year in biology, 15 in geology, and about 30 every year in mathematics. Indeed, the Chemistry Department at William and Mary, for example, has been one of the 15 major producers of American Chemical Society-certified B.S. graduates in the nation in each of the last four years. And, over half of those graduates were women! It should be noted also that our Chemistry Department has produced more women graduates in the last 10 years than many predominantly women's colleges, including Mount Holyoke. In the sciences, the Departments of Physics and Computer Science offer doctoral work. The Biology, Chemistry, and Mathematics Departments offer master's degrees. Geology is solely undergraduate in its offerings. These offerings in the sciences are strengthened in a number of ways, some of which relate to our proximity to NASA's Langley Research Center and to the newly funded Continuous Electron Beam Accelerator Facility in Newport News, Virginia. Since we are here today to talk about undergraduate science education, I will attempt to concentrate on those aspects of our programs that we find helpful to its practice.

An important factor supporting science education at William and Mary is the integration of graduate work in departments with undergraduate programs of unquestioned quality. Generally these graduate programs are small—in Biology, perhaps 15 master's candidates in all; in Chemistry, about 6 to 8; in Physics, 5 or 6 Ph.D.'s each year. Nonetheless, I do not hesitate to say that it is because of, *not in spite of*, these graduate programs that our undergraduate programs in the sciences have been able to remain strong and to flourish. Our freshman lab sections (20 to 28 students in size) are taught by senior faculty in the company of teaching assistants from the master's and senior undergraduate ranks. And the senior faculty are present in the lab throughout the scheduled lab time. Our introductory science courses, indeed all of our classes in the sciences, are taught by regular faculty. Twenty years ago teaching loads were 16 hours per week, now they are 7 to 10 hours. Twenty years ago the Chemistry faculty numbered 4; this year it numbers 14. Twenty years ago there were no graduate programs at William and Mary. The conclusion should be clear. Because of our state university status and its attendant formula-based funding, the presence of graduate programs, even those of modest size, generates additional resources of considerable importance to the well-being of our undergraduate programs. Faculty numbers have increased directly as a result of our engaging in graduate work. At the freshman-sophomore level, 22 FTE's are required to generate a faculty member in the sciences. At the master's level, 6 FTE's are needed; at the Ph.D. level, the number is 3. Similar important benefits derive for the library and for the operating budget from which we must equip our laboratories.

More important, lower teaching loads and more faculty colleagues have helped to build an environment in which scholarship flourishes. At William and Mary, our science departments have chosen to use the occasion of graduate work to maintain a tradition of undergraduate programs of unquestioned quality. They have chosen to make undergraduate research participation a critical and considerable feature of their curricula. Nearly every student undertakes an independent study or honors project amounting to 25 percent of his or her senior-year programs. Involvement in such projects often begins in the junior year and carries on through the summer preceding the senior year. As many as one-third of our science majors participate each year in a 10-week program during the summer, similar to the Undergraduate Research Participation (URP) program. Even as NSF support for such programs declined (is it fair to say disappeared?), our faculty members were fortunate enough to be successful applicants for Petroleum Research Fund Type B grants or Research Corporation grants, and our science departments were able to seek funding for such programs from private foundations and the chemical industry. More often than not, the work accomplished by these undergraduate participants is published in a refereed journal. This work may take a little longer, but it costs slightly less on average to undertake and is every bit as important to the discipline as the work done at major research universities.

There is nothing unique about such an investment of faculty time and institutional resources to research programs in undergraduate science departments of quality. Nothing unique, but something distinctive to be sure. Undergraduate research participation—real research with true collegial participation, externally funded, eventually published—is the distinguishing characteristic of outstanding undergraduate science departments in the United States. The American Chemical Society's Committee on Professional Training has recognized this fact recently. NSF is to be commended for recognizing this fact in many of its recent program emphases.

Perhaps the commitment by faculty to these programs (which are often all-consuming ventures) arises out of self-interest. They do not have armies of graduate students to carry out their ideas in the lab. They must patiently coax the sophomore chemistry major, or the junior biology concentrator, into learning the techniques fundamental to a project and then motivate that young man or woman to spend long, productive hours in the lab while carrying the courseload typical of a full-time undergraduate student. This rarely happens at the major research universities. Only a few, no more than 50, mostly private with a few notable public colleges and universities, have just the right combination, that critical mass, if you will, of dedicated faculty, outstanding students, and sufficient resources to practice this most important "art form" successfully. Significantly, for our purposes here today, those 50 or so institutions are the baccalaureate origin of more than 40 percent of the Ph.D.'s awarded in the sciences each year.

William and Mary is one of these institutions, and we know the quality of our undergraduates. These young men and women of science are the best this nation has to offer. What I am saying is that it is essential to the future of this nation's competitiveness in the world that talented undergraduates in science at any institution be supported appropriately. This is particularly so at those institutions whose dedication to the endeavor and whose success in executing it are clearly identifiable. The determining criterion for award of such support must be demonstrable quality at the undergraduate level, not the number of Ph.D. graduates at an institution. Outside support coupled with internal support of material and philosophical kinds will make the difference for many institutions. What forms should this support take?

Let me describe the faculty development programs at William and Mary and then offer several suggestions regarding NSF participation. Each year, William and Mary offers, on a competitive basis, 21 semester research assignments (full pay for a semester) within its faculty of 370. Additionally it offers 36 competitive summer research grants each year. It is easy to see that no more than 10 percent of our faculty can participate in any one year, far less than would be able to do so if we had a true sabbatical program. In the sciences, some faculty awarded a semester's leave for research are able to extend such opportunities by obtaining outside support for their research. Competitive programs that increase the availability of such support to faculty who work primarily with undergraduates are an important need. NSF has helped with the introduction of its Research in Undergraduate Institutions (RUI) program. In our opinion, it should be expanded. Summer stipends provided through this program often make the difference between continuity and productivity in an undergraduate research effort and frustration of that effort.

Another way that the National Science Foundation can encourage undergraduate research programs is to assist universities in providing appropriate reward structures for faculty. NSF should, in our opinion, give serious thought to offering a program of challenge grants to endowment for faculty compensation similar to the successful program offered for a number of years by the National Endowment for the Humanities. This program should be highly competitive, should make substantial awards, and must be merit-based.

Another area in which institutions like William and Mary have difficulty meeting their reasonable needs is equipment. We are painfully experiencing the effects of rapid escalation in the costs associated with equipping science laboratories over the last decade. The Commonwealth of Virginia has recognized this problem as well and noted recently that $400 million may be needed to replace obsolete equipment and purchase new equipment at state institutions during the next decade. Fortunately for universities seeking external funding for their equipment needs, NSF has established both research equipment and instructional equipment programs. Nevertheless, the funds allocated to these programs ought to be increased dramatically. Again, such awards should continue to be merit-based and, in our opinion, should be managed within the appropriate disciplinary directorate at the Foundation.

The National Science Foundation can pursue at least two no-cost policies that are of considerable importance to primarily undergraduate science departments. First, it can seek to encourage representative membership by qualified scientists from primarily undergraduate science departments on its relevant boards, councils, and panels, including the National Science Board. Second, it can, in its many publications, recognize the special and sizable role such well-qualified science departments of which I have spoken play in the scientific life in the United States. Hearings like these are an important step in this regard.

Finally, and perhaps most important, NSF must attempt to increase its support for summer undergraduate research participation. We know that while the choice to study science is made in junior high school, the decision to go on to graduate school is made much later. Often, the quality of the undergraduate programs in science that our young people experience is the determining factor in this decision. As I hope I have made clear earlier, that quality is determined in large measure by the opportunity for undergraduate students to participate in research.

If we establish or enhance funding opportunities that provide for an appropriate balance between the needs of faculty and graduate students at the major research universities of quality and the smaller, but equally critical, needs of the equally meritorious, although primarily undergraduate, institutions, we will be assured of a continuing supply of talented scientists.

Issues in Undergraduate Education in Science and Engineering

Betty M. Vetter

Executive Director
Scientific Manpower Commission

Over the past few years, the nation has become deeply concerned about the quality of precollege education being provided to its children, particularly in science and mathematics. Although this concern has not yet resulted in the kind of quality in education that we seek for all our sons and daughters, steps are under way to improve the qualifications of teachers and the conditions under which they carry out their tasks, to require more participation in science and mathematics by all students, to change the curriculum to better suit their needs, and to recognize the changing demographics of our school population and the resulting changes that will be required to prepare all students for further education or for entry into the workforce.

We must turn to the next level of education, not because the precollege level has now been made satisfactory, but because the problems of providing quality undergraduate education also require action.

Measuring Undergraduate Education: Degree Awards

A major problem in examining undergraduate education in science and engineering is a lack of pertinent, timely data. Even the most obvious data need—degree awards by field, sex, citizenship, and minority status—is not available in a timely fashion. Although we ultimately learn the number of baccalaureate graduates each year, the data are two to four years late and are incomplete in providing sufficient breakout to assess trends in the participation of various groups. The most current data on bachelor's and master's degree awards by sex and field are for 1982. The most current data delineating these degree awards to minorities are for 1981. In the case of minorities, we also lack data from earlier periods by which to assess trends in participation in these fields.

The available data, though not current, are invaluable for their trend information. Most recently, those data indicate a significant decline of 7.4 percent in the number of male students earning baccalaureate degrees in science and engineering between 1972 and 1982, even as the number of women earning those degrees increased 46.3 percent and minority graduates rose 4 percent, for an overall net increase of 7.4 percent.[1,2]

Men. The number of male graduates has dropped 35.4 percent in the social sciences and 1.8 percent in the life sciences, while rising 34.8 percent in engineering, 11.6 percent in the mathematical and computer sciences, and 1.6 percent in the physical sciences. At least some of this increase is due to rising numbers of minority students (particularly Asian) and foreign nationals.

The dropoff of White males from science and engineering over the past decade, both at the bachelor's level and at graduate levels, is troubling. While the available data do not generally provide information by sex, field, minority status, and citizenship so that U.S. White males could be separated out, we do know that White men earned only 53.5 percent of science and engineering bachelor's degrees in 1981 (the latest available data for minorities), while U.S. minorities earned 11.1 percent, women earned 37.1 percent, and non-resident aliens (almost all male) earned 3.9 percent.

Although we cannot identify the White men within the all male group of science/engineering (S/E) bachelor's graduates in previous years, we know that in 1965, men earned 78 percent of all the S/E bachelor's degrees, with that percentage moving down to 73.9 percent in 1970, 68.4 percent in 1975, 63.7 percent in 1980, and 62.6 percent in 1982. The rapid drop is not just a function of increasing numbers of women in this population, but also indicates reducing numbers of men. When the minority men, who now earn about 8 percent of these degrees, and the foreign students, now representing about 3 percent of the total, are removed from this population, we can surmise that the number of White male U.S. citizens seeking and earning degrees in these fields may have dropped more than is desirable. Our concentration on women, minorities, and foreign nationals may have caused us to miss these data, and I suggest that NSF might wish to examine the reasons for it. However, it should be noted that the dropoff of men has occurred not only in science and engineering, but in all baccalaureate fields. The number of men earning baccalaureate degrees dropped 8.6 percent over the decade from 1972 to 1982; the number earning master's degrees fell 5.8 percent, first professional degrees, 2.2 percent; and Ph.D.'s, 25.2 percent.[1]

Doctoral degree data provide a better long-term picture, reflecting baccalaureate production as well. Although we cannot separate White male citizens in the doctoral data, we can see the data for male U.S. citizens, and find that in the 14 years between 1970 and 1984, their proportion of earned S/E doctorates has declined from almost 72 percent to less than 50 percent (Table 1).[3]

Table 1. S/E Doctoral Awards by Sex and Citizenship, 1970–1984.

Year	S/E Ph.D.'s	Men Only	U.S. Men	U.S. Men as % of S/E Ph D.'s
1970	18,321	16,541	13,150*	71.8
1971	19,485	17,495	13,734*	70.4
1972	19,556	17,390	13,519	69.1
1973	19,555	17,020	13,028	66.6
1974	19,086	16,382	12,111	63.5
1975	19,048	16,047	11,987	62.9
1976	18,790	15,628	11,799	62.8
1977	18,281	14,989	11,287	61.7
1978	17,956	14,430	10,794	60.1
1979	18,247	14,393	10,737	58.8
1980	18,171	14,072	10,399	57.2
1981	18,662	14,303	10,370	55.6
1982	18,747	14,216	9,994	53 3
1983	18,799	13,961	9,605	51.1
1984	19,008	14,005	9,439	49.7

* Estimated by author

Source National Research Council data

A number of possible reasons for this decline in the face of a continually rising population during those years have been outlined elsewhere by the author;[4] many of them may have to do with the quality of U.S. undergraduate education in science and engineering. In the process of trying to increase the participation of women and members of racial or ethnic minorities, it seems important not to lose track of the fact that the number of U.S. males, particularly White males, earning S/E degrees has been dropping steadily for a decade.

Women. Over the past several years, the data have become much better than before in tracking the progress of women through the baccalaureate level and into the S/E labor force. We have seen tremendous increases in the numbers of women earning degrees in these fields, although this appears to be as much a function of more women seeking higher education as of a shift toward science and engineering.[5] Both the number of women and their proportion of total degree awards have climbed in every field, and at approximately the same rate. Just as for men, the degree awards to women in mathematics have dropped while increasing in computer science, with a significant rise in the math/computer science grouping.[1] In 1982, women earned almost 38 percent of all the S/E degrees awarded, with their proportions ranging from 12 percent in engineering to 53 percent in the social sciences. In 1970, they earned only 26 percent of these degrees (Table 2).

Table 2. Science and Engineering Bachelor's Degrees, 1965–1982.

Year	Total S/E	Physical Sciences[1]	Engineering	Math Sciences[2]	Life Sciences	Social Sciences[3]
All Bachelor's Degrees						
1965	164,936	17,916	36,795	19,668	34,842	55,715
1966	173,471	17,186	35,815	20,182	36,864	63,424
1967	187,849	17,794	36,188	21,530	39,408	72,929
1968	212,173	19,442	37,614	24,084	43,260	87,774
1969	244,519	21,591	41,553	28,263	48,713	104,399
1970	264,122	21,551	44,772	29,109	52,129	116,561
1971	271,176	21,549	45,387	27,306	51,461	125,473
1972	281,228	20,887	46,003	27,350	53,484	133,604
1973	295,391	20,809	46,989	27,528	49,486	140,579
1974	305,062	21,287	43,530	26,570	68,226	145,449
1975	294,920	20,896	40,065	23,385	72,710	137,864
1976	292,174	21,559	39,114	21,749	77,301	132,451
1977	288,543	22,628	41,581	20,729	78,472	125,143
1978	288,167	23,175	47,411	19,925	77,138	120,518
1979	288,625	23,363	53,720	20,670	75,085	115,787
1980	291,983	23,661	59,340	22,686	71,617	114,779
1981*	291,590	23,952	63,673	26,199	66,832	110,934
1982	298,847	24,052	67,400	31,866	63,884	111,645
Degrees Awarded to Women						
1965	36,213	2,532	139	6,453	8,277	18,812
1966	39,482	2,333	146	6,702	8,464	21,837
1967	44,002	2,402	184	7,334	8,948	25,134
1968	53,463	2,674	211	8,841	10,091	31,646
1969	63,196	2,952	313	10,348	11,308	38,275
1970	68,878	2,969	338	10,516	11,875	43,180
1971	72,996	3,014	365	9,818	11,803	47,996
1972	77,671	3,148	501	9,734	12,694	51,544
1973	83,839	3,121	580	9,985	14,570	55,583
1974	91,793	3,536	706	9,719	17,836	59,996
1975	93,342	3,838	860	8,656	29,811	59,177
1976	95,597	4,139	1,443	7,678	23,789	58,584
1977	97,453	4,551	2,086	7,488	25,609	57,719
1978	100,060	4,987	3,497	7,110	26,954	57,512
1979	102,292	5,287	4,919	7,421	27,548	57,117
1980	105,974	5,651	6,014	8,247	27,596	58,466
1981*	106,842	5.888	7,083	9,655	26,786	57,430
1982	111,541	6,186	8,299	12,055	26,282	58,719

[1] Includes Environmental Science

[2] Includes Computer Science

[3] Includes Psychology

* Beginning with 1981, NCES data are for 50 states and D C only Prior years include territories and protectorates

Source Series of Earned Degrees Conferred, 1965–1982, National Center for Education Statistics, using National Science Foundation field definitions

A continued increase in S/E baccalaureate degree production is unlikely for either men or women, given the smaller size of the college age group for the next 10 years, but even women's continued proportional gain cannot be assured. For example, the proportion of women in the first year of engineering school dropped slightly in fall 1984 after a steady and significant increase in each of the past 15 years.[6] The assumption cannot be made that women will continue to enter these fields in increasing proportions, ultimately reaching parity with men. The need for continuous monitoring and for steady encouragement for women to enter science and engineering has not been reduced by the previous gains.

Minorities. The picture for minorities is less clear, and also shows less progress. Except for Asians, underrepresentation in education and particularly in science and engineering education is evident (Table 3).

Blacks and Hispanics continue to be seriously underrepresented in science and engineering, despite some increase over the past decade that has resulted from serious efforts on the part of academic institutions, industry, and some government agencies. Unfortunately, very little data exist for earlier periods. American Indians also are underrepresented, to a somewhat lesser degree.

In 1977, the Higher Education Panel of the American Council on Education examined bachelor's degrees awarded to minority students in 1973–74 and concluded that Black, Spanish-surnamed, Asian, and American Indian students earned about 7.8 percent of S/E baccalaureates that year.[7] However, the science and engineering fields used by this panel differ from those ordinarily used by NSF by excluding agriculture and natural resources as well as computer and informational sciences. The social sciences, on the other hand, include some specialties that would be excluded in NSF data, particularly history, international relations, and urban studies. Although the data are not fully comparable with other data used earlier, the 1974 estimates are compatible with data for 1981, and both years are shown in Table 4. Note that the total for all S/E is larger than shown in Table 2 or used for the calculations in Table 3 because of the inclusion of more social science groups. Computer science degrees are omitted in both years.

All minority groups have increased their proportion of these science and engineering degrees, but none of them except the Asians have come close to their population representation.

The Asian Edge. Because of the apparent overrepresentation of Asians in science and engineering, this group deserves a special look. If indeed they do participate at unusually high rates, we might learn from this how to increase participation by other minority groups. However, there are several indications that U.S.-born Asians, particularly those who are second or earlier generation Americans, may be underrepresented in S/E fields, as are other American minority groups. We do not have totally adequate data, but there is evidence that the apparent overrepresentation of Asians is a result of recent immigration rather than of differences in the choices and accomplishments of U.S.-born Asian-Americans.

As shown in Table 3, the minority representation in education is quite different from that of the population as a whole, and drops for most minority groups with each succeedingly higher education level. However, in both educational attainment and science and engineering participation, Asian representation appears to be higher than Asian representation in the total population, as also is true for the White, non-Hispanic group.

The higher representation of Asian students, both in general college enrollment and especially in engineering and science enrollment and degree attainment, is particularly marked at the graduate level, and carries into the U.S. labor force. However, this appears to be largely a function of increasing numbers of foreign-born Asians entering U.S. graduate schools, earning advanced degrees, and then entering the U.S. labor force.

In 1973,[8] and again in 1979,[9] the National Research Council examined the doctoral S/E minority population

Table 3. Percentage of U.S. Minorities in Various Population Groups (Data are for 1980 unless otherwise noted).

	White	Black	Hispanic	Asian	Indian	Foreign
U.S. Population	8[illegible].0	10.0	6.5	1.6	0.6	3.0
Elem/Secondary Enrollment	73.3*	16.1*	8.0	1.9	0.8	—
High School Graduates 1978	82.3	11.7	4.2	2.8	0.7	2.7
Undergraduate Enrollment	80.6	10.1	4.2	2.3	0.7	2.1
Graduate Enrollment	81.9	5.5	2.2	2.1	0.4	7.9
S/E Graduate Enrollment 1982	62.3	2.8	2.2	2.2	0.3	22.7
First Profess. Enrollment	89.3	4.6	2.4	2.2	0.4	1.0
Total Enrollment 1982	80.7	8.9	4.2	2.8	0.7	2.7
Bachelor's Degrees 1981	86.4	6.5	2.3	2.0	0.4	2.4
S/E Bachelor's Degrees 1981	85.0	5.7	2.4	2.7	0.4	3.9
Master's Degrees 1981	82.0	5.8	2.2	2.1	0.3	7.5
Ph.D's 1983	76.9	3.2	1.9	3.3	0.3	14.4
S/E Ph.D.'s 1983	73.9	1.8	1.5	4.3	0.2	18.3

* Includes Hispanics.

Source U S Bureau of the Census, National Center for Education Statistics, National Science Foundation, National Research Council, and Scientific Manpower Commission data

Table 4. Bachelor's Degrees in Science and Engineering, 1974 and 1981.

	Total Number		Minority Percentage									
			Black		Hispanic		Asian		Indian		All	
Field	1974	1981	1974	1981	1974	1981	1974	1981	1974	1981	1974	1981
Biology	53,41/	43,216	3 6	5.3	1.1	2.7	1.7	3.5	.1	3	6.5	11.8
Engineering	62,319	74,954	1.8	3.3	1.4	1.9	1.5	4.1	4	.3	5 1	9.6
Math	24,730	11,078	4.6	5.3	.7	1.7	1.7	3.5	.1	.2	7.1	9.7
Physical Science	26,708	23,950	2.7	3.6	1.3	1.7	1.1	2.5	.2	.3	5 3	8.1
Psychology	52,428	40,833	4.8	8.1	1.4	3.2	1.0	2.1	.3	.5	7.5	13.9
Social Science	159,261	100,647	7.2	8.1	1.4	2.9	.8	1.6	.3	.4	9.7	13.0
All S/E	378,863	294,678	5.0	6.0	1.3	2.5	1.2	3.1	.3	.4	7.8	11.9

Source. National Center for Education Statistics, American Council on Education, and Scientific Manpower Commission data

with some startling results. Among the 10,987 Asian S/E doctorates in the 1973 labor force, 36.9 percent were foreign-born U.S. citizens, 52.7 percent were noncitizens, and only 10.4 percent were native-born citizens. Thus, although Asians represented 5 percent of all doctoral scientists and engineers that year, they were only 0.6 percent of all native-born doctoral scientists and engineers. This was not the case for other minority populations.

The 1979 study found that 80.1 percent of the total S/E doctoral population of 324,335 were U.S.-born. Among the 21,388 Asians included in that total, only 8.5 percent were U.S. natives, while 91.5 percent were foreign-born. Thus, although Asians were 6.6 percent of all doctoral S/E degrees in 1979, they were only 0.7 percent of those born in the United States. Again, other minority groups do not show this pattern, as shown in Table 5.

This data base also provides us with some insight to the influence of foreign birth on the proportion of women in S/E within each racial/ethnic group. Except among the Hispanics, this doctoral population contains a higher proportion of women among the native-born than among the foreign-born. Among Asians, this contrast becomes more striking among the more recent doctorates. Those who earned the doctorate between 1970 and 1978 show 10.1 percent women among foreign-born Asians, but 22.5 percent among those who were born in the United States.[9]

Although we do not know the country of birth for bachelor's graduates, we can examine the most recent data on S/E degrees[10] awarded to minorities and draw some inferences (Table 6).[2]

Asian students, including immigrants, earned 2.7 percent of the S/E bachelor's degrees that year. Non-resident aliens earned 3.9 percent. Although we cannot be sure how many of these foreign students were Asian, we know from other sources, namely the Institute for International Education, that among 94,000 foreign undergraduate students in the United States in 1983–84, 32.2 percent were Asian. Within this group, 55.1 percent were studying science or engineering.[11]

Among the 22,589 non-resident aliens earning bachelor's degrees at U.S. institutions in 1981, 12,904 (57.13 percent) majored in science or engineering. We might assume that about 32 percent of these foreign S/E baccalaureate graduates, or 4,130 of them, were Asians. Additionally, some smaller proportion of the U.S. Asian students were born outside the United States but achieved immigrant status by the time of college graduation. Thus, the 2.7 percent representation of Asian-Americans shown in Table 6 is higher than the actual representation of U.S.-born Asian graduates, although we cannot tell by how much. Nonetheless their representation among S/E baccalaureate graduates appears to be somewhat higher than their representation in the U.S.

Table 5. Doctoral Scientists and Engineers by Birthplace and Racial/Ethnic Group, 1979.

	Total	U.S.-Born	%	Foreign-Born	%	% Women in U.S.-Born	% Women in Foreign-Born
Total	324,335	259,845	80 1	50,638	15 6	—	—
Whites	282,231	252,775	89.6	29,456	10 4	11.1	10.9
Blacks	3,500	2,822	80.6	678	19 4	25 5	8.7
Hispanics	2,515	1,610	64.0	905	36.0	11 4	17.9
Asians	21,388	1,812	8.5	19,576	91.5	12.5	10.9

Source: National Research Council

Table 6. Science and Engineering Bachelor's Degrees by Sex and Race/Ethnicity, 1981.

	Number	% of Total	% of Same Sex	% of Same Race/Ethnic Group
TOTAL	331,684	100.0		
Men	208,615	62.9	100.0	—
Women	123,069	37.1	100.0	—
White	281,850	85.0		
Men	177,338	53.5	85.0	62.9
Women	104,512	31.5	84 9	37.1
Black	18,811	5.7		
Men	9,252	2.8	4.4	49.2
Women	9.559	2.9	7.8	50.8
Hispanic	7,910	2.4		
Men	4,773	1 4	2.3	60.3
Women	3,137	1.0	2.6	39.7
Asian	9,007	2.7		
Men	5,927	1 8	2 8	65.8
Women	5,927	0.9	2.5	34.2
American Indian/ Alaskan Native	1,202	0.4		
Men	701	0.2	0.3	58.3
Women	501	0.2	0.4	41 7
Non-Resident Alien	12,904	3 9		
Men	10,624	3.2	5.1	82.3
Women	2,280	0.7	1.9	17.7

Source: National Center for Education Statistics, Office for Civil Rights

population, but perhaps slightly below their representation among U.S. high school graduates, as shown in Table 3.

Among American-born Asians, the only minority group that *may* be adequately represented in science and engineering, the interest in these fields may relate to cultural differences in the Asian-American home, a genetic superiority for achievement in math-based fields, the presence of role models, or to the unusually high level of education of Asian-American mothers at the time their children are born, as has been described by the author in earlier papers prepared for the Office of Technology Assessment.[12]

Among the 3,612,258 babies born in the United States in 1980, 2,898,732 (80.2 percent) were White, 589,616 (16.3 percent) were Black, 82,454 (2.3 percent) were Asian, and 307,163 (8.5 percent) were Hispanic. The racial groups may also include the Hispanic population.[13]

The most striking feature of this 1980 crop of babies, when looked at as racial or ethnic groups, is the wide variation among the mothers in age and educational level. Among all 1980 White mothers, 15.6 percent had completed four or more years of college. Among Black mothers, the proportion was 6.3 percent. For Asian mothers, however, the proportion of college graduates is 30.2 percent. This particular statistic is not available for Hispanic mothers, but we have a related one from which the inference may be drawn that the proportion who are college graduates is very small indeed.

Among the 1980 mothers, 4.0 percent of the White, 5.0 percent of the Black, 10.0 percent of the Asian, and an astonishing 37.1 percent of the Hispanic had completed fewer than 10 years of education. The high proportion of Asian mothers with very little education appears to be due predominantly to the influx of refugees from southeast Asia in that year.

The percentage of 1980 births to mothers under the age of 20 was 13.5 percent for White women, 26.5 percent for Black women, 39.0 percent for Hispanic women, but only 6.0 percent for Asian women.

It is not idle speculation that the mother's educational level (and her age as it relates to a delay in childbirth for educational pursuit) is a dominant factor in the child's abilities and attainment. An earlier study carried out in 1980 by the National Opinion Research Center (NORC) of the University of Chicago for the Department of Defense and the Department of Labor made the startling finding that among individuals in a representative selected sample of male, female, minority, and majority youth, the strongest single predictor of both the score on an administered Armed Forces Qualification Test and reading ability was the mother's educational level.[11]

A policy that encourages and provides for the highest possible level of education for girls and women, preferably before they have children, might be the single most significant measure that could be taken to improve opportunities for minorities, as well as for majority youth. Further investigation seems to be merited.

Educational Quality at the Undergraduate Level

The deteriorating quality of precollege education has been measured in a number of ways, including the long decline in test scores, an increase in remedial college courses and enrollments, changes in dropout rates, and employer complaints about the general inability of many high school graduates to read, to communicate, and to perform simple mathematical tasks. The quality of education provided to the typical undergraduate cannot be assessed by any set of available data. Although we can observe the performance levels of some students by GRE scores, only those considering graduate school are tested. We know little about the quality of instruction offered in our colleges and universities to those students who take courses in science and math, except that in some fields a shortage of qualified teachers has existed for several years. These fields certainly include computer science and engineering, and may include other areas as well.

Foreign Teachers. U.S. colleges and universities have responded to these shortages by utilizing more part-time faculty, and, increasingly, utilizing foreign students and graduates as teaching assistants and as regular faculty members.

The use of foreign faculty brings with it a number of problems for undergraduate education. The obvious language barriers make communication difficult for students as well as for their teachers. Foreign teachers bring to the classroom their own cultural biases, which are known to reflect adversely on women, and may also negatively affect male students of any racial or ethnic background. Studies by the Project on the Status of Women in Higher Education of the American Association of Colleges have found that foreign faculty, even more than U.S. faculty, tend to subtle behaviors by which women are ignored, overlooked, or made to feel invisible, in addition to the more overt sexist behavior by which women are singled out and disparaged. The problems for women in our own culture grow out of the ways in which we perceive and evaluate them, with expectations differing and often lower for women than for men. These problems are exacerbated for women, particularly in non-traditional fields, by male faculty and graduate teaching assistants from countries where women, by statute or custom, have a very restricted role, are assumed to be intellectually inferior, are perceived as property, or are defined only in terms of their sexual role. The results are well documented by the Project on Women.[11] Importantly, the disproportionate number of foreign students and foreign faculty who are male is both a symptom of the problem and an exacerbation of it for American women.

An Aging Faculty. Because of a relative surplus of faculty in most fields, the present tenured faculty is aging, and the number of young faculty members being employed in science is relatively low. The conventional wisdom, at least, suggests that the best undergraduate faculty will be a mix of older and younger teachers. Many science departments are top-heavy with older faculty. In physics, for example, which has had an oversupply of graduates since the early 1970s, U.S. students have reacted to this oversupply by majoring in other fields, so that physics departments have [illegible] shrinking, faculty has been aging, and 40 p[illegible] of physics Ph.D.'s are awarded to students who are [illegible]ign-born.

Precollege Teacher Preparation. The problems of ill-prepared teachers in science and mathematics at the precollege level are well documented, although much needed statistical detail is lacking. The undergraduate colleges are not producing the new science and mathematics teachers presently needed, and the number needed will grow fa[r] faster over the next decade than present graduation ratios can provide trained teachers. Here, again, we lack adequate data to assess the quality of present science and math teachers, and, in this instance, we lack data even to assess the number of graduates who are preparing to be science and math teachers. This is because such graduates are variously reported as earning degrees in a subject field, or earning degrees in education. The data do not indicate which subject-field graduates also have teaching credentials, nor do we know much about the proportion of those with teaching credentials who actually enter employment as teachers in these fields.

Quality of Undergraduate S/E Students. Although there are no available data to measure the quality of U.S. undergraduate education in science and engineering, some information has been sought about student quality. In February 1984, the Higher Education Panel of the American Council on Education (sponsored by NSF and others) asked senior academic officials their opinion of student quality in the sciences and engineering.[15] A majority (61 percent) of the officials queried believed that student quality had not changed significantly over the previous five years; about one-fourth thought the quality had improved, while about one-sixth felt that a significant quality decline had occurred.

Despite an actual decline in the number of White males earning bachelor's degrees in science and engineering over that period, 53 percent of the respondents felt that there had been no shift away from S/E among their most able undergraduate students. The remainder generally believed that the shift had been toward science and engineering (40 percent) rather than away from it (7 percent). Particularly among the 100 institutions with the greatest S/E baccalaureate production, three-fourths of the officials felt that the distribution of their most able students had shifted, and all of these saw the shift as moving toward science and engineering. However, they may have been recognizing only the shift toward engineering, physical sciences, computer science, and life science, ignoring the obvious decline in the social and behavioral sciences.

At graduate institutions, 60 percent of officials believed the quality of applicants for S/E graduate study had not changed significantly, and only one in eight thought the quality had declined.

Quality of Education. It may be correct to assume that the quality of science and engineering *students* is as high now or higher than in earlier years. However, there are some indications that the quality of *education* provided for them may not always be as high as in previous years. For example, a number of engineering schools have had to increase class sizes and, in some cases, the number of students taking laboratory courses has necessitated delays in obtaining required sequence work. Also cited as possible bases for lesser quality are the increasing use of foreign teaching assistants, the heavier teaching loads of faculty members, an increase in the use of part-time, temporary faculty, and specifically the aging of facilities and equipment in most science and engineering departments. Faculty in computer science note similar problems of burgeoning enrollments, too few faculty, and insufficient facilities and equipment.

Even if the quality of education has not depreciated seriously for students majoring in science and engineering, there may be significant deterioration in both the quantity and the quality of education being supplied to non-majors taking courses in science, engineering, or computer science. Over the past decade, as lower division requirements were gradually removed at many institutions, fewer students chose to take courses in these fields, and some have graduated without any college-level background at all in science, mathematics, or technology. Curriculum changes may be required to interest non-majors in such courses. Here, as in other instances, the data are sparse.

Role of NSF

What can NSF do about any of these problems?

1. It can collect or support the collection of some missing data required to study and understand where problems exist.
2. It can support studies examining the causes (and perhaps suggesting cures) for some of the problems.
3. It can support model or pilot programs on an experimental basis.
4. It can support efforts for curriculum change that appear to be required, certainly for non-majors and probably for S/E majors as well, in order to assure a basic scientific and technological literacy among college graduates in all fields.
5. It can support the replacement and updating of equipment and facilities, particularly at those undergraduate colleges that produce a preponderance of our doctoral scientists and engineers.
6. It can examine the problems of an aging faculty and suggest mechanisms for maintaining a present surplus of potential S/E faculty in some fields, in order to assure an adequate faculty in the next decade.
7. It can and must be an alerting mechanism within the government to provide information to government agencies, to colleges and universities, and to students making career choices of changes (present or anticipated) in patterns of demand or of supply.

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Undergraduate Science and Engineering Education

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The analysis and revitalization of undergraduate science and engineering education are critical tasks for the National Science Foundation. Major research breakthroughs affect our quality of life and our national security, making science education for both the specialist and the general public important issues.

My testimony will focus on the major areas where the National Science Foundation can help improve undergraduate education in the biological sciences. These areas were identified by a constituency that has three components. First, as president-elect of the American Society for Microbiology (ASM), I represent its 34,000 members. The American Society for Microbiology is the largest life-science society in the world with members in universities, hospitals, government, and industry. At least 140 are also members of the National Academy of Sciences. Because facets of molecular biology, biochemistry, genetics, virology, immunology, cell biology, etc., involve microbes and cells, our members represent many broad disciplines in the biological sciences.

My second constituency includes major research universities, represented by Pennsylvania State University. My previous associations with the University of California as a graduate student, the Massachusetts Institute of Technology as a research associate, and Purdue and Penn State Universities as a faculty member have provided a broad background for comparison. Penn State is representative of large land-grant universities with a wide range of programs including 5,220 undergraduate courses. Moreover, Penn State has a unique feature in its Commonwealth Campus system. Students can take their first two years of baccalaureate degree work at any of 20 campuses throughout Pennsylvania before completing their degree requirements at the Penn State University Park campus. This Commonwealth Campus arrangement provides insight into the educational concerns at colleges with a limited research emphasis.

My third area of representation comes from personal experience in directing research and development activities at a biotechnology company and from my current role as Head of the Department of Molecular and Cell Biology and Director of Biotechnology at Penn State. The Department has 35 faculty members and offers programs in microbiology, biochemistry, medical technology, and molecular biology for about 450 undergraduate majors. Although the Biotechnology Institute is new and does not yet offer undergraduate courses, we are designing an interdisciplinary program that will offer unique training in biotechnology. The commercial use of biological systems depends on our ability to use microbes for production, and the new thrusts into biotechnology make undergraduate education in science and engineering particularly crucial. My personal experience in industry has convinced me of the need to improve both the quality and the quantity of our undergraduate training.

With these three different constituencies, one might expect it to be difficult to unravel the complex issues affecting undergraduate education and identify specific problems. This is not the case. Some problems dominate so completely that they are visible from several perspectives. I will focus on these and address the question of how the National Science Foundation might develop systematic approaches toward their solution. Although it is tempting to place the burden solely on NSF, it is important to remember that its resources are limited. Therefore, my proposals identify critical areas where NSF can serve as a leader for solving problems, but also suggest the use of other partners in this enterprise. The colleges, universities, and scientific societies have specific expertise that can supplement the needed resources from NSF.

There are three primary areas that I would like to bring to your attention curriculum development, teacher effectiveness, and physical resources

Curriculum Development

The rapid pace of research discoveries has made many undergraduate courses and curricula obsolete. The quality of revisions often varies widely among different colleges and universities. Curriculum revision and the establishment of standards is one area where the scientific societies could have a significant role in conjunction with NSF. For example, in 1985, the American Society for Microbiology adopted a minimum core curriculum for baccalaureate degree programs in microbiology. This course of study is interdisciplinary in nature and spec-

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ifies courses in immunology, microbial genetics, and microbial physiology; all areas of current shortage in the labor force. The intent of a core curriculum is to provide a common framework for the 337 departments that offer academic degree programs in microbiology.

The ASM has also initiated discussions with the National Accrediting Agency for Clinical Laboratory Science to develop jointly a programmatic approval process for clinical microbiology training programs at the baccalaureate level. There are two key elements of the program: development of standards for assessing the minimal competencies of individuals who have completed such a program, and procedures to review the applications from departments proposing to conduct programs. The ASM, through the National Registry of Microbiologists, already has a mechanism in place to certify the competency of clinical and industrial microbiologists to prospective employers.

Such programs illustrate one role of scientific societies in establishing standards in undergraduate education. However, curriculum revision requires considerable commitment of both time and effort. Funding by NSF to promote curriculum evaluation and revision could greatly enhance the interactions between scientific societies and educational institutions to solve these problems.

Teaching Effectiveness

In order to address the problems associated with teaching effectiveness, there must be an understanding of the causes of ineffective instruction. A highly discussed issue at research universities is that the research emphasis detracts from teaching quality. I find no data to support this argument, and in fact the converse is likely. Research-intensive universities no doubt have faculty who are excellent scientists with limited teaching skills. They also have fine teachers who have no research programs. The major point is that poor teaching is *not* correlated with good research. Teaching ability is an individual trait dependent on many factors. Personally, I have found most university researchers to be concerned, dedicated, and hard-working teachers who identify student interactions as a prime reason for remaining in the university environment. In fact, many examples exist of faculty research benefiting and subsidizing undergraduate education by providing equipment and supplies for demonstrations and research projects.

One major problem affecting the quality of teaching revolves around the large number of students. Even the most dynamic teacher loses effectiveness when lecturing before classes of several hundred. Even the most understanding advisor can become impatient when overwhelmed with students. For example, science courses at Penn State for undergraduate majors often have over 200 students. Classes for non-majors in biological science range from 100 to more than 800. Although the faculty work hard to maintain quality in these courses, the ability to communicate to large, heterogeneous classes is limited.

The factors leading to large classes are complex, and it is not realistic to believe that NSF alone can solve the problem. However, an analysis by NSF of the elements of teaching effectiveness and recommendations for changes could be effective for obtaining support from universities and government for initiating necessary actions.

A second problem occurring primarily at non-research-oriented colleges is the lack of exposure of teachers to new concepts in science. My own field has undergone a revolution in knowledge over the last decade, and this excitement can better be conveyed by a teacher conversant with new ideas and concepts. An important program that would help teachers share in this excitement would be NSF competitive grants for faculty of small colleges to take sabbatical leaves at research institutions. Although such leaves occasionally occur, currently they are cumbersome to arrange and rely upon the host faculty member obtaining a supplement to an existing grant. A program permitting more faculty to take leaves and gain insight into scientific advances would greatly improve teaching effectiveness at these colleges.

A third problem concerns the impact that the secondary school education has on undergraduate teaching effectiveness. Although the analysis of secondary education is not the primary charge of this Committee, you should be aware that science literacy at the undergraduate level stems from quality teaching in the secondary schools. In this regard, there is a role for NSF to support greater exchange and cooperation among secondary school teachers and our colleges and universities. This role could include efforts to revise textbooks, increase available literature, make films, support workshops, and foster closer cooperation between college science departments and secondary school science teachers. A greater continuity in the science curriculum would permit offering more advanced material and increase the enjoyment and effectiveness of teaching at the undergraduate level. This increased exposure of secondary school students to the excitement of science will repay society many times in the future.

Physical Resources

Recently, great attention has been drawn to the lack of modern instrumentation in our research laboratories. This lack is even more evident in teaching laboratories where funds for equipment purchases have been virtually non-existent for years. Not only does limited equipment force students to work in large groups, it eliminates the possibility of students doing any experiments involving modern, state-of-the-art techniques. The need for new laboratory facilities and equipment becomes critical when coupled with the extraordinary advances in modern biology which have changed dramatically the methods used to investigate biological systems. Modern biology has become technology driven.

Even in microbiology, the traditional microscope often has been replaced by ultracentrifuges, scintillation counters, and DNA synthesizers.

The crisis is amplified because the same forces causing these changes are also creating greater needs for well-trained individuals to work in biotechnology firms. This growth is reflected in a 1983 survey by the Office of Technology Assessment (co-sponsored by ASM). This survey reported increased needs by biotechnology companies for individuals with advanced degrees and expertise in hybridoma biology, recombinant DNA technology, and cell biology. The overall annual growth rate for these positions between 1979-81 was 35.9 percent.

The problems with poor facilities and outdated equipment occur in many areas other than biological sciences. However, there is a severe problem in biology that I have not heard discussed for other areas: the expensive supplies needed to operate modern laboratories. The high cost of culture media, chemical reagents, and other materials requires that students do experiments in large groups or, in many cases, forces the elimination of experiments entirely. Many universities have deleted advanced laboratories from their curricula, and students are often limited to the most fundamental laboratory exercises and demonstrations.

The absence of laboratory experience results not only in the lack of experimental skills but, even worse, in the lack of understanding of biology as an experimental science. In a society where science and technology so greatly influence our lives, we are graduating students with limited factual knowledge and understanding of scientific experimentation. We will rely on some to become our future researchers, while many will be leaders who serve on public boards concerned with the effects of research on their community, environment, and economic development. As a consequence, we will have a society ill-equipped to make either the future scientific advances or the important political and ethical decisions affecting our lives.

What can be done to solve the crisis caused by outdated equipment and the high cost of laboratory supplies? The equipment problem can be addressed by augmenting the funds available through NSF for scientific instrumentation and appropriating a portion for competitive grants for undergraduate teaching. This is not a new proposal, but its age does not make it less important.

The second problem of insufficient funds for laboratory operations will require new programs. One approach that builds on our traditional granting mechanism would be for individuals or departments to submit proposals for the development and operation of new laboratory courses. Although there could be some dangers associated with opening the funding of our educational programs to competition, there could also be some advantages with a peer-reviewed competitive process that rewards faculty interested in developing new courses.

Even if the above programs are established, the immediate resources will not be sufficient to solve such an extensive nationwide problem. Thus, other possibilities should be considered. Several faculty members have commented that NSF had sponsored an Undergraduate Research Participation program which provided limited stipends for undergraduates to do research during the summer. This program was extremely important because students could obtain sophisticated training and individual attention within a research laboratory. Such undergraduate research courses are already the major laboratory experience for many students. Unfortunately, there are far more undergraduates who need laboratory experience than our research programs can accommodate during the academic year, and most students cannot afford to do research without pay during the summer. Stipends in the range of $1,000 to $1,500 (plus a small amount for supplies) could permit many more students to gain valuable experience doing research in universities and industries. The program would have the added advantage of permitting students enrolled at colleges without research emphasis to profit from the opportunity of working elsewhere during the summer. The funding of an undergraduate research program would be a rare instance where a relatively small investment each year could have a major impact on undergraduate science education.

An additional approach to providing current scientific information is to sponsor workshops on specific topics to supplement undergraduate courses. This is currently done on an informal basis when special techniques or topics require outside expertise, but, in general, it is not a frequent approach at the undergraduate level. However, NSF could examine the possibility of providing materials and sponsoring workshops that could be taken to several institutions at a low cost. The American Society for Microbiology provides highly successful workshops for professionals, often in conjunction with scientific meetings. This theme could be modified to provide a similar service at undergraduate colleges and universities, and, in fact, it would be valuable for NSF to work with scientific societies to prepare and disseminate these materials.

The development of computer-simulated experiments could help decrease the cost of laboratory courses. This is currently employed in a biochemistry laboratory at Penn State, where the students use the computer to review procedures and analyze potential problems before doing the experiment in the laboratory. This system is extremely popular and reduces wasted time and supplies caused by students starting the experiment before understanding the protocol. My personal view is that the computer substitutes for the age-old lab manual, and that its success relies on the computer enticing the students to study the material. But, even if this is the reason for its success, it is an educational tool that does force students to think experimentally. I want to emphasize that the computer simulation should not replace the laboratory experience, but should supplement it by presenting variables, problems, and results that cannot be experienced directly in large undergraduate courses.

A federally sponsored program to develop computer simulations of experiments could augment training received in traditional laboratories. Such a program could provide grants to faculty interested in developing computer software for courses and sponsor activities within scientific societies for the development of packages to be used by their members. These funds could also facilitate the exchange of such information and help incorporate it into established curricula.

Another suggestion, based on my industrial experience, where limited funds were often leveraged to seek the best return on investments, is that NSF implement programs that use matching funds from other university, government, or industry sources. This recommendation could be particularly important for obtaining the costly equipment and supplies for undergraduate courses.

To be most valuable, the requirement for matching funds must be reasonable. Even though I have a relatively large departmental budget at Penn State, it would still be difficult to provide more than a few thousand dollars of uncommitted funds for any one new project. However, such small contributions can extend the limited NSF funds and can demonstrate the university's commitment to the program. The other essential requirement is to keep the paperwork to a minimum. Limited faculty time is the basis of many of the current problems, and new programs that are overly unwieldy will not lead to improved undergraduate education.

My final recommendation is for NSF to continue the review started by this Committee and develop a quantitative means for measuring the success of programs that are initiated. This recommendation is based on my belief in the need for accountability. In order to hold a program accountable for improving a segment of undergraduate education, we need a standard to monitor improvement. Although it is tempting to launch programs without this component, I believe it is a critical element to aid decisionmaking on the merits of programs, their need for funds, and their continuation.

Conclusion

This report emphasized critical areas where NSF can function to improve curriculum development, teacher effectiveness, and physical resources in undergraduate education. The importance of addressing these issues cannot be overstated. Recent scientific breakthroughs have opened extraordinary opportunities for biologists, and their work will impact health care, agriculture, and everyday life. However, students must be highly trained in modern science if they and our nation are to seize these opportunities.

Many of the problems, such as the lack of equipment, have developed through years of neglect, and major, long-term efforts are needed to reverse the process. Although NSF should not be expected to solve these complex problems alone, it can serve as a catalyst by launching new programs that stimulate cooperation with other partners seeking solutions. The lack of laboratory courses is a primary example where new grants for equipment, supplies, student research, innovative course design, and traveling workshops could plant the seeds for new growth and approaches within the scientific societies, private sector, and universities. The development of these programs is an appropriate charge for NSF that would have enormous long-term benefits to our society.

Issues in Engineering Education

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I am delighted to come here today to address your interests in undergraduate science and engineering education. With your leave, I will talk principally about engineering, since that is my own background and over the years has been of concern to me in the industrial research and engineering context. By the way, I believe that the issues in science and engineering undergraduate education are fundamentally different. Many differences stem from the disciplinary character of science as contrasted to the problem-solving character of engineering. They have some macro-issues in common: faculty inadequacies, lack of facilities and equipment, the need for improved curriculum, and desire for quality graduates, but the differences are more significant. So, let me focus on engineering.

Engineering education has been examined more often and in greater depth than perhaps any other part of the university. Examination is a difficult task, for engineering does not fit the disciplinary mold of most academic sciences. It tends to be amorphous and diffuse, and contains within it many diverse subjects. Further, the goals of engineering education are not easily agreed upon.

I will not review all the previous studies of engineering education. Let me just note that in the middle and late 1960s, there was an in-depth look, culminating in the establishment of the Commission on Engineering Education. It was eventually absorbed into the National Academy of Sciences. Closely associated was the study that yielded the Goals Report of the American Society for Engineering Education (ASEE). And, of course, there is the recent effort of the National Academy of Engineering.

The early activities were concerned with a variety of issues: the competition between engineering science and engineering practice; the paucity of design in the curriculum; the proper use of digital computation in engineering education; the adequacy of arts, humanities, and communication skills in the curriculum; the relative roles of laboratory work and theory; and the proper influence of immediate industrial needs on engineering education. There has been good progress on a number of these fronts in the past 15 years, but most of the issues are still there and must be confronted with modern engineering in mind, just as the Academy study indicates.

I have great confidence that this Committee will aid educators, and those of us concerned, toward a strategy for engineering education that is up to the demands of the rest of this century. So let me address only some topics that I consider crucial.

First, there is the matter of science and research versus practice in the curriculum. I am definitely a devotee of basics, particularly mathematics, physics, and chemistry. But if we are to let, as they say here in Washington, "engineering professors be engineers," there must be a component in the curriculum that addresses synthesis as contrasted to analysis. Synthesis includes design and its recent popular partner, manufacturing engineering. On the macroscale, we just do not know how to teach this well. There are many proposals and attempts—some with considerable merit. For example, the MIT Chemical Engineering Department has renewed its Practice School, which gives students and professors the opportunity to work at an industrial site. The Practice School is very expensive to operate, and it is oriented more toward operations than synthesis in many cases. The so-called co-op work-study programs are fine in many instances, but they cannot be expanded to handle the mass of students. Case studies have been used to instill a sense of engineering realism. These are only three approaches, but I think it fair to say that this puzzle of how to teach synthesis as a part of real engineering is an issue for our times.

A hint of how to go about this task was suggested some years ago by Herbert Simon in a remarkable series of lectures at MIT. His point was that design (and manufacturing) required codification as a disciplinary activity, and that the new modeling and design aids from computer science could be a principal tool in this effort. Without saying more, let me urge that NSF help academia and industry pursue this path in a more fundamental way than it has been pursued, despite progress we have seen in computer-aided design, computer-aided manufacturing, and computer-integrated manufacturing.

The second matter I would like to address concerns the competition between academia and industry for students, not to mention for faculty. The competition for students arises because industrial salaries attract students at the conclusion of their baccalaureate degree.

Furthermore, industry promises additional education and training, even lifelong education. And, it is true that industry is spending monumental sums on educating its employees. This indicates the wisdom of the long-held belief, as stated in the ASEE Goals Report, that engineering practice requires the equivalent of graduate education. Whether students get that education in industrial or academic programs, they will get it. Thus, undergraduate engineering education should not strive to produce the complete engineer in four years. NSF could perform a vital role by bringing industry and academia together to formulate a strategy for each which recognizes the realities of this developing situation.

Finally, let me address the matter of quantity versus quality in engineering education. Usually, I side with quality, particularly where engineers are at issue. But recent events in engineering colleges have caused me to look at quantity. The principal event is the general restriction on engineering enrollments that has been invoked one way or another by academic institutions. Of course, I understand the reasons for these restrictions: inadequate numbers of faculty, lack of facilities, and unwillingness to follow the ups and downs of the engineering enrollment cycle and the demand cycle that causes it. However, I have no doubt that the demand for engineers is in a long-term growth phase. The reasons are many, but principal among them is the increasing technological sophistication required in manufacturing and operations and in new fields such as bioengineering. The use of well-educated people in the factory and plant is one of the major strengths of the Japanese. For the United States, movement in this direction is a key to today's holy grail, international competitiveness. Add to that the needs of federal megaprograms—Strategic Defense Initiative, the Space Station, the Department of Defense buildup, even the Superconducting Super Collider—and the increasing need for more engineers is clear.

But how can this buildup be accommodated with the budgetary situation being what it is? Perhaps the best that the National Science Foundation can do is to expand the Engineering Research Center Program in a major way. Through that means, greater and perhaps long-term industry involvement can be achieved, and educational capacity increased at least indirectly. Another dimension is state and local governments. Ambitions for local economic development and jobs are pushing governments to support stronger educational institutions within their political boundaries. These trends can be intensified and accelerated by federal programs, particularly from NSF. That ought to become a major avenue for action. The objective would be to avoid alienating or rejecting many potentially fine students who want to become engineers. I have another, perhaps, sub rosa objective. It is merely to produce enough ambitious engineers to overwhelm the lawyers, financial, and business types who have come to dominate national leadership.

Let me conclude by saying that I have no doubt that engineering education is undergoing another transformation, away from a strict disciplinary approach and toward more emphasis on engineering synthesis, operations, and the back end of the innovation chain—namely, toward economics, marketing, service, and distribution. This direction is being encouraged by industry, but it has its dangers, including the subversion of long-held and still valid goals for engineering education. In conclusion, let me affirm those goals. Our engineers should not lack academic fundamentals, should be aiming for life-long education, should know how to use modern tools for problem-solving, should be effective communicators, and should be informed men and women of affairs. Achieving such goals, while satisfying the employers of engineers, is a demanding task. NSF has over the years and can in the future play a central role in achieving it.

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Undergraduate Science and Engineering Education

Anthony P. French

Professor of Physics
Massachusetts Institute of Technology

President
American Association of Physics Teachers

Since 1964 I have been a professor of physics at the Massachusetts Institute of Technology. However, my testimony to the Committee is in my capacity as the current President of the American Association of Physics Teachers (AAPT).

The background to this presentation is a document that has been prepared by the AAPT together with the American Physical Society (APS). Between them, these two societies represent the bulk of the physics profession, especially with respect to physics education, in the United States. We have a shared concern for physics education in the colleges and universities of this country, and we are grateful for this opportunity to discuss this concern with the Committee.

This Committee has already heard a number of powerful statements concerning the status of undergraduate education in science in this country and the importance of the role that the National Science Foundation has played and should again play in this area. Most, if not all, of the important questions have therefore already been raised. However, one contribution that the AAPT and the APS can make is the body of specific information contained in our background document. Besides embodying the work of several of our committees concerned with education, it also reports on the collected views from a large sample of physics departments in a variety of institutions of higher education. This information has come primarily from two sources: (1) two conferences for physics department chairpersons, both organized jointly by the AAPT and the Education Committee of APS, and (2) a nationwide survey conducted by the APS with assistance from the American Institute of Physics (AIP) and AAPT.

The Background Report

With the above introduction I should like to direct the attention of the Committee to the text of the background document, "Priorities for Undergraduate Physics Programs" (text attached). My presentation will emphasize its main features, findings, and recommendations.

The Special Importance of Undergraduate Programs

There is an urgent need for the strengthening of science education in the United States at all levels. However, as someone who had his education in a typical European system, I should like to emphasize the particular responsibility that devolves upon undergraduate education in science, and especially in physics, because of the shortcomings of precollege science education in this country.

By international standards, the amount and depth of high school education in physics in the United States is appallingly meager. The teaching of physics as a separate subject begins as early as the sixth grade in many European countries (and also in the USSR). Even students not planning to major in science will have taken at least three years of physics in high school. A student entering a university as a freshman planning to major in physics may well have been studying physics for a total of six years or more, up to a total of more than 500 class hours. (My authority for these figures is a survey of secondary physics education published in *Europhysics Education News*, No. 11, August 1983.) Contrast this with the one year of high school physics (about 100 hours) that is accepted as normal in the United States (and is all that is required, for example, even for entry to such a technically oriented school as MIT). This points in the first instance to an urgent need, not only to strengthen our high school physics programs at the existing 11th and 12th grade levels, but also to extend them into lower grade levels. However, the time scale for any major change of this kind is obviously very long. In the meantime, our undergraduate programs must carry the main burden of trying to bring our students, in the short space of four years, up to the level of the graduates from universities in other technologically advanced countries. This is a tall order, and it would be idle to pretend that the goal is always achieved.

Nevertheless, our colleges and universities on the whole do a fine job within the constraints under which they operate. But it is of vital importance that the quality of this effort not be imperiled—and, more than that, that it should be improved and strengthened in all possible ways. I believe that NSF has a crucial role to play in this regard, by reintroducing some of its programs that were highly effective in the 1960s, and by adding new programs of the kind discussed in the attached report.

Research Versus Education?

There has been a regrettable tendency in many quarters (including the universities themselves) to regard the interests of research and of undergraduate education as being almost inimical to one another. From a narrow point of view this might seem to be the case. If, in particular, NSF has a certain total budget, formally partitioned between support for research and support for education, then certainly a dollar increase in the one entails a dollar decrease in the other.

However, any such view of the situation is extremely short-sighted. It has always been true that research at the universities (as compared to pure research institutions) has contributed, out of all proportion to its size and cost, to the production of original discoveries and creative ideas. And the essential ingredient is the constant stimulus provided by the partnership of bright young students with their faculty supervisors. The students are mostly graduate students, to be sure (though not always—remember Brian Josephson, for example), but these graduate students must have been undergraduates first. The attached report presents dramatic evidence that the production of prospective graduate students in physics within the United States has declined seriously over the past decade and is still going down. It should be a matter of simple self-interest for the research community to support efforts to reverse this trend.

It would perhaps be possible to read into the preceding remarks an implication that it would be desirable to merge the research and educational support activities of NSF. This, however, is *not* my intention. I believe that the administration of educational programs in science is most effectively carried out, as has been done ever since the NSF was founded, under the aegis of a separate education division. There *is* a great deal of accumulated expertise in matters of science education in general, and I would strongly advocate a continuance of the present structure

Attachment

Priorities for Undergraduate Physics Programs

Executive Summary

The American Association of Physics Teachers (AAPT) and the American Physical Society (APS) Education Committee provide the following recommendations based upon the Conference of Physics Department Chairs held at the National Academy of Sciences on May 17 and 18, 1985, the Survey of Quality and Quantity of Undergraduate Programs and Students (conducted by APS and analyzed by AAPT in the Spring of 1985), and the deliberations of the committees of AAPT, APS, and the American Institute of Physics (AIP)

Findings:

1. Undergraduate physics programs have experienced declines in the quantity and quality of students enrolled.
2. The poor condition of undergraduate laboratory instrumentation is the most significant problem now facing physics programs.
3. Support for undergraduate research has decreased and is viewed as a high-priority area for increased action.
4. Computer access is a significant new worry expressed by the chairs of the physics degree-granting institutions.
5. There is no appreciable difference in the problems and priorities for action as reported by chairs of undergraduate and graduate physics departments.

Recommendations:

1. The National Science Foundation should expand its existing undergraduate programs and add several new ones.
2. Undergraduate laboratory equipment and instrumentation programs should be given first priority for expansion. All types of institutions (Ph.D., M.S., B.S.) should be eligible since we find no differences in the severity of the problem by level.
3. NSF should reinstitute programs for support of undergraduate research. The Undergraduate Research Participation programs sponsored by NSF in the sixties and seventies were viewed as particularly effective. Undergraduate research programs should include support for undergraduate research at primarily undergraduate institutions and at graduate institutions. These programs should also include support for bringing students from non-research institutions to research institutions.
4. When addressing curriculum concerns, NSF should focus on questions of ensuring computer access and integrating computer and video disk technology into the undergraduate programs.
5. NSF should initiate faculty development programs that:

   —Would encourage young research faculty members to get involved in teaching development,
   —Would allow four-year college faculty members to interact with research scientists, and
   —Would increase the participation of women and minorities in research and teaching

Introduction

The American Association of Physics Teachers has had a long and deep interest in the problems of undergraduate

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physics education. Since our founding in 1930 at a joint meeting of the American Physical Society and the American Association for the Advancement of Science, undergraduate and graduate physics education has been our primary concern. During the sixties the AAPT was the major force behind the activities of the federally funded Commission on College Physics. Since the untimely demise of the Commission in a period of federal budget cutting, AAPT has assumed the role (not to mention the archives) that the Commission once held. In that role, we sponsor general meetings on these issues, topical meetings on single issues, publication of resource materials for undergraduate educators, and development of program standards and guidelines. Our committee structure addresses many of the concerns of undergraduate education ranging from curriculum through professional concerns. Our journal, the *American Journal of Physics*, is the oldest, largest, and most prestigious journal to address issues in undergraduate and graduate physics education.

The American Physical Society is the nation's largest and oldest organization of physicists. The APS Committee on Education has been one of its most active committees in recent years. There is very close cooperation between the Education Committee and the AAPT, and this cooperation has included joint sponsorship of many activities in support of physics teaching. Among these activities are joint conferences, surveys, and committees. Under AAPT and APS prodding, the American Institute of Physics developed an Educational Policy Committee to guide AIP educational activities and to act as a forum for the nine member societies: APS, AAPT, Optical, Astronomical, Crystallographic, Rheology, Physicists in Medicine, Vacuum, and the Acoustical Societies. APS and AAPT appoint over half the members of this committee, which has now operated for nearly two years.

During 1985, two major programs were conducted which have a direct and important bearing on issues in undergraduate science education: the conference of physics department chairpersons held in May 1985 (and building on a similar conference held 18 months earlier) and the Survey of Quality and Quantity of Undergraduate Programs and Students. Each of these programs involved a large and representative portion of the physics undergraduate community and each provided strong direction to us and to federal agencies.

Recommendations and discussions presented in this paper represent a distillation from the output of these two programs, and from AAPT committees and the education committees of AIP and APS, but the report has been prepared by A. P. French (MIT), President of AAPT, and J. M. Wilson (Maryland), AAPT Executive Officer, and reviewed by R. R. Wilson (Cornell), President of APS, and H. Lustig (CCNY), APS Treasurer.

The Conferences of Physics Department Chairs

In September 1983 and April 1985, two separate two-day meetings were held in the Washington area for department chairs of physics departments from all over the United States. The conferences, sponsored by AAPT and APS, each drew over 150 attendees. The topic of the first conference was "Education of the Physicist" and for the second it was "Education for Professional Work in Physics." The chairs concluded that, although physics research has flourished during the last decade, serious educational and manpower problems lie ahead. Many of the issues from the earlier conference surfaced again at the 1985 conference.

Speakers informed the conferees that the record of accomplishment in research was one to be proud of. In a preliminary report on the National Academy of Sciences Survey of Physics, W. F. Brinkman of Sandia Corporation said that current progress in explaining fundamental forces, the evolution of the universe, and the properties of matter has been excellent. R. W. Schmitt of General Electric, Chairman of the National Science Board, noted that physicists continue to perform well in their traditional roles of providing the intellectual foundation for research, achieving "the breakthroughs that change our world," and illuminating practice by providing "the basis for realistic yet usable mechanics of complex materials."

The 1985 conference heard a description of the just-beginning study of national science policy being carried out by the House Committee on Science and Technology. With a 1986 report date, the study will consider a broad range of issues affecting the federal government's support of basic and applied research in physics and other sciences and engineering. A central question is whether the traditional mechanisms for allocating support to science will continue to serve the nation well in an era of intense international economic competition, budget deficits, multidisciplinary research projects, and large-scale research enterprises competing with "small science."

Assessing manpower issues, D. Corson, President Emeritus of Cornell, described a number of serious problems that have intensified in recent years. These include: depressed annual production of physics Ph.D.'s, a decline in the percentage and number of U.S. citizens receiving a physics Ph.D., little progress in recruitment of minorities and women, a median age of physics faculties that is the highest of any of the sciences or engineering (and rising rapidly), and demographic trends likely to reduce the number of physics graduates until well into the 1990s. Smaller physics departments, in particular, are likely to find the next few years quite difficult.

H. William Koch, Director of the American Institute of Physics, made some similar observations at the 1983 conference. Figure 1 shows the annual production of Ph.D.'s over the last quarter century, while Figure 2 illustrates how the ratio of physics doctorates to total natural science and engineering doctorates has plummeted over the last half century. These declines in absolute number and percentages were accompanied by a changing mix of physics graduate students. In 1970-71, 82.4 percent of the graduate students were U.S. nationals, but by 1982-83, that percentage had dropped to 59.9. The increasing number of foreign nationals has masked the dramatic decline in the number of U.S. students enrolled in graduate programs in physics. In 1970-71, there were 3,213 entering U.S. students compared to 1,718 in 1980-81—a decline to nearly half the number a decade earlier. The decline has continued in the 1980s.

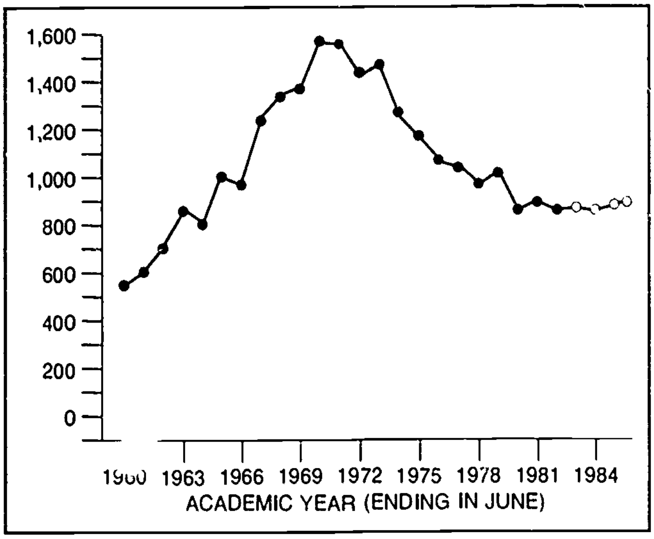

Figure 1. Annual Production of Physics Ph.D.'s in the United States.

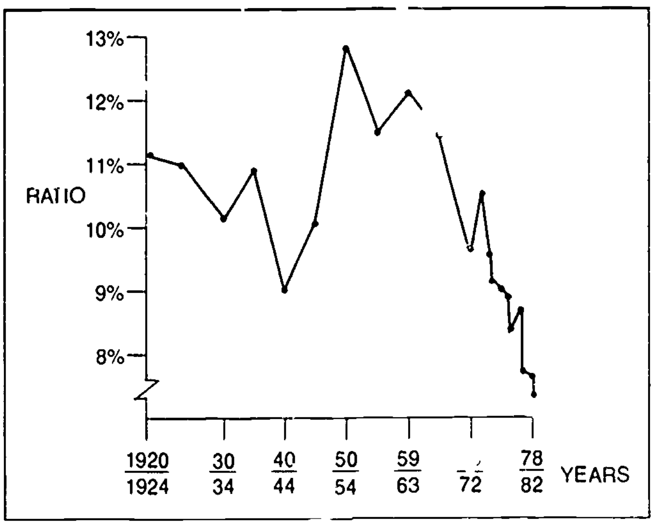

Figure 2. Ratio of Physics Ph.D.'s to Total Ph.D.'s in Natural Science and Engineering.

At the 1985 conference, reports were also delivered on the Survey of the Quality and Quantity of Undergraduate Physics Majors (see below) and on recruitment of minorities and women in engineering. The conference also conducted a series of small group discussions on more specialized issues ranging from tailoring education to the jobs to the use of computers in physics. The groups gave high priority to restoring programs of federal support for undergraduate science education, particularly the undergraduate research participation programs. They also noted with approval the reinstitution of NSF programs for support for undergraduate laboratory instrumentation and research in four-year colleges and hoped that those programs would expand. The groups reported a high demand for physics graduates at all levels.

At the 1983 meeting, a group of department chairs headed by R. Tribble, Chair at Texas A&M University, and W. H. Kelly, Dean of the College of Science at Iowa State University, studied the role of undergraduate research and the associated equipment needs. They concluded that "most if not all colleges and universities in this country are suffering from a shortage of up-to-date laboratory equipment." They advanced a resolution that passed without dissent from the 183 attendees:

> "We request the American Association of Physics Teachers, the American Physical Society, and the American Institute of Physics work to inform the National Science Foundation, Members of Congress, university presidents, and state legislators of the serious problem of lack of funds for equipment for undergraduate physics laboratories and the importance of developing sources of funding to provide capital equipment specifically targeted to undergraduate instructional and research equipment."

Survey on the Quality and Quantity of Undergraduate Physics Majors

A survey of the chairpersons of all U.S. physics departments was designed to get opinions and new ideas on how to raise the quantity and quality of undergraduate physics majors. Robert Resnick of RPI headed the project and provided most of this analysis. The survey was conducted by the American Physical Society with assistance from AIP and AAPT.

The number and quality of physics majors are affected by a whole range of issues, from the crisis in science and math instruction in the primary and secondary schools to the national economy and the job market for physicists. The survey focused on the short term and dealt with the current situation. Besides calling for new ideas and general comments, the survey asked for specific ratings and comments on a list of curriculum offerings, educational materials and physical resources for undergraduates, programs to attract women and minority students into physics, visiting scientist programs, and undergraduate research participation programs.

Responses were received from 553 of the 791 U.S. physics departments, a 70 percent rate, 83 percent of the doctoral institutions responded. It was interesting to note that we found no significant differences in needs or priorities reported by the chairs when we analyzed the result by either level of program or size of program.

A detailed summary of the ratings and comments on the ten specific items to be evaluated is given in the *Proceedings of the 1985 Conference of Physics Department*

Chairs from the American Association of Physics Teachers. The following figures and tables summarize some of the responses.

Figure 3 shows the distribution, by type of school, of responses to the questionnaire. Figure 4 gives the distribution of different kinds of courses and programs offered by undergraduate physics departments. Table 1 shows the existence of special programs for women and minorities. Table 2 shows the distribution of undergraduate research participation programs and visiting scientist programs. Table 3 gives the chairpersons' ranking of the areas most important to stress for new initiatives to funding agencies, breaking down the responses according to the Ph.D., M.S., and B.S. granting institutions represented (note that a ranking of 3.0 would mean that every chair ranked this item as his number one item; 2.0 is a very high ranking on this scale). And, Table 4 summarizes the chairs' observations about the present quality of undergraduate students compared to those in engineering and computer science.

The survey committee developed some general conclusions from the results and analysis of the comments section as to how physics departments could raise the quality and quantity of undergraduate physics majors:

1. Greatly increase the interaction between physics faculty and high school math and science students and teachers.

2. Put your best people into the introductory physics course as lecturers and recitation-discussion leaders, for if you cannot win students over in that course then all the subsequent programs and ideas that are suggested are much less effective than otherwise. In that introductory course, the area of most concern, however, is the laboratory—the low quality of the experiments, the equipment, or the teaching assistants.

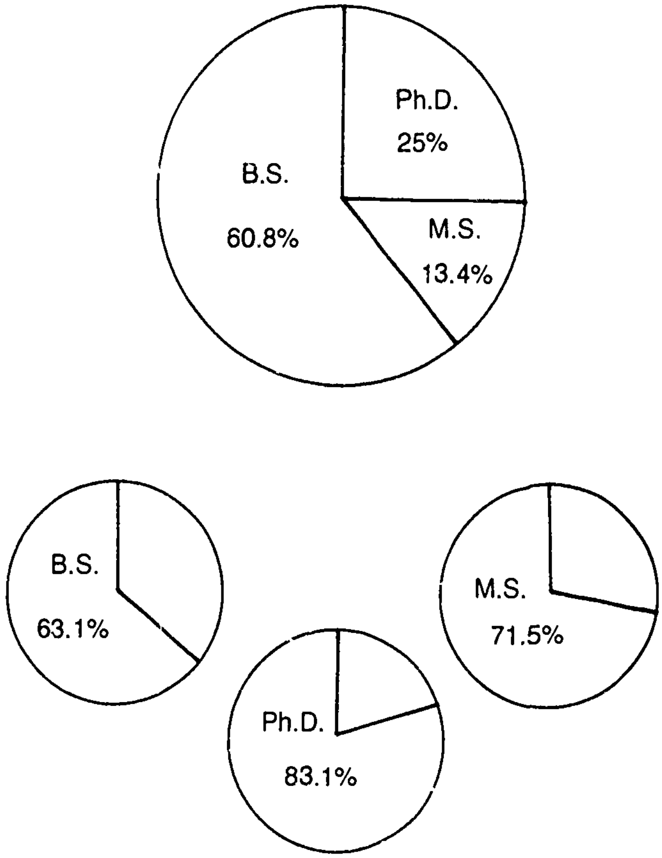

Figure 3. AAPT/APS Survey: Distribution of Responses by Type of School.

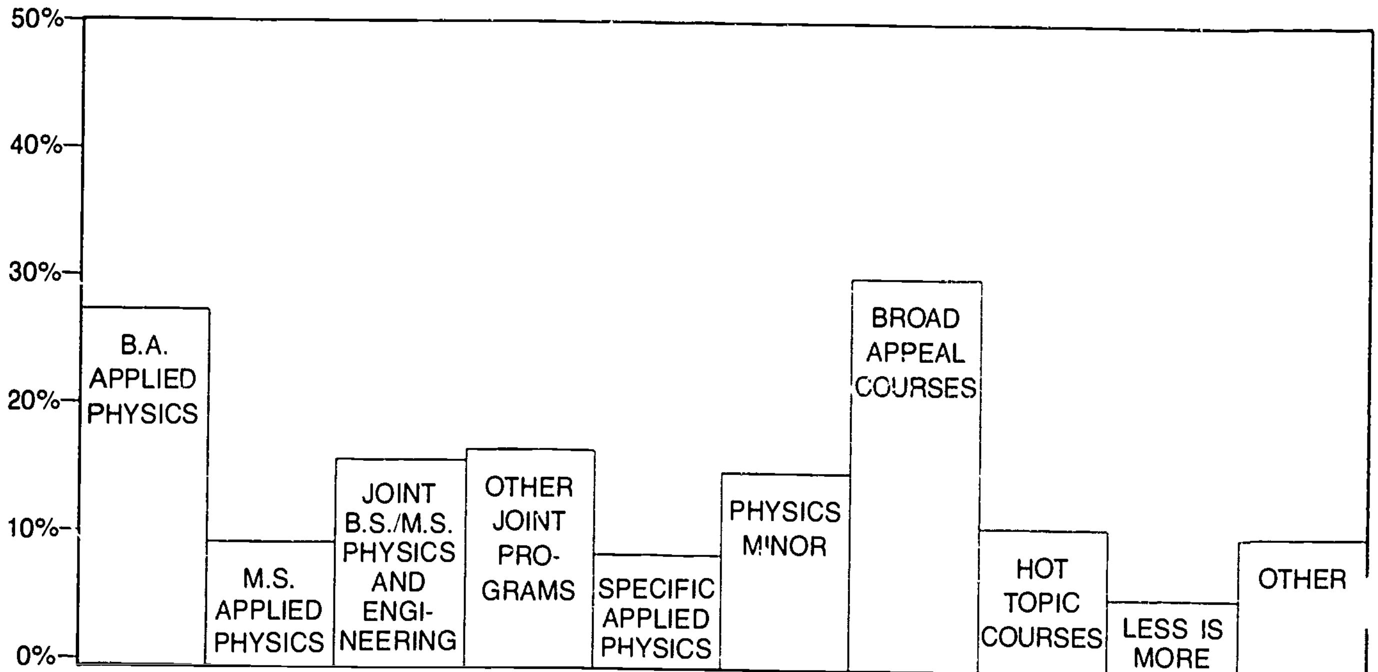

Figure 4. AAPT/APS Survey: Distribution of Different Kinds of Courses and Programs Offered by Undergraduate Physics Departments.

Table 1. AAPT/APS Survey. Special Programs.

Special Women's Programs		
All	38 of 543	7%
Ph D	14 of 138	10%
M S	6 of 73	8%
B.S	18 of 332	5%

Special Minority Programs		
All	46 of 543	8%
Ph.D.	15 of 138	11%
M S	7 of 73	10%
B S	24 of 332	7%

Table 2. AAPT/APS Survey. Distribution of Undergraduate Research Participation Programs and Visiting Scientist Programs.

Undergraduate Research Participation Programs

	All	Ph D	M S	B A
With Prof./Credit	67%	77%	84%	59%
With Prof./Pay	38	63	53	23
Summer Intern	32	56	34	21
Other URP	12	16	5	12
None	23	13	11	30

Visiting Scientist Programs		
All	170/543 =	31%
Ph D	36/138 =	26%
M.S.	22/73 =	30%
B.S	112/332	34%

Table 3. AAPT/APS Survey: Priorities for Action (rated on a 3-point scale).

1 Laboratory Equipment		
All	2.0	
Ph.D	2 1	
M.S	2 1	
B A	2 0	
2 Undergraduate Research Programs		
All	1 0	
Ph D	9	
M S.	1 0	
B A	1 0	
3 Computer Access		
All	.66	
Ph D	83	
M S	90	
B A	53	*5th Priority
4 Curriculum Development		
All	61	
Ph.D	.50	*5th Priority
M S	51	
B A.	67	*3rd Priority
5 New Educational Materials		
All	54	
Ph.D	50	*4th Priority
M S	36	
B A	59	*4th Priority
6 Visiting Scientist Programs	25	
7 Minority Programs	.12	
8 Women's Programs	11	
9 Other	11	

Table 4 AAPT/APS Survey: Quality of Undergraduate Physics Majors.

	All	Ph D	M S	B S.
Compared to Ten Years Ago				
Better	74	14	15	45
Same	277	70	36	171
Worse	158	44	15	99
No Opinion	10	3	0	7
Compared to Computer Science Majors				
Better	250	55	38	157
Same	147	40	11	96
Worse	37	13	3	21
No Opinion	76	22	14	40
Compared to Engineering Majors				
Better	184	59	27	98
Same	194	41	22	131
Worse	48	19	3	26
No Opinion	68	8	14	46

3. Involve students in undergraduate research participation programs early on, for access to research laboratories attracts undergraduates. The single item that was regarded as the most effective way to get high-caliber undergraduate students into physics, and to keep them there, was involvement in research.

4. A significant number of students who like physics choose, nevertheless, to major in engineering or computer science, according to comments received, because a physics bachelor's degree is viewed as less saleable than one in engineering or computer science Here, the advice was to educate recruiters and industry in general on the value and virtues of an undergraduate physics program and to correct high school counselors' false impressions that the physics job market is still poor.

5. Moreover, curriculum offerings should be expanded in applied areas of physics and more use made of joint majors, especially with engineering and computer science departments.

6. In order to raise or maintain the quality of the undergraduate physics majors program, especially at the small schools, respondents called for expanded funding for undergraduate research participation programs, for purchase of modern equipment in the upper-division laboratories, and for sponsorship of visiting scientist programs.

7. And, finally, we should greatly increase the opportunities, use, and visibility of women and minorities already in physics as role models to attract more majors from these ranks.

Summary

All of our sources of information recognize the central role of the undergraduate laboratory experience in the training of scientists. Support for programs to improve these experiences is consistently given the highest priority. Physicists are much less enthusiastic about curriculum projects. Concerns in this latter area center on the role of the computer in undergraduate physics education and especially on how this will affect the selection of topics in the introductory physics sequence and on how modern physics topics might be included. Otherwise, physicists seem to be comfortable with the undergraduate physics curriculum and feel that it is doing a fine job in preparing new physicists.

Physicists are very worried about infrastructure questions. Facilities are viewed as adequate, but there are enormous equipment and personnel problems. Almost every physics department reports that the state of equipment and instrumentation is bad and getting worse rapidly. Programs make do with what they have but fall further and further behind the state of the art. Graduates of many science programs find that they must undergo a lengthy period of training after they enter industry because of inadequate laboratory experiences.

Support for equipment purchases for undergraduate laboratories has been the absolute first priority for physics departments for at least the last three years. The situation is seen as deteriorating rapidly. Closely related to this is support for undergraduate research programs. Physicists view this as vital to any student's training but find it difficult to obtain support.

Even at the doctoral institutions, undergraduate research is seen as a problem area because it is hard to justify the use of scarce research resources in support of undergraduates. Research programs can be more productive when the resources go to graduate students. Support for undergraduate research is considered to be an educational responsibility, not a research responsibility. At the four-year schools, research opportunities could be either easier to obtain or more difficult depending upon the character of the institution. At those few four-year institutions with substantial research in progress, undergraduates are centrally involved. Unfortunately, "Big Physics" and limited resources combine to restrict research funding and to direct it to major institutions. The NSF program on research in four-year institutions has been an important recent improvement in that situation, but much more remains to be done.

There are two methods of ensuring research experience for undergraduate students at the smaller institutions. The first is to provide funding for research at undergraduate institutions. As noted, this is being done, but it could be expanded. The other is to provide funding for support for students from these institutions to "intern" for a period at nearby research institutions. Here, the NSF role could be important to catalyze a few of these programs as well-funded demonstrations while providing partial support to a large number of others.

The personnel problems are not as easy to solve. Mechanisms must be found to increase the number of U.S. students going into physics. Another mechanism must be found to allow universities to continue to add young faculty in spite of the present "fully tenured-fully staffed" situation pointed out by Corson.

Undergraduate physics education is still quite effective, but there are a number of severe problems that must be addressed—and soon. In contrast to the situation at the precollege level, the problems appear to be manageable if we act decisively. However, American science depends upon undergraduate and graduate education to make up for deficiencies in precollege education. If we allow the undergraduate programs to flounder, we may do irredeemable damage to our scientific and economic health. It is most important that we improve the state of precollege education. It is equally important that we act now to limit the damage to our undergraduate science programs.

Addendum

The History of NSF Support for Science Education

Almost immediately after its creation in 1950, the National Science Foundation began its support of science education, especially through its graduate fellowship program. This grew rapidly, and was soon followed by major projects in curriculum development and teacher training, especially at the secondary-school level—the PSSC physics program, and then by similar projects in chemistry and biology. By the early 1960s, the total support of science education programs was about $80 million per year and represented more than one-third of the Foundation's budget.

The story since that time has been very different. In terms of constant dollars, the support for both graduate fellowships and for other educational programs has declined drastically. The situation is shown most vividly, perhaps, by the attached graph (Figure 1), showing the support for science education (excluding predoctoral fellowships and traineeships) as a percentage of the total NSF budget. From a high of over 30 percent in about 1960, the percentage dropped to only about 6 percent in 1980. Shortly thereafter it fell to essentially zero. (Of course the total NSF budget increased greatly over the years but the support for education, in terms of constant dollars, fell by a factor of more than three over this period.)

The most recent budgeted figure is shown by the single point for fiscal year 1986—about 3 percent of the total budget, corresponding to an actual figure of approximately $50 million.

The Council of Scientific Society Presidents, on May 15, 1985, passed a resolution urging support for an NSF education budget of at least $100 million for college and precollege science and engineering education. It is worth noting that this would still be far below the level of support provided in the early 1960s, which in terms of current dollars would be equivalent to about $300 million per year.

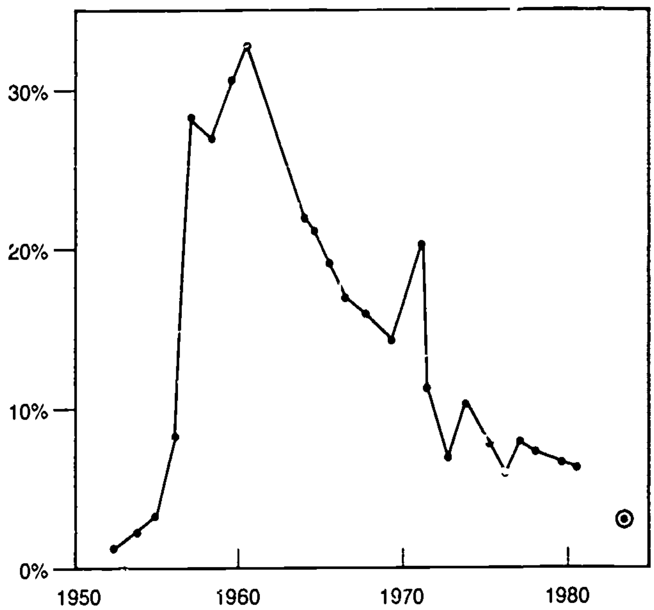

Figure 1. NSF Support of Science Education as Percentage of Total NSF Budget (predoctoral fellowships and traineeships excluded).

Source: Compiled from National Science Foundation Annual Reports

U.S. Engineering Undergraduate Education

Fred W. Garry

**Vice President for Corporate Engineering and Manufacturing
General Electric Company**

It is always tempting to reach for some profound new insight when asked to comment on such a nationally important topic as undergraduate engineering. Although my membership on the board of managers of two predominantly undergraduate engineering institutions, my advisory committee membership at several other more research-oriented engineering schools, and my position as a senior engineering executive of a company that employs about 1,100 new engineering undergraduates a year provide more than a casual relationship with the subject, I am certainly not an academic and my views must, therefore, be thought of as those of a concerned professional who has helped struggle with campus problems, and as an even more concerned professional engineering manager whose company conducts roughly 2 percent of the nation's R&D—R&D that supports a broadly diversified industrial and service business portfolio that is, in a sense, a microcosm of the goods-producing sector of the nation.

It is gratifying to realize that NSF is now focusing attention on the undergraduate engineering issue. Over the past five years, the "crisis in engineering," defined primarily as a shortage of qualified faculty and modern laboratory equipment, resulted in increased industry and government support aimed at expanding the pool of native-born Ph D. holders and providing new equipment for graduate laboratories.

Although this support is still properly viewed as inadequate relative to the total need, the action has addressed a first-order need to stimulate doctoral study and thus develop a few more state-of-the-engineering-art qualified faculty members to handle the step-function increase in engineering enrollments and address the need for greater and greater numbers of advanced degree engineers to carry out rapidly expanding industrial research projects.

Certainly, this attention to graduate engineering education and on-campus research is essential:

- To develop and retain faculty,
- To carry out a broader range of fundamental research projects, and
- To provide an on-campus excitement to stimulate both students and faculty.

But, in the totality of the need to provide the engineering resource required to maintain U.S. leadership in the global industrial marketplace, it is only one link in a long chain whose other links include:

- The stimulation of children's interest in math and science at an early age,
- Strong secondary school learning opportunities in the subjects required for a career in engineering and science,
- Excellent undergraduate programs,
- Opportunities for advanced degree work, and
- Continuing, structured education for professionals as contrasted to periodic and casual training throughout the engineer's career.

I am not sure that I understand what charter role NSF has in the precollege world, but it is certainly true that all recent studies provide a disappointing picture of how inadequate is the preparation most American youngsters are receiving for careers in science and engineering or, for that matter, even for personal decisionmaking in an increasingly technologically based society. My personal belief, however, is that NSF should play an increasing role with the primary and secondary educational fraternity to assure that our young people have a thorough grounding in this area.

NSF does have a significant responsibility for the health of U.S. scientific endeavors, and, because excellence at the top can only be built on a quality underpinning, it is apparent that strong undergraduate engineering programs at both major research and less research-oriented colleges of engineering are essential for the nation's security and economic competitiveness. But the harsh fact that about three-fourths of U.S. engineers hold only a bachelor's degree, of course, begs the question of whether today's jam-packed, four-year programs provide adequate preparation for today's engineer

In the case of a company such as General Electric, we rely upon both internal and external basic research, engineering research as a link to fundamental scientific discovery, and leading-edge engineering execution to provide global competitive status. To meet our needs, the percentage of advanced degree holders has risen sharply at General Electric in the past decade. Today, nearly 70 percent of our key engineering people have advanced degrees, including about 25 percent who hold doctorates. Nearly one-fourth of our GE manufacturing managers, incidentally, also hold advanced degrees.

I believe that tomorrow's engineering education will, more and more, extend beyond the campus. About 1,200 of General Electric's most recent engineering hires are currently pursuing company-university cooperative programs leading to a master's degree. Some 20,000 additional people are expanding their technical strengths through training programs using the latest video-based distributed educational concepts that provide for on-site, minimal career-disruptive learning. All this speaks to the need for forefront, multinational companies to be able to make decisions at the leading edge of technology.

It is my belief that all U.S. industrial firms, faced with the worldwide technical challenge, will find a continuing need—not only for more engineers but, also, for engineers with new, higher levels of technical competence encompassing stronger fundamental analytical skills, multifunctional as well as multidiscipline systems orientation, and familiarity with the tools and practices of modern industrial engineering.

Although this total preparation is obviously beyond the scope of today's four-year programs, it points to the need for excellence in all aspects of the undergraduate experience as the bedrock upon which we build.

Today, I would like to pass along to you my observations on five basic undergraduate engineering schools' problems that have consistently been front stage at college of engineering board of trustees meetings during my two decades of participation at such sessions. I might add that at board of visitors meetings at several other schools, the concerns are similar and influence my views.

Physical Plant

Let us begin with the subject of the physical plant. Expanding enrollments, new technology, new tools, and new engineering practices dictate the need for classroom and laboratory improvements. Then again, the quality of life expectation of today's engineering student requires that the college must provide acceptable modern dormitory space, good food service areas, athletic and recreational facilities, and some of what I will call "gathering space" for social interaction. Changing technology and expanded liberal arts programs both demand better library facilities. Computers, peripherals, and software storage dictate some increase in dormitory living/study space. In addition, the faculty wants good offices

Although it may sound vulgar to suggest that, in today's world, it is hard to attract persons to a learning environment that is not in itself esthetically attractive, it is a basic student and faculty recruiting fact. As a result, capital campaigns to raise money for new brick and mortar for various adjunct facilities, as well as for classroom and laboratory buildings and equipment, must be launched every year or two after the preceding one, and each extends over several years.

A number of foundations, alumni, and individuals have contributed large amounts to such drives, but new kinds of equipment, new programs, and continuous progress in current programs make this a never-ending task. State legislatures provide brick and mortar at public universities, but at both public and private engineering schools, the facilities are far from adequate for modern undergraduate work I believe federal funding will be required—at least for laboratory work.

Laboratories

Laboratories (including design related laboratories) and lab equipment are special cases for funding. Engineering education is investment intensive, and it has become increasingly more costly to equip college laboratories with equipment representative of the type used in leading-edge industrial engineering departments. Although some help has been provided, particularly for graduate programs, there is a huge unfulfilled need at all degree levels for funds to buy or for gifts of instrumentation and gear. This implies high initial investment for sophisticated devices, which are also costly to maintain, particularly when used by inexperienced undergraduate students.

Lab equipment must be updated frequently, and the cost level of lab courses has resulted in some curtailment to assure funding for the less expensive lecture courses. I believe that NSF funding assistance to guarantee proper laboratory experience at the undergraduate level is one of the most important steps that must be taken. Such "hands-on" work provides a "gut" feel of equipment and parts that is a requisite element of preparation for a career in engineering.

Experience teaches us that creativity in science and engineering requires more than the acquiring of knowledge. In particular, it derives from personal participation. Laboratory training provides an opportunity for teacher-student interaction at a "doing" as well as a "listening" level. Physical experience in the laboratory can promote an excitement, a passion for doing things, that can transcend the more passive lecture hall experience. It is, furthermore, a "team" experience as compared to the classroom's individual activity. The lab helps prepare the engineer-to be for the large-scale, multidisciplinary, multifunctional projects that will predominate during the engineer's entire professional career.

Grants for undergraduate laboratories would provide an opportunity for faculty scholarly work as well as permit student participation in creative as well as routine "required" experimental work.

Computers

Expanded computer facilities are essential It is obvious that today's B.S graduate in engineering must have facility in the computational and graphics use of computers, including the capability to design and write software programs.

Today's increasingly powerful personal computers can handle about 90 percent (it is estimated) of the undergraduate engineering students' needs. As a practical matter, every student should own or have a college-provided terminal available to him for easy, frequent access. But, although the personal computer has adequate computational speed for most undergraduate work, the student must also have access to a mainframe or a minicomputer for stored data or to provide the large amount of memory required, for example, for finite element analyses.

Even as an undergraduate, the future engineer should at least have been exposed to modern computer-aided engineering systems such as those manufactured by Calma, Computervision, Intergraph, and others. Laboratory equipment demands increasing amounts of computer backup, and it is apparent that local area networks must soon link terminals across the campus.

My faculty acquaintances estimate that computer capital costs work out at about \$500 to \$1,000 per year for each undergraduate. There is, of course, additional expense for managing, updating, operating, and maintaining increasingly more elaborate systems.

The computer industry has been generous in providing much new equipment, but to a limited number of schools. Federal and state funds must be added to get the capability up to even minimal levels in all engineering colleges.

Faculty Recruitment and Retention

The recently published National Research Council report, *Engineering Education and Practice in the United States*, points out that only 2 to 3 percent of engineering graduates opt for a career in teaching. It also notes that the percentage of doctoral engineers who teach has declined about 25 percent in the past decade.

NSF, through the Presidential Young Investigator awards and other grants, has provided increased assistance for young engineers to pursue doctoral careers and accept faculty positions. Industry has also contributed funds and equipment to encourage entrance into teaching and campus research and, concurrently, to provide support for current faculty. A primary thrust of the General Electric Foundation, for example, is the enlarging and strengthening of engineering faculty.

In talking to faculty and certain ex-faculty, I have sensed that persons who choose engineering as a career have a yen to make things, to find specific applications for their technical knowledge rather than just treat it in an abstract sense. Undergraduate engineering requires excellent teaching, but total dedication to teaching can be stultifying.

For the professor who works at the undergraduate level, research or personal non-teaching development support that provides an opportunity to take an active part in the drama of progress that is altering our world is not only personally stimulating, but will, I believe, enable the professor to communicate the excitement generated by the experience to his students. Engineering faculty, in my view, should be engineers who teach—not just clones of scientists and academics.

But faculty shortage, with consequent heavy teaching loads, inadequate facilities, and the minimal funding available to many undergraduate faculty members, makes it difficult to find time to compete for or carry out consulting or research projects. Even when the college has a strong sabbatical or leave of absence policy, engineering professors find it difficult to participate for both financial and intangible reasons:

- Their absence demands finding substitutes or further increases the load of colleagues,
- Sabbatical support, however well intended, is generally less than needed to relieve the full financial strain of moving or a two-location existence, and
- Absence or temporary relocation leads to personal and family stress situations.

Even so, many faculty members struggle creatively, successfully, and, I think, heroically with this refreshment issue. It seems to me, however, that the continuing development programs for faculty are pretty much ad hoc.

Although I have been trying to make a case for some level of research support on all campuses, it is obvious that it is financially impractical to provide the very sophisticated research facilities needed for leading-edge work—except on a few campuses To stay abreast with both university and industrial research and development, faculty at other colleges must somehow be made aware of the discoveries resulting from this work.

It is not clear to me just how faculty members from a predominantly undergraduate school could get to participate, for example, as associates at a primary research center or in subcontract roles on their own campus. Although undergraduate faculty experience at a primary center would be great (assuming it could be worked in reasonably schedule-wise and could be funded as part of a sabbatical or leave of absence), I assume that in some cases even a full professor on a temporary basis would be less contributing and less cost effective than a graduate student assistant, but the overall gain might justify some seeming inefficiency in the specific project. NSF, as one of the principal funding agents of the research, could structure grants that provided for such visiting faculty participation.

In addition to sabbaticals at university sites such as the Engineering Research Centers that are being supported by NSF, I believe that greater interaction of both undergraduate and graduate faculty with industry is essential:

- To provide experience in the multifunctional process of coupling technology to the marketplace,

- To provide firsthand knowledge of the tools and practices employed by today's engineers,
- To acquaint faculty with the talent requirements of various industries, and
- To identify the industrial barrier problems that will better orient university research.

Although many industries have increased their funding of on-campus or cooperative research and consulting work, NSF supplementary support could accelerate the expansion of this vitally necessary interaction.

Again, if satellite teaching as proposed by National Technological University permits us to take advantage of today's communication technology for graduate study and continuing education for industry, why should we not consider similar technology applications for the "continuing education" of faculty on campuses not equipped for advanced research projects. Electronic seminars are not a total answer, but are perhaps a cost-effective and convenient aid to staying current, particularly when enhanced by periodic research participation through sabbaticals.

So much of our attention has (with due cause) been given to producing an increased crop of new engineering Ph.D.'s that we have given less attention than the situation deserves to enhancing and updating the capabilities of current faculty. Full utilization of the majority of existing faculty, retrained as necessary, is essential; it is impractical to believe that we can produce new, truly qualified faculty at a rate that will meet the demand.

It is probable that some small percentage of current faculty will not find it possible to meet tomorrow's challenge. Industry has used, and some colleges are beginning to adopt, early retirement policies that provide one form of humane solution to the problem and that make new appointments and/or necessary promotions possible under more acceptable conditions.

Student Financial Assistance

It has long been recognized that, in the mid-1980s, there would be a substantial downward trend in the number of high school graduates. Even with the possible expansion of the pool of engineering recruits through increased enrollment of women and minorities, the cost of attracting highly qualified engineering freshmen will affect the budget of the admissions office. It may be that, except for a 290-pound tackle who can run 100 yards in 10 seconds, a high school student with a combined SAT over 1200 may be the most sought after of persons in our nation.

Would-be engineers seem to be influenced in their undergraduate school choice by the facilities on the campus and the job-securing success of recent graduates to a far lesser extent, I believe, than "science" students are influenced by the reputation of the senior faculty and, in particular, by the availability of financial aid.

Engineering school trustees, administrators, and faculty grapple with the problem of student financial assistance at virtually every session. As a rule, some 70 to 80 percent of students would not be able to pursue an engineering career without state assistance, scholarships, loans, or other forms of aid. Families and summer jobs seldom provide for total needs, and the college must help the student obtain 20 to 30 percent of the cost of the college program. Most state aid is not transportable among the states and this limits the enrollee's choices.

Summary and Recommendations

These, then, are the most troubling and persistent issues I have encountered at undergraduate colleges. I have treated them singly, but they obviously impact on one another; and, although they are not only a question of funding, all would be substantially relieved by an influx of dollars.

To provide the additional funds and to stimulate the actions needed to assure the high quality educational experience our future engineers must receive during their undergraduate days, the National Science Foundation must negotiate budget additions that would permit:

1. Increased investment in classroom, laboratory, and other needed engineering campus structures.
2. An increase in the funds available for undergraduate laboratory equipment and computers—either as direct grants or as an agreed-upon percentage of the total cost on a shared basis with the college and industrial supplementary funds. It is conceivable that NSF might also be able to structure shared-use programs for certain very expensive laboratory devices among some groupings of colleges. The 10 to 15 percent annual maintenance cost should also be considered.
3. Additional funds for faculty research at predominantly undergraduate schools.
4. Structuring grants for research programs at major centers to make sabbatical participation by undergraduate faculty more feasible.
5. Further stimulation of university industry interaction in design/manufacturing research—particularly for future faculty. The vast majority of engineers pursue careers in development, and the primary task of engineering schools is to prepare young people, at all degree levels, for this work.
6. Continuation of federal student loan programs or direct grants that would supplement state or other aid sources.
7. Funding of new initiatives to utilize modern communication technology—satellite TV, video tape, etc.—to increase productivity of undergraduate instruction and to provide for student and faculty video seminars. Perhaps NSF could sponsor program development, help defray broadcast costs, provide hardware, or distribute quality materials.

It may be impolitic to suggest that a nation that spends about $100 billion a year on R&D and several additional billions per year on college programs in science and engineering has not adequately supported or properly balanced its investment in this field. However, it is a fact that our industries are losing world market share even in high-tech areas such as electronics, and our trade balance in manufactured goods has slipped from a positive level to a deficit of nearly $100 billion in the past five years.

Although many factors influence this sad state of affairs, the fact that many products are, or are perceived to be, poorly engineered indicates that we must improve the design-related competency of all our engineers at all degree levels.

U.S. engineers often do big things well but execute poorly the details that more often than not make the quality difference. I believe that quality engineering of offerings to the marketplace builds upon the solid fundamental base acquired in the undergraduate period.

Undergraduate Science and Engineering Education

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Former President of the American Mathematical Society

It is a pleasure to be able to come to Washington and express my ideas about mathematics education, for I have been interested in that topic for a long time, starting with my involvement in the School Mathematics Study Group in the 1960s. However, if there is any thing that I have learned in the last 25 years, it is that education is not a simple matter and there are no easy solutions. Whatever changes you may plan, they must be robust enough to survive the inevitable adjustments that will be made as change is proposed in a system as large and sprawling as the American educational system.

I note with some concern that the title of your Committee contains the words "science" and "engineering," but not "mathematics." Of course, I realize that "science" is intended to cover mathematics, and that in the long history of the National Science Board and the National Science Foundation mathematics has always been recognized as a science and that the Foundation has always supported mathematics. Nevertheless, I think that there is some danger that the Foundation, by continually classifying mathematics with the other sciences, may adopt support policies that are inappropriate for mathematics. Mathematics is very different from the other sciences; the difference is probably just as great as the difference between science and engineering. Every project in engineering depends to some extent on basic science and mathematics; in the same way, every branch of basic science depends to some extent on engineering and mathematics; and mathematics depends on science and engineering as sources of problems and inspiration. The interdependence of the whole structure is remarkable; it is impossible to say where engineering begins and science ends and equally impossible to locate the boundary between mathematics and the other sciences, but this does not imply that engineering, mathematics, and the various branches of science should all be supported in the same way.

The fundamental difference between mathematics and the other sciences is that mathematics is neither an experimental science like chemistry nor an observational science like astronomy. This distinction is beginning to blur because of the advent of computers, but it will be a long time, if ever, before the distinction disappears. This difference has important implications for strategies in education and for the more general question of appropriate patterns of support.

Nowhere is the difference between mathematics and the other sciences clearer than in the area of precollege education. We start teaching mathematics in kindergarten and we expect children to learn in grade school a body of knowledge that will be the foundation for all of their future work in mathematics. Because it is known that arithmetic will be a permanent foundation and because it is so easy to grade arithmetic problems as right or wrong, the subject is usually taught under high pressure with frequently adverse effects on children's attitudes toward mathematics. Other sciences are taught in grade school but in a much more casual manner and with no intention to be the definitive treatment of the subject in a child's education. I do not believe that any biology teacher in high school or college expects to rely on biological knowledge taught in grade school.

Everyone pays lip service to the idea that mathematics ought to be taught in connection with applications; yet, it is almost invariably the case that children's mathematical skills are way ahead of their knowledge in areas where applications are real. Thus, children learn formulas for the area of a triangle and the circumference of a circle before these concepts have any meaning for their lives. This difficulty afflicts more mature students as well, all the way up to the point where the physics department insists that the second-year calculus course take up Stokes' theorem early in the first semester because it is so important in some areas of physics.

Ultimately, I believe, a complete overhaul of the science-math-technology curriculum will be necessary. But, certainly, this cannot be done all at once. I do not advocate any revolutionary steps in the immediate future, but I see no reason to believe that our present curriculum is optimal. If, indeed, it is already optimal, then our present difficulties are far worse than has ever been suggested.

Anyone who has taught mathematics knows that there are immense differences in learning style and learning rate from one student to the next. Probably these differences are equally great in every subject, but because of the relative ease of assessment and the highly cumulative nature of mathematics, they seem more visible in mathematics than in most other subjects. Whatever the causes, these differences are extremely important in education. To keep up with the class, the slower students are pushed along at too rapid a pace and the result is frustration, fear, and resentment, while the faster students are soon bored and lose interest for lack of challenge. The educational system must ultimately arrange to allow children to advance at different rates in different subjects.

I recommend, therefore, that the National Science Foundation continue to support and broaden its support for research on the truly basic questions confronting education in the area of math-science-technology. Without suggesting that these are the only topics or even the most important topics, I mention the following:

- Would we do better to focus young children on the qualitative aspects of mathematics rather than the purely quantitative?
- How do children (and older students) actually learn math and science?
- Is a unified curriculum in these areas desirable?
- Is there some way to adapt the curriculum to different styles and rates of learning?

Work on these and many other topics must be regarded as basic research, and we must recognize that there is little hope of an immediate payoff. It will be 20 years in any event before any of today's kindergarten children reach the Ph.D. and begin to affect the scientific structure of the United States. There is a tremendous time lag built into the system. If we intend to keep our educational system in step with the times, we must seriously and steadfastly support basic educational research; we cannot afford to breathe hot and cold on basic research from one year to the next or from one administration to the next.

Many of the previous witnesses at these hearings have pointed to the value of research grants at colleges in enlisting students as future scientists. In a laboratory science, an inexperienced student can be brought in and given a minor job that is nevertheless meaningful to the research at hand and then gradually be worked into a role of significant participation. Research grants in laboratory and observational science support and encourage students at every level from the beginner to the postdoctoral research fellow. But, in mathematics, it is virtually impossible to make use of a beginning student, beginners simply do not have enough knowledge to be of any use in most mathematics research projects. This state of affairs may change a bit in the future as the computer makes mathematics somewhat more of an experimental science, but it will be a long time before this becomes an important way to recruit students into mathematics. This is another significant difference between mathematics and the other sciences.

Recruitment into mathematics has been aided in the past by summer programs for talented high school students such as those at Hampshire College and the University of Chicago. There have been specially designed summer research programs for undergraduates, and there have been many renewal programs for precollege teachers. Support for these programs has diminished during the last 10 years, and I recommend that it be restored.

Much has been said about computers and their influence on teaching. I am quite convinced that computers will have a profound effect on mathematics education, but I am not at all sure what that effect will be. As a sideline observer of the rise of our computer culture, I know that in virtually every domain in which they have been introduced, computers have had a greater effect than was expected, but often that effect has been different from what was originally expected. Twenty years ago, grandiose claims were made for computer-assisted instruction (CAI). These claims have since receded, but CAI is not dead; it will eventually find its niche in the educational system. Now there is great stress on computer graphics as a learning tool, but we do not yet know how to write graphics programs sufficiently flexible to realize our dreams, nor do we know that they will prove as effective as we hope.

We are just beginning to see how computers can make mathematics an experimental science, and, incidentally, we are seeing the apprenticeship system start up in mathematics. This is because it is not at all unusual to find an undergraduate with sufficient programming expertise to make a real contribution to an experimental mathematics project.

Professor Steen, President of the Mathematical Association of America, has proposed that every professor of mathematics should be provided with adequate access to computers. His proposal appeals to me for several reasons. First, it will urge mathematics professors to start thinking about how to use computers in their teaching. Second, it will inevitably produce some really useful pedagogical programs. Third by getting many mathematicians started on an experimental approach to their research, it will both advance mathematics and provide more opportunities for undergraduates to become involved. Finally, universal access to computers is surely coming eventually, and there is much to be said for getting on with it.

Professor Steen has also pointed to the sharp downturn in the number of American students going on to graduate education in mathematics. I believe that one of the causes of this downturn has been the relative lack of support for mathematics students compared to those in the other sciences. This refers both to direct financial support in the way of fellowships and research assistantships and to indirect support in terms of encouragement and a sense of social value. The newspapers have recently been full of statements pointing out the lack of qualified math teachers and predicting dire consequences from this lack. I believe these articles themselves have begun to restore a perception of the social value of the study of mathematics that had all but disappeared, and I think I already see a corresponding upturn in interest in mathematics as a career among our entering students. I think that recruitment into mathematics and science, as well as most other professional careers, is heavily influenced by various expressions of social appreciation.

The Truman Fellowship Program is a major fellowship program designed to encourage students to take up careers in public service. It is a competitive program for college sophomores that awards two fellowships in each state to students planning such a career. The awards run for four years, two years of college and two years of graduate school; this makes the Truman Fellowship very attractive. But beyond the monetary rewards, the program itself tells students that public service is an esteemed profession; this message has undoubtedly caused many students to consider careers in public service, many more than the number of fellowships awarded.

I recommend that the National Science Foundation institute a similar program for mathematics and science.

Another form of student support that the federal government should pursue is the forgivable loan for students who go into teaching. The armed forces support ROTC programs, which pay almost the full cost of college in return for four years of service after college. In effect, they are paying a signing bonus of around $40,000 to able college students. Presumably, the Department of Defense regards this as a paying proposition, even though fewer than half of the students so recruited remain in the services beyond their four-year obligation. If we seriously propose to upgrade teaching in our schools, then a forgivable loan program would seem to be even more a paying proposition. Suppose, for example, that $5,000 could be forgiven for each year of teaching in a school or college. That would make teaching an attractive career to many students who today feel obliged to enter a more highly paid profession because of the weight of the debts they have accumulated while in college. Such a program would be well beyond the scope of the National Science Foundation, but I hope you will consider endorsing the idea. In various forms this idea has been around for a long time, an endorsement by the National Science Board might bring it into being.

ERIC

Conditions and Trends in U.S. Undergraduate Science and Engineering Education

David T. McLaughlin

President

Dartmouth College

The charge to your Committee, "to consider the role of the National Science Foundation in undergraduate science and engineering education," is both challenging and significant in terms of the future of this country. One of the major issues confronting America today is our declining international industrial competitiveness. Although this problem is due to a combination of complex issues, certainly one cause is insufficient emphasis on technological innovation. The stimulation of creative thought can be a major impetus for productivity improvement when considered in its broadest sense—the creation of new products and the application of new technologies.

In this regard, universities have the capacity to play a major role in assuring the vitality of our economy. They are a significant source of new discovery and, importantly, they educate those responsible for extending the boundaries of technology to open new horizons for research and scholarship. The thoughtful combination of the liberating arts with the skills embraced by science, engineering, and mathematics departments establishes the basis for technological leadership which is the focus of your concern. It is in that sense that I consider your efforts so vital.

For some time, much has been written and said about the "crisis" in science and engineering education in the United States. The underlying theme of that discussion has been on the issue of *quantity*—the numerical parameters of the problem. For example, it is cited frequently that there was a decline of almost 40 percent in the number of undergraduates in America who intended to major in science during the seventies; that Japan, with a smaller population base, may soon have more engineering graduates than the United States; or that we have fewer engineering graduates than graduates of law schools. Quantity is undoubtedly an important dimension of the issue, but there is a growing concern that while we have been concentrating on size, we may have inadvertently downplayed *quality*. This preoccupation with the quantity issue is readily understandable—it is a real phenomenon and more easily measured than changes in quality. We find ourselves now, however, in a situation that requires us to revise our national agenda. In the last few years, engineering enrollments (at the undergraduate level at least) have grown dramatically, and the results of this growth are now being reflected in the number of graduates. While there are indications that this trend has begun to stabilize, the number of science majors is still on the rise, with the result that expanded enrollments have adversely affected teaching loads at many institutions. It is time, therefore, to shift our emphasis from quantity to the equally important dimension of quality.

Quality as an issue for science and engineering education is manifest in many ways. Three such forms come importantly to mind. The first relates to the capability of our universities to deliver, in a creditable way, the basic educational experiences our students need. As enrollments have grown, there has not been a comparable growth in numbers of faculty. The result has been increased student-faculty ratios, larger classes, and inadequate time for student-faculty interaction and mentorship. The net effect of this has been—inevitably—some lessening in the quality of science and engineering education. As the number of students electing these disciplines has increased, the required re-allocation of teaching resources within educational institutions has been slow to occur, partly because the pool of qualified talent to fill open faculty positions, particularly in computer science and engineering, proved to be inadequate. The lack of faculty in sufficient numbers is now beginning to be addressed effectively in several ways by education, government, and industry. The National Science Foundation has itself been active in this area with excellent programs like the Presidential Young Investigator awards which encourage younger faculty members to remain in academia. All of these remedies, however, require a significant amount of time and sustained support to have a measurable impact. During this adjustment period, most universities have begun to take the only meaningful alternative path open to them—they are limiting enrollments in critical disciplines such as computer science and electrical engineering. Through these efforts, and the natural self-selection on the part of students themselves, a managed stabilization of enrollments seems to be occurring on a national scale, and we will probably see within the next five years a gradual improvement in the teaching situation except for some few key disciplines such as electrical engineering. A recent article in *Engineering Education News* noted that undergraduate engineering enrollments dropped 2.8 percent in 1984, while electrical engineering enrollments rose from 106,240 in 1983 to 110,666 in 1984. That same article also noted that an informal survey found that 18 of 29 schools already limit electrical engineering enrollment.

A second major quality issue that has plagued science and engineering education is the current state of instructional and research facilities and the ability of academia to integrate new technology into the curriculum. This issue is belatedly receiving well-deserved emphasis. While the dimensions of the facilities problem have been defined in the range of billions of dollars and some remedies have been proposed, the solutions being pursued are, in my judgment, less effective than they need to be, particularly as they relate to undergraduate science and engineering programs.

In this regard, colleges and universities have a real need to re-equip their teaching laboratories, for example, undergraduate physics and chemistry facilities have deteriorated badly over the last decade. While welcome, corporate product contributions are not a particularly effective source of redress in this regard. The types of equipment needed are basic in nature—instruments and supplies—and not the type of commercial offerings corporations normally donate. In the past, the National Science Foundation has been of major help in this area and I would urge their continued support.

Additionally, in some areas the rate of scientific discovery and technological development is so high that we are hard pressed to modernize curricula fast enough to keep up. A good example of this is molecular biology. It is clear that the techniques and technologies surrounding molecular biology will have increasing impact, not only on our scientific understanding of the origins and development of life on earth, but on such areas of modern society as medicine, law, and business. Since molecular biology is built upon interdisciplinary fields such as biochemistry and biophysics, our curricula in basic science must reflect the importance of these areas. This is not an isolated instance.

Almost certainly, partnerships involving the government, corporations, and colleges and universities will be necessary to bring about the needed changes in undergraduate science and engineering education. As demonstrated by the situation in molecular genetics, the companion problem faced by educators to that of funding needed new laboratories is the integration of new technology into the curricula of the schools. With the increasing complexity of technology, the subjects are more and more interdisciplinary in scope. Robotics, for example, involves mechanics, electronics, computers, and artificial intelligence. While integrated educational processes are needed, the schools and their curricula are still organized around traditional disciplinary lines. What is required for an understanding of complex new areas of technological study, like molecular genetics or robotics, is more extensive dialogue between the educational and industrial communities about the nature of curricular development. The National Science Foundation, with its recent reorganization of the Engineering Directorate, has clearly recognized the issue and could become a major force as a catalyst in this important dialogue. All of us must find more creative ways to maximize the impact of the scarce resources available.

The third issue of quality is just beginning to emerge, and yet it may be the one of greatest importance. This relates to whether the existing fundamental structure of science and engineering education is consistent with the goal of producing the innovative leaders needed for our technologically oriented society. In this regard, there is room for concern. The source of this concern lies in the realization that the character of innovation has grown tremendously in complexity—both in its technical aspects and in its impact on society. At the same time, the evolution of our technical educational system has been toward more specialization, which tends to resist the inherent multidisciplinary character of contemporary problems. A more integrative approach based on broad technical educational principles may be more responsive to current requirements.

Engineering and science are inextricably intertwined. Engineering is simply the application of scientific principles for the benefit of society. Our system of education in science and engineering, as it is now constituted, tends to shortchange both the "science" and its "application." For example, the science underlying technical innovation can no longer be restricted to physics and calculus. The budding innovator should be introduced to a wide spectrum of sciences, including biochemistry, computer science, and materials science, as well as the traditional disciplines of physics, chemistry, and mathematics. In turn, if an innovator is to be effective in the applied arena, we must provide educational experiences that explain the processes of industry—the financial, managerial, and social science and interpersonal skills required in the real world. We must also make a greater effort to sharpen their communications skills, for no new innovation will be brought to practical fruition if it cannot be communicated to others effectively. Accomplishing all of this is not easy, I realize. It clearly requires breaking down some of the traditional "departmental" barriers, and investing more time in preparing students for the professional world. I suspect that what is required is no less than a complete restructuring of the science and engineering curricula in place today, with a heavy orientation to the liberal arts as an underlying base.

Such a curriculum should be a well-integrated science and engineering program containing the following elements:

- A strong, broad science base,
- A core of interdisciplinary engineering courses,

- A strong liberal arts component including humanities, social and behavioral sciences, and communications skills (both oral and written), and
- A heavy emphasis on project-oriented courses to convey the open-ended and multidisciplinary nature of most contemporary problems and their economic, social, and political ramifications.

Such a program would prepare students for participating fully in an ever-accelerating technological world.

The feasibility of this suggestion is validated by the fact that this type of engineering education is already occurring in a few places. Two specific examples of programs that have adopted this general approach are the engineering programs at the Thayer School of Dartmouth College and the Worcester Polytechnic Institute. Other schools provide the opportunity for some students to structure such a program, but only at their own initiative. It is vital that, at this juncture of our technological evolution, we strive to create an educational process in this country that is more consistent with the opportunities the future holds, and the almost unlimited potential our students have for grasping these opportunities.

In conclusion, let me state that the needs of undergraduate science and engineering education are obviously many. Clearly, the limited resources available to the National Science Foundation cannot meet them all. It is important, therefore, that priorities be established and resources be directed to those areas with the highest priority. Further, the Foundation should strive to identify those areas where its contribution will have maximum leverage. From my perspective, the important areas where such leverage could occur are the following:

1. *Curriculum innovation.* As I noted in my comments, that is an area where major and significant effort is needed. The National Science Foundation may be the only accessible source of resources for those educators who are willing and able to address this important issue. While the Foundation has a history of supporting research and innovation on educational issues, in the most recent past it is my understanding that the Foundation has decreased significantly its sponsorship of research and experimentation directed toward the education process for scientists and engineers. A reconsideration of this strategy is recommended.
2. *Undergraduate teaching equipment.* Equipment needs for science and engineering have been well-documented. The primary emphasis to date, however, has been on research equipment and computing environments. As important as these are, modern equipment and instrumentation for teaching laboratories are just as vital to the educational process This is a neglected area from which the Foundation would realize significant returns if it were addressed.
3. *Research participation.* At one time the Foundation had an active program to support the participation of undergraduates in research. This was a reasonably inexpensive but highly effective program that encouraged bright undergraduates to get involved with the creative activities of the faculty early in their careers. The undergraduate programs of science and engineering would be greatly enhanced if this program were reinstituted.

It is my sincere belief that the Foundation can continue to make a significant contribution to undergraduate science and engineering education with a relatively modest commitment of resources. It is that belief that leads to the recommendations I have suggested. By concentrating on a limited number of high-leverage initiatives, the return will be maximized. The three initiatives I have noted are directed to this end.

I appreciate your time and attention today, but even more so your commitment to the technological excellence of our nation—the well-being of future generations depends on it.

Undergraduate Science and Engineering Education

W. G. Simeral

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Today, I would like to discuss the role of American liberal arts colleges in science education. In terms of the matrix ot issues and concerns that you are using in these hearings, my remarks will fall chiefly into the category of "basic sciences" at "four-year institutions"—specifically four-year, independent, private institutions that are primarily, if not exclusively, undergraduate in character.

There is no question that while liberal arts colleges do not train students for particular vocations, these institutions nevertheless provide the nation with a cadre of people prepared for service in all walks of life. Many liberal arts college students concentrate on humanistic studies, but science and mathematics are and always have been integral to a liberal arts education.

Generally speaking, there are two fundamental goals of science education at the undergraduate level: to train science majors and to provide some basis of scientific awareness and understanding for non-science majors. These goals have been likened to those of music education, which prepares both performers and audiences. But, while American undergraduate science education is very good at preparing performers, it is not very skilled at cultivating an audience.

I believe that liberal arts institutions are ideally suited by philosophy and temperament to accomplish both these goals of science education at the undergraduate level. Allow me to examine each in light of what I know to be the capabilities of our best liberal arts colleges.

First, how good are liberal arts colleges at preparing scientists? Consider one important measure—Ph.D. production. By definition, few colleges that fall into the liberal arts category grant Ph.D.'s. But many of them are well positioned at the front end of the Ph.D. "pipeline"—they are the sources of many of the baccalaureate graduates who go on to earn the Ph.D. The National Research Council publishes a list that ranks institutions in this way. As you might expect, the large universities—some granting thousands of bachelor degrees each year—come out ahead. Only a handful of our top liberal arts colleges are found in the first 50.

But, if you factor in the size of the institutions, you get a different picture. In a study published recently by the Great Lakes Colleges Association, Ph.D. productivity was based not only on the *number* of an institution's graduates who earned a Ph.D., but also, the *percentage* of graduates who did so. Of the top 50 institutions in this listing, half are liberal arts colleges. Another list in the same survey shows the top 50 institutions specifically according to science Ph.D. productivity. Here, again, nearly 40 percent of the top 50 are liberal arts colleges. This suggests that in terms of preparing students for careers as scientists, liberal arts colleges can hold their own with the universities.

Even so, some may ask, if there were no liberal arts colleges or if science education declined at those colleges, wouldn't the number of scientists remain the same? Wouldn't the same people who now go to a liberal arts college to receive science training go to a university instead and then on for the Ph.D.?

I am inclined to think that the answer to these questions is no. All things being equal, if we eliminated the liberal arts colleges or if these colleges curtailed their science education, we would see a falling off in scientists and in science Ph.D. production. Let me explain why.

First, our private colleges represent a substantial investment in resources and people, and their replacement value is prohibitively high. If a college closes or eliminates a program, comparable facilities do not reappear overnight in a form equally accessible to the college's traditional constituency.

In the absence of liberal arts colleges, a portion of the students who would otherwise attend them would still obtain an education, but some would not. In other words, liberal arts colleges represent educational opportunity—and the total opportunity they offer is not necessarily interchangeable or redundant to the opportunities available elsewhere.

More specifically, I think a decline in science education at liberal arts colleges would signal a decline in people with science degrees in general. I do not believe that other institutions would automatically compensate for the loss. Nationally, only 7.7 percent of all bachelor's degrees are awarded in the basic sciences. But, among one group of liberal arts colleges—the 48 colleges that participated in a conference on science education at

Oberlin College last June—24 percent of all bachelor's degrees are awarded in basic science.

And, liberal arts colleges have been nearly immune to the erosion of interest in science degree programs we are seeing elsewhere. The percentage of their freshmen students that plan to take degrees in science remains steady at about 30 percent, or four times the national average for all institutions.

Moreover, a deterioration in science education at liberal arts colleges would almost certainly result in fewer people with advanced science degrees, because the academic environment at liberal arts institutions naturally encourages students to pursue advanced work. Liberal arts college graduates tend to view their undergraduate education not as a capstone but as a foundation for more to come. And, I believe that the achievement of many liberal arts college students after graduation is the result of the reinforcing atmosphere and student-faculty relationships characteristic of the liberal arts college experience.

Just as it is possible to overlook the role of liberal arts colleges in training scientists, one may be similarly inclined to discount the role of these institutions in scientific research. Admittedly, the quantity of research at liberal arts colleges is limited—chiefly by the availability of funding, but also to an extent by educational mission. But, the quality of such research when it is funded and performed at undergraduate institutions tends to be very high.

Support for research at these colleges will be necessary in the future to maintain the efficacy of their science education programs. Research at the undergraduate level provides many benefits:

- It offers opportunities for faculty development,
- It enhances teaching, and
- When it involves undergraduates, research gives advanced or especially creative students firsthand experience with the activity central to graduate and professional work in the sciences.

Nevertheless, liberal arts colleges have found it difficult to obtain research funding. I spoke with one biology professor at Franklin and Marshall who recently obtained a grant. He said that his experience in applying for funding suggests that NSF and NIH are grossly lacking in knowledge of what can be accomplished at a good undergraduate institution. As a result, it takes longer for a liberal arts college researcher to establish a reputation than for a university faculty member, in part because the liberal arts college professor must spend so much time educating the foundations about his institution. This unawareness by major science foundations of liberal arts college capabilities raises serious doubts as to whether liberal arts college grant proposals are indeed given fair and equal consideration in competition for research funds.

I am convinced that liberal arts institutions have played and continue to play a crucial role in training scientists. But they face serious challenges, the main challenge at the moment being financial stability. College costs are increasing at a rate that is greater than the growth of support funds that supplement tuition. The operating funds of the liberal arts college have historically been drawn from tuition, gifts, investment earnings, and grants. In recent years, liberal arts colleges have become more tuition-dependent.

Over the last 12 years, even as federal funds to colleges shifted from research to student financial aid, liberal arts colleges found themselves caught in a financial bind. Despite a modest increase in the total federal dollar figure for such aid, more people have become eligible to receive it, and expenses have increased more rapidly than federal funds have grown.

This means that the colleges themselves are making up the difference by providing a larger slice of a growing pie. At Franklin and Marshall, we have seen the college's contribution to financial aid grow from just over 20 percent of our students' total from all sources in 1981 to more than 65 percent this year. In the current environment, the cost of tuition and fees and the amount of financial aid available are key factors that determine where many students choose to matriculate. In this regard, most liberal arts colleges are at a disadvantage in competing for their share of a shrinking student population.

Another challenge liberal arts colleges face in maintaining high-quality science education is attracting and retaining faculty in the physical sciences and in computer science. Most liberal arts colleges cannot afford to pay market rates for the highly qualified professionals they need to teach their students. The national average salary for a college professor is slightly more than $30,000 per year. This means that young assistant professors with Ph.D.'s in chemistry, mathematics, and computer science are offered salaries in the low to mid $20,000's. Each year they see graduates with bachelor's degrees go off to business and industry and earn as much or more.

This was not always the case. By the late 1960s, faculty salaries had achieved a comfortable level relative to other professional jobs in our society. But, in the 1970s, that position declined as professors' pay increased at less than the annual Consumer Price Index. Looking ahead, we can see that it will become increasingly difficult to attract qualified professors in scientific and technical fields where there is competitive demand from other sectors.

It should not go unnoticed, then, that the achievement of liberal arts colleges in the sciences has been financed mainly by the liberal arts colleges themselves and by tuition payments. They have not been beneficiaries of large sums of grant money nor have they received much government assistance for research or for science programs. So, not only are these colleges producing a disproportionate number of scientists given their size, they are doing so in a very cost-effective manner.

But, however laudable their resourcefulness, many of these institutions are reaching the limits of their financial ingenuity. They need help if they are to continue to do their excellent job of educating scientists.

The Oberlin conference I referred to outlined some initiatives that can be taken on the part of government, industry, and foundations to help renew liberal arts colleges—particularly those with strong science programs. Among their suggestions:

1. NSF should propose a challenge grant program similar to that of the National Endowment for the Humanities.

2. Federal research fund administrators should recognize that in appropriate fields, research at colleges can be of a quality that is fully competitive with larger institutions.

3. Corporate support of academic research should pay more attention to work at undergraduate colleges. (At Du Pont, we have earmarked nearly a quarter million dollars annually for chemistry departments in liberal arts colleges, and we hope our example will encourage other companies to follow suit.)

4. Foundations should continue their traditional support of innovative programs at colleges, particularly programs aimed at stimulating creative responses to the challenges facing higher education.

That last recommendation is especially pertinent to the other area of science education that I spoke of earlier and which I would like to turn to now. the need to develop an educated "audience" for science in our society.

There has been much discussion of the long-term consequences for science and engineering in a society that is generally ignorant of science and how it is applied. A growing number of public policy issues deal with scientific questions, and voters and their representatives are often ill-prepared to decide the issues before them. We have only to look at nuclear power, toxic waste management, and biotechnology for examples of critical issues being decided in a climate of fear and misunderstanding.

In a recent editorial in *Science*, editor Daniel Koshland stated unambiguously that "the world is divided into two conceptual groups, the scientist and the non-scientist, and the communication gap between them is wide and serious." He cited two particular concepts that the public needs to understand when considering scientific issues. One was the notion of risk levels, specifically "zero risk," which many non-scientists erroneously believe is scientifically achievable. The other was the methodology of "the control" crucial to scientific inquiry in the natural as well as social sciences, but apparently meaningless to whole portions of our population. Koshland believes that these and other concepts underlying scientific knowledge are "directly transferable to public policy and should be taught at every level of education."

Most of us would agree with these observations. However, I would go a step farther. Even some of our scientifically trained people may not fully understand scientific concepts. Another recent article in *Science* reported that Professor George Pimentel of the University of California, Berkeley, told a AAAS-sponsored gathering of science teachers about a group of high school science teachers at a Berkeley summer school. Their disconcerted reaction to chemistry laboratory demonstrations showing various means for measuring temperature suggested to him that they may "have very grave needs of depth and understanding."

So, while the gap between scientists and non-scientists exists and must be dealt with, we cannot assume that the problem is one-sided. True, most non-scientists do not understand science. But, we also have to make certain that people trained in science have a genuine understanding of their own fields, along with an appreciation of how science interacts with other values in society. In other words, our science students need to be educated liberally.

Professor Jan Blits of the University of Delaware, who has written about the need for liberally educating scientists, says, "It is necessary for science students to study more deeply in their field." By depth, he does not mean more technical courses, he means studying the intellectual presuppositions of science, the concepts that distinguish a scientific discipline from other sciences and other forms of knowledge.

How have our colleges and universities responded to these needs, both of the scientist and the non-scientist? Since the 1960s, we have seen some efforts to educate students to a fuller awareness of the role of science and technology in society. These programs fall under the heading of what we have come to call "scientific literacy."

Such courses generally tend to fall into two types. One type is the historical or state-of-knowledge survey—the so-called "tourist-bus survey"—that attempts to give students an insight into the major achievements of science. This kind of course exposes students to the wonders of science achievement, but gives little indication of how those achievements came about and less insight into principles on which they are based.

The second kind of course focuses on one or more contemporary problems that are science-related and examines the social, political, and ethical implications. We might call these "issues" or "topics" courses. Typically, these courses do not provide instruction in science principles and the logic of science, nor do they require such instruction as a prerequisite. They run the risk of making students superficial experts on the debate points of a policy issue without giving them the intellectual tools to deal with such questions generally.

In short, we have been trying to teach people to think about science in society without teaching them to think about science. Our efforts aimed at scientific literacy seem wedded to what Professor A. B. Arons, of the University of Washington, called "the notion that understanding of science can be achieved by purely verbal inculcation."

What then should be the goals of scientific literacy programs? I think that we need to develop three broad areas:

1. We have to introduce people to the idea that science is something that is practiced, not something that exists in books. It is a human activity, the product of human intelligence operating in a methodical way. Only when people understand the scientific method can we expect them to distinguish between experimental observation and untested inference; between theory and opinion. In other words, people must have some grasp of the philosophy of science.

2. We have to make certain that students experience the experimental side of science at the undergraduate level, regardless of major or specialty. It would be especially valuable for individuals to have good basic knowledge in at least one natural science. We cannot expect people to evaluate theories of nuclear winter, for example, unless they first have studied physics or biology.

3. We have to instruct people in the history of science—the manner in which scientific knowledge influences the course of history, interacts with society and other forms of knowledge, and helps develop our world view.

These goals for scientific literacy should apply to every undergraduate student, science specialist and non-specialist alike. We cannot assume that the science major will automatically be instructed in each of these areas.

The courses should be taught by scientists—perhaps in conjunction with philosophers, social scientists, historians, and others—but active scientists have to be the key.

Above all, scientific literacy programs should emphasize hands-on experience with science. We have to disabuse ourselves of the idea that you can learn about chemistry without picking up a test tube, or about biology without dissecting a specimen, or about astronomy without looking at the sky.

Clearly, these approaches to scientific literacy are obtainable throughout American higher education. But, I believe that the institutions in the best position to promote these goals at the undergraduate level are the liberal arts colleges that I have been discussing. Let me explain why.

A scientific literacy program that aims to achieve the goals I have outlined appeals in the most fundamental sense to the liberal arts spirit. The idea of scientific literacy should find a willing audience in the students of liberal arts colleges precisely because it is so consistent with the liberal arts ideal.

Also, the commitment of professors at liberal arts colleges is to undergraduate teaching. As such, liberal arts college professors are used to dealing with students early in their academic careers and with those who are not necessarily science majors

Finally, the atmosphere at these colleges encourages interdisciplinary activities and innovative courses. It may seem vague to talk about "atmosphere," but it is an unavoidable observation in the case of the liberal arts college. It is a function of small size, close community, and educational mission—all of which can be brought to bear on promoting a new emphasis in the curriculum.

A few years ago, the National Research Council published a report called *Science for the Non-Specialist: The College Years*. The study found that, nationwide, provisions for effective science education of non-specialist undergraduates are profoundly deficient. One of the recommendations of the study, members of this Committee may recall, was a strong urging that the National Science Foundation assert a leadership role in developing support programs for the science education of the undergraduate non-specialist. I think the time has come to consider funding development work along those lines, and I would urge that we look to the liberal arts colleges as a source of ideas and innovation.

It has been my aim, then, to remind the Committee of the vital role that liberal arts colleges play in science education at the undergraduate level. Whatever recommendations proceed from the Committee's deliberations would, I hope, recognize liberal arts colleges as full partners with the universities and other institutions of higher learning in providing science education for our students.

More specifically, I have sought to call attention to the fact that at the undergraduate level we need to provide excellent science training for the science major, as well as appropriate science education for students in other majors. In discussing this dual responsibility, I have tried to show that our leading liberal arts colleges are capable of providing both. The specialized science training they offer is comparable in quality to our finest universities. And, I believe these colleges can lead the way in effecting scientific literacy among the college-educated sector of society.

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Undergraduate Mathematics

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I am very pleased that the National Science Board has undertaken a study of undergraduate education. As President of the Mathematical Association of America (MAA), I am especially pleased to have been invited to testify about collegiate mathematics. Most of our 20,000 members teach college mathematics, and most of the undergraduate mathematics education in this nation is provided by members of our Association. I speak also as a member of the Council of Scientific Society Presidents (CSSP) in commending you for this study, especially since last spring CSSP adopted unanimously a resolution urging continuing NSF support for both college and precollege programs in science and engineering education.[1] We applaud your interest in collegiate mathematics and in its relation to science and engineering education.

I am Professor of Mathematics at St. Olaf College in Northfield, Minnesota, one of the science-intensive liberal arts colleges referred to by Frederick Starr in his earlier testimony to this Committee. St. Olaf has 3,000 students; about 10 percent of each year's graduates major in mathematics. The quality of our program, and of those at many of the leading liberal arts colleges, was strengthened during the last decade by many former programs of the National Science Foundation: Undergraduate Research Participation, Instructional Scientific Equipment, Science Faculty Fellowships, Comprehensive Aid to Undergraduate Science Education.

These NSF programs accomplished good things in their time, and I can say from firsthand experience that they helped enormously to strengthen the mathematics and science programs at my institution. Today, however, I am going to speak not particularly about these programs or about liberal arts colleges, but about the needs of collegiate mathematics across the nation.

Mathematics

As I am sure you know, mathematics is both an enabling force and a critical filter for careers in science and engineering. Without quality education in mathematics, we cannot build strong programs in science and engineering. NSF policy for science and engineering education—both precollege and college—must be built on this central fact: Mathematics is not just one of the sciences, but is *the* foundation for science and engineering.

The relations between mathematics and science have always been close. But because computers make possible mathematical analysis of many scientific and engineering processes, these relations are now both more pervasive and more significant than ever before. Whereas in the past only theoretical science required advanced mathematics, today all science-based fields use sophisticated mathematical models. This suggests another fact that dominates the undergraduate curriculum. Mathematics is changing dramatically in content, in scope, and in application; it is not only being applied, but is being continually created.

Several recent studies[2,3] call attention to sudden growth in the frontiers of the applied mathematical sciences, a growth that is creating unprecedented demand for individuals capable of creating and using mathematically based scientific tools. These studies point to such things as communication theory, transonic flow, chemical reactions, computational complexity, quantum field theory, computational statistics, combinatorial optimization, pattern recognition, ill-posed problems, nonlinear equations, and parallel computing.

This growth in mathematics and its applications forces fundamental rethinking of the mathematics curriculum. Yet, because mathematics education is a continuous sequential process from primary school through graduate school, changes in any part have important consequences both for other parts of mathematics education and for subsequent courses in science and engineering. The results of advanced research influence the curriculum at every level, while at the same time mathematics education lays the foundation for research of the future. These close links between education and research have stimulated promising new alliances in the national mathematics community,[4] alliances based on a shared belief that mathematics, from education through research, is a seamless fabric.

Collegiate Mathematics

Collegiate mathematics stands at the interface of educational and research issues in the mathematical sciences.

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The mathematics faculties of our colleges must provide courses for future scientists and engineers, programs for prospective elementary and secondary school teachers, strong majors for those intending to enter graduate school, remedial courses for those entering college unprepared in mathematics, general education courses for students not majoring in a scientific discipline, and a variety of service courses ranging from elementary statistics to advanced operations research. Moreover, in most institutions, mathematicians also teach some computer programming and elementary computer science.

The future quality of our nation's science and technology depends on the ability of today's mathematics faculties to meet these diverse obligations. Exciting developments in the mathematical sciences resonate with creative ideas for curriculum innovation to provide challenging opportunities in undergraduate mathematics. Yet, the record of the recent past suggests that our mathematics faculties are under great stress, and are increasingly unable to meet national needs in collegiate mathematics.[5]

For example, demand for undergraduate mathematics courses has doubled since 1970, but, during that same period, the nation's college mathematics faculty has increased by only about 50 percent. Each term about three million students receive mathematics instruction from about 30,000 faculty members. Despite this record demand for mathematics courses, the number of students majoring in mathematics has declined by over 50 percent, and advanced (post-calculus) enrollments have declined from 20 percent to 5 percent of undergraduate mathematics. Indeed, approximately three-quarters of all mathematics credits awarded by colleges and universities are for courses more appropriate to the secondary school curriculum. What is worse, about 100,000 workbooks are sold each year on the subject, "Arithmetic for College Students."

Remedial, elementary, and service courses drain faculty time and energy. Increased elementary enrollments combined with decreasing numbers of majors have simultaneously unbalanced the curriculum and depressed faculty morale, energy, and aspirations. In too many departments, the result is a downward spiral of withdrawn faculty, uninspired teaching, and uninterested students.

Other signs of stress are harder to quantify, but no less real. Mathematics departments, with few exceptions, do not have adequate access to computing resources that are appropriate to the actual use of mathematics in today's scientific and industrial world. As a consequence, computing has had very little impact on the mathematics curriculum—neither on what should be taught nor on how it is taught. In this age, undergraduate mathematics needs to be conducted in active symbiosis with powerful computers—for symbolic manipulation, for graphical display, for numerical analysis, and for simulation.

Computers are important tools for scientific and engineering modeling precisely because they enable effective applications of mathematics. As an engine for applied mathematics, a computer embodies powerful approximate techniques that have greatly expanded the scope of mathematical models. What formerly existed only in theory now occurs every day in every laboratory right before our eyes. The computer revolution is just the visible tip of a much deeper revolution in applied mathematics.

Inevitably, the availability of computers and the demand for new applications compel us to rethink priorities for mathematics education at all levels. To prepare students adequately for their careers in the 21st century, undergraduate mathematics programs must include core principles of computer science (algorithms, data structures, complexity theory), a contemporary view of numerical methods and approximation techniques; robust, computer-intensive statistical methods; graphical techniques for exploratory data analysis; and computer algorithms for optimization problems. This constellation of subjects is now widely known by the title "mathematical sciences," although the word "mathematics" is still often used as a short-hand synonym.[6] The reality behind the name is both simple and awesome: Undergraduate mathematics is a totally different subject than it was 20 years ago.

Unfortunately, in far too many departments, mathematics courses are dated both in spirit and in content—primarily because faculty have not had sufficient opportunity for professional development. An active college mathematics curriculum should change half its courses every decade. For example, courses in mathematical logic, discrete mathematics, operations research, theory of computation, and combinatorics, although rare 10 years ago, are now commonly offered by every good department of mathematical sciences. Creating these courses—and their successors for the next decade—is an essential but too often neglected part of the work of college faculties.

Liberal Education

Equally demanding and even more neglected are the challenges of providing mathematical courses appropriate for liberal education.[7] For students in the arts and humanities, mathematics is an invisible culture—feared, avoided, and consequently misunderstood. Too often, such students are forced to retake high school courses whose only purpose is to master skills that now can be performed far better by a computer. Illiteracy in mathematics breeds illiteracy in science and technology, thereby driving the two cultures even farther apart.

In a society dominated by complex systems, we need to do far more than we now do to convey to our society's future leaders—our present students—that mathematics is not magic, and that even those without advanced technical training need to know how to ask appropriate questions and demand responsible answers.[8] We live in a "minds-on" world created by tools of applied mathematics—robotic devices, economic models, war games, expert systems—yet plagued by ethical issues of hidden assumptions and unintended side effects. In some systems order begets disorder, while in others the reverse is true. Paradoxes, dilemmas, and uncertainty pervade complex systems, whether in biology or in economics, in engineering or in medicine. As computers begin to dominate the areas of certainty—calculations—we must cultivate in humans—our students—a tolerance of ambiguity and understanding of uncertainties that abound in the scientific and mathematical models of our daily lives. This is yet another important task for an already overworked faculty.

Mathematics in the Marketplace

In the 1970s, the tight job market drove many students away from careers in mathematics teaching; now attractive offers from industry and computer science are doing the same. As a consequence, the age distribution of the mathematics faculty is heavily skewed toward the upper end: Over three-quarters of the nation's mathematics faculty were educated in a pre-computer age. Despite the increasing demand for collegiate mathematics, too few new Ph.D.'s are in the pipeline for replacement positions. The number of new U.S. citizen doctorates available for replacement in college and university mathematics departments is now as low as in the pre-Sputnik era (under 400 last year), and one-third of those enter industry. Over 40 percent of the Ph.D.'s and, in some departments, over two-thirds of the graduate students are from other countries.[9] Once again, as happened for different reasons a generation ago, U.S. mathematics is becoming a subculture of immigrants.

At the bachelor's and master's level, the demand for mathematics graduates has never been greater. We all know of the serious national shortage of graduates who are adequately prepared to teach high school mathematics. What may not be so evident is the dramatic increase in demand from industry for students with bachelor's or master's degrees in the mathematical sciences to join teams dealing with computing, statistical, or management issues. The academic focus of these "mental" or "artificial" sciences (as distinct from the "natural" sciences) resonates with the needs of industry for employees trained to work with abstract, quantitative, symbolic models. Salary data, an indirect indicator of demand, support the anecdotal evidence from many departments that demand for such individuals is very high.

Totally apart from education, the manpower needs of industry and defense are truly staggering. Supercomputer installations alone, estimated to reach about 200 per year by the early 1990s, will each require a dozen or so scientists capable of understanding and advancing research in scientific computing. Although these scientists will in many cases have advanced degrees in science, computer science, or engineering, all would need at least the equivalent of a good undergraduate major in mathematics.

To put all this in perspective, you should know that each year the United States produces only about 10,000 bachelor's degree graduates in mathematics, only 10 percent of whom go on to a Ph.D. in any field. Just to support the needs of scientific computing, to say nothing of the needs of high school and college teaching, the United States will need to double the number of undergraduate mathematics majors. And, as we all know, the total population of college-age students will continue to decline for another 10 years.

However, increasing the number of undergraduate majors in the mathematical sciences is not in itself a sufficient response to our manpower needs. It will not help at all just to cut lower in the talent pool for undergraduate majors. What we need, instead, is a nationwide endeavor to attract the best young minds to undergraduate mathematics, not just to replenish the Ph.D pipeline in mathematics, but to support all fields of science and engineering that build on solid training in undergraduate mathematics. I submit that the only effective way to do this is to make sure that across the country, in every college, large or small, there are mathematics teachers who are professionally alive, involved in their field, knowledgeable about recent advances in applicable mathematics, and conversant with the many challenging problems yet to be solved.

Strategies for Renewal

In summary, our nation faces serious challenges in undergraduate mathematics, ripe with opportunities for both professional and liberal education. Yet, our mathematics faculties have to a large extent been left behind by the dramatic impact of computing and are cut off by lack of time for professional development from the rapidly advancing frontiers of their own discipline. As a consequence, they preside over a curriculum dominated by courses that are either too elementary or too old-fashioned. Although this portrait is not typical of the research universities and selective liberal arts colleges, it is, I believe, a fair assessment of collegiate mathematics at most of the nation's two- and four-year institutions where the vast majority of our students are educated.

Revitalization of undergraduate mathematics will require programs, in colleges across the country, that are closely linked to the frontiers of pure and applied mathematics. Students in every institution—not just at Berkeley or Harvard, St. Olaf or Swarthmore—need to see mathematics as an active, growing discipline with challenging unsolved problems worthy of their serious attention. This applies to future scientists and engineers as well as to future mathematicians; it applies as well to future lawyers and doctors, educators and ministers. Educated people need to know that mathematics is active, and that its applications really matter.

For all the reasons that have traditionally rooted good teaching in sound scholarship and research, it is essential that undergraduate faculty maintain active professional lives. To be realistic we have to recognize that only a select few will truly advance the research frontiers of mathematics—and be eligible for support by traditional research grants from NSF and other agencies. Recent studies suggest that about 10 percent of full-time college mathematics faculty members are actively engaged in publishable, competitive, first-class research. For the vast majority, mathematical scholarship is more necessary and appropriate as a stimulus to thinking, an inspiration for teaching, an example to attract students into careers in mathematics, and a means of incorporating recent developments into the undergraduate curriculum.

Research in mathematics is not like research in the laboratory sciences. Whereas undergraduate research can thrive in most chemistry, biology, or physics research laboratories, research in mathematics is so far removed from the undergraduate curriculum that little if any immediate benefit to the undergraduate program ever trickles down from standard NSF research grants. Publication patterns provide vivid proof: Hardly ever does one see papers in mathematics authored jointly with students, either graduate or undergraduate. There are a few exceptions—in applied mathematics, in statistics, and in new areas of combinatorial mathematics. But, as a general rule, undergraduates can neither participate in nor even understand the research activity of their mathematics professors. Programs to support collegiate mathematics must recognize this basic difference.

The key to revitalization of collegiate mathematics is a faculty that is intellectually alive. For some, that means research: for others, problem-solving. Still others may engage in curriculum reform, lateral growth into new disciplines, introduction of computer methods, or development of teacher training institutes. What matters most is that the faculty develop an environment in which students can encounter mathematics as a living, growing discipline.

Need for Action by NSF

Collegiate mathematics requires support by the National Science Foundation for two simple reasons. First, mathematics is a critical national resource that is no longer being renewed at a rate adequate to meet the future needs of our nation. Second, without active support from NSF, the necessary renewal probably will not occur.

Others in these hearings have argued that the crucial needs of science and engineering education are support for faculty, facilities, and instrumentation. For collegiate mathematics, I would put it differently: Our need is support for faculty, faculty, and faculty. Nothing is more important to college education than a faculty that is intellectually alive. No amount of bricks, mortar, or silicon can substitute for lack of faculty energy, imagination, or will.

A rapidly advancing discipline together with steadily increasing teaching loads leaves most faculty with no time for necessary professional development. But, lack of time is not the only issue; so is lack of compelling professional incentive. Continued NSF emphasis on research grants reinforces the natural tendency of deans and tenure committees to emphasize traditional published research above almost all else as a measure of individual worth in the academic world. If we want to improve undergraduate education, we have to readjust the academic reward system to provide a better balance between research and professional development.

Research for its own sake leads directly to fundamental advances in knowledge. What I am talking about is scholarship in the service of education, a bridge between the two fundamental missions of our educational system that leads indirectly to research in the future. In mathematics, especially, we need NSF programs that build these bridges.

Suggestions for Action

First, I would suggest a competitive system of NSF faculty fellowships, sufficient in number to invite large numbers of applicants and sufficiently varied in purpose to promote a wide variety of accomplishment: curriculum development, student projects, professional travel, research support, computer needs. Such fellowships should be specifically targeted for projects that seek the improvement of undergraduate education, they would make a major impact on professional development of the collegiate mathematics faculty across the nation.

The act of applying by itself is a good first step in developing a sound program of professional development; in many cases, local funds might be found even if the application is unsuccessful. Fixed stipends would favor those who most need the support—younger faculty in smaller institutions. By standardizing the financial award and by streamlining the selection process (perhaps by subcontract to professional societies), the Foundation could support a sufficient number of individuals to attract many faculty to apply. Ideally, there should be many awards even in departments where there may not have been any similar grants in recent memory—and where the leverage of these fellowships would be the greatest.

Here is another way to make an immediate dramatic impact on the ability of the nation's mathematics faculty to offer a challenging, modern curriculum. Put a high-powered computer workstation on the desk of every college and university mathematics instructor. College mathematicians know enough to teach themselves how to use it, and ever afterwards they will teach their students in a different and more effective way. I do not propose this as an equipment program, but as an innovative means of making an immediate and much-needed impact on faculty development. In the long run, computers should be supported by institutions, as desks and typewriters now are. But, in one bold move, without elaborate review procedures or continuing commitments, the Foundation could transform the teaching potential of the entire mathematics faculty of this nation.

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Third, to increase leverage of limited NSF resources, and to reach the many faculty who never deal with government agencies, it would be wise to take advantage of the expertise of existing professional organizations (NCTM, MAA, AMS, CBMS, MSEB, BOMS, etc.) that already have in place effective national networks of meetings, publications, and professional support activities. The present undergraduate mathematics major, common to almost all institutions, was the result of an NSF-supported effort in the post-Sputnik era to use the leverage of professional societies in laying out guidelines for a modern curriculum. We need to take similar action now to engage teachers across the country in a way that provides great benefit for least cost.

Finally, to make any of these suggestions operationally effective, the Foundation must recognize that mathematics is different from science, and that undergraduate education is different from research. The relation between research and teaching in mathematics is not the same as it is in science; the role of mathematics as a foundation for science and engineering is unique; and the sheer magnitude of mathematics education (precollege and college) sets it apart as distinctive. For these reasons, it is essential that the Foundation solicit continued advice from individuals with substantial experience in undergraduate mathematics. Research expertise is no guarantee of good judgment in collegiate issues, nor is experience in laboratory science a good guide for the needs of the mathematical sciences. Thus, my fourth and most urgent recommendation: Make sure that NSF proposal reviewers, members of advisory committees, and staff members are selected so as to provide balanced, informed advice, including appropriate numbers of individuals with substantial experience in undergraduate mathematics.

Conclusion

The mathematics community itself has recognized the need for coordinated action to address the basic facts of mathematics and mathematics education. Mathematics is fundamental to science, it is changing rapidly, and it is a seamless fabric from grade school to graduate school. Unfortunately, the traditional separation of education from research continues in foundation funding practices as it does in university tenure and promotion proceedings. This division is both an anachronism and an impediment at a time when the mathematical organizations themselves are working hard to bridge the gap between research and education in the mathematical sciences. The greatest contribution NSF could make to undergraduate mathematics would be to help us close this gap.

Notes

1. On May 15, 1985, the Council of Scientific Society Presidents unanimously adopted the following resolution

"Mathematics, science and technology education are essential to the long-range security and economic well-being of the nation. Therefore, the Council of Scientific Society Presidents commends those members of the Administration and Congress who have supported urgently needed funding for the National Science Foundation education budget In particular, to provide needed long-term leadership, we strongly urge support for a continuing annual baseline National Science Foundation budget of at least 100 million dollars for college and precollege science and engineering education."

2. The changing nature of mathematics and its relations to science and engineering are described very well in the 1984 report, *Renewing U.S. Mathematics*, prepared by a committee of the National Research Council chaired by Edward E David, Jr. Arthur Jaffe's paper, "Ordering the Universe: The Role of Mathematics," in Appendix C outlines major recent contributions of mathematics to problems of computation, physics, engineering, and communication.

3. Extensive discussions of the needs in scientific computing are contained in the recent report, *Future Directions in Computational Mathematics, Algorithms, and Scientific Software*, of a panel chaired by Werner Rheinboldt (see *Notices of the American Mathematical Society*, November 1985).

4. The impact of the David Committee's report, together with parallel work by the Conference Board of Mathematical Sciences (CBMS), set the stage for the National Research Council to establish two Boards—the Board on Mathematical Sciences (BOMS) and the Mathematical Sciences Education Board (MSEB)—to provide a continuing national capability to assess issues in mathematics research and mathematics education. Through these Boards, the nation has an unprecedented opportunity for coordinated leadership in mathematics and mathematics education.

5. The state of collegiate mathematics is described more fully in my paper, "Renewing Undergraduate Mathematics," which appeared in the August 1985 issue of the *Notices of the American Mathematical Society*

6. The definition of an undergraduate major in the mathematical sciences was set forth formally for the first time in a 1981 report of the Committee on the Undergraduate Program in Mathematics (CUPM), *Recommendations for a General Mathematical Sciences Program*, Alan Tucker (editor), Mathematical Association of America, 1981 Similar issues are discussed in the papers in two more recent volumes, each based on conferences sponsored by the Alfred P. Sloan Foundation. *The Future of College Mathematics*, Anthony Ralston and Gail Young (editors), Springer-Verlag, 1983, and *New Directions in Two Year College Mathematics*, Donald J. Albers, Stephen B Rodi, and Ann E Watkins (editors), Springer-Verlag, 1985.

7. For fuller discussion of current issues in liberal education, see *Integrity in the College Classroom*, a recent report of the Association of American Colleges, which attributes the devaluation of undergraduate education to a conflict between narrow graduate-school professionalism and the broader goals of liberal education.

8. See my paper, "Mathematics: Our Invisible Culture," prepared for the September 1985 Tome Centennial Symposium on Science and the Liberal Arts at Dickinson College.

9. An article in the November 15, 1985, issue of *Science* ("Americans Scarce in Math Grade Schools," p 787) cites examples of top-ranked graduate programs in mathematics in which only one-fourth of entering graduate students are U.S. citizens This information suggests that the downward trend in percentages of U S citizens among mathematics Ph.D. degrees will continue for quite a few years.

Undergraduate Science and Engineering Education

Robert R. Wilson

President
American Physical Society

I am not going to read my formal statement (text attached), which was prepared at the headquarters of the American Physical Society. The basis of the statement and the conclusions are essentially the same as those so eloquently expressed by Tony French in his testimony. Instead, I would like to emphasize a few points he has already touched on. The first is the intimate and vital relationship between research and teaching which ensures the continuation and vigor of science. The second has to do with the last recommendation of our formal testimony, "that special attention should be paid to the need for more women and minorities in physics." Finally, I want to suggest that a two-way visiting scientist/visiting student program between the large universities, industrial and governmental laboratories, and the non-research colleges be instituted as a way of tapping present, vast, unused research talents—be they minorities or whatever—and, further, that this be done in a way that allows more undergraduates to have a valid research experience.

Of course, the problem we are discussing today is complex. We have to teach one another and somehow learn what it is that we need to do. In that context, we particularly welcome your Committee's timely hearings on the important subject of undergraduate science and engineering education.

I hardly need to preach to this group in these surroundings that science is a warm human activity; it is not the result of dull people in white coats just turning the crank of the vaunted "scientific method" and thereby almost automatically producing science. No, it is a glamorous, exciting, romantic activity. The creation of knowledge is complicated, like all life. It involves interactions among many disparate individuals who range from technicians and clerks, shopmen and bureaucrats, computer scientists and instrumentalists, to those highly publicized "stars" who receive most of the credit. All of these people contribute importantly. Even Newton, after inventing classical mechanics, said that he had only stood on the shoulders of others and seen a little farther.

Standing on the shoulders of others while doing science is becoming more and more descriptive of what much of science is all about. And the "others" in diverse ways experience a tremendous satisfaction that comes from participation, at whatever level, in the adventure of science. That participation extends to some degree throughout our society, from our President and Congress to the citizens who pay for it.

Without quite understanding this complex system that is science, just as we do not understand family relationships, we must have been doing something right in this country. Families continue to flourish and bring up children that populate our society. Similarly, science has flourished here as it has nowhere else in the world. I argue that the success has come from a participation in research that embeds science in the culture of our country. We have, or have had, an enlightened constituency that has valued science. If we have a culture that places a high value on science, then scientists will emerge from that culture.

There are many ways that our culture comes to place a high value on science; one of the most important is through our schools. Insofar as there can be a true understanding of what science is and what science does (or does not), it will be valued. And this understanding, I believe, comes about best inasmuch as there is a direct exposure to the process of science.

I have previously emphasized the warm human aspects of science. In some major way, the production of scientists is a "laying on of hands" process. It is an exposure of young people to older people who care about science, who do research, who have the research fever. When you see such scientists in action you see that they are intuitive, dedicated, sometimes aggressive, even occasionally logical, and that ambition, love, power, and compassion as well as the other human attributes play a role in the creation of knowledge. It is when students experience that excitement directly that they too might catch the research fever.

It is the cold logical presentation—as in many textbooks—that sometimes leads students to think of science as a dull activity, something that is beyond them. It is that false notion of dehumanized science that may turn them away from science.

I would like to cite two stories from my own experience about how I got into physics. These may illustrate some of the aspects I have been discussing.

I was living in a small mining town in Wyoming, and I was not a particularly bright student—not intending to go to college. One of my high school teachers spent his summers as a high-rolling gambler in Jackson's Hole. Well, you have no idea what panache that gave him with the students. He was a person venerated by all of us, a man of significance—a real role model. He taught history and was talking about the Greeks and their ideas of the elements, air, earth, fire, and water, and the forces of love and strife. He emphasized what a simple theory this was, how easy it was to understand, and that, in principle, it should explain all matter—all life. Then he said he had just been reading in the papers that the Greeks had got it all wrong. He explained that now it was understood that it was possible to make any atom out of only two just-discovered elements, protons and electrons, which could be stuck together by electromagnetic forces. He explained to us how this would be much simpler than the notions of the Greeks and, again, if this were true, how one might understand the whole world.

It hit me like a bolt of lightning, and I went around in a daze thinking about this simple theory. It inculcated in me a desire to know more about this way of understanding everything. Of course, he (indeed, all of the physicists in the late twenties) got it quite wrong. It turned out to be much more complicated, but it is not an awful lot more complicated, in that today, in some sense, with three elements and three forces, well, in principle, it might be that you can understand almost everything. We are more sophisticated than that by far, but nevertheless it is a fascinating idea. It was a fascinating idea for the Greeks, and it is a simple, fascinating idea today. It is at the center of much that is done in physics.

Well, this first story indicates how my own interest in science was aroused from a culture, our culture, that placed a high value, mainly a gambler's fancy, on the ideas of science.

I did get admitted to the University of California—by taking an extra year of high school—and as a freshman I kept that interest in atoms still paramount in my mind. I wiggled and wangled a visit to E.O. Lawrence's Radiation Laboratory. The Russian Ambassador was coming that afternoon, and there was Lawrence himself sweeping the floor. He saw me lurking around, a freshman, and he said, "You're not doing anything, young man. Here, you take over. You sweep the floor!" So I swept the floor, and, because there were such interesting things going on around me, such exciting people—Ernest Lawrence himself, and such shiny things and blinking lights and galvanometers swinging back and forth, people rushing back and forth—I swept the floor three times. Later on after I left the place, in a euphoric mood, I mentioned to my fellow students what had happened to me, and I pointed out modestly that the *director* had asked me to take over for him and without any particular preparation I had managed to do the job.

That really hooked me, and I soon thereafter went back to Ernest Lawrence and got involved in undergraduate research. In doing it I could see and interact directly with the faculty at the University of California. That changed my whole life. Certainly I learned tremendously from my undergraduate exposure to those exciting people at the University of California. It is that which I would hope more people could see—that science is not completely a logical business. It is more than logic, it has to do with such things as determination and with what I call infection of the research fever. It is the exciting talk, the heated debate, the free give and take, and then the resolution by experiment and by reason—not by authority.

It is this kind of direct exposure to working physicists that I hope would happen to more students attending colleges where presently no research is done, where they have no opportunity for this to happen. This refers not only to many of the so-called minorities colleges, it refers to the some five-eighths of all the colleges, so that most of the students in this country have no opportunity to experience real research at all. How can we expect, then, to have a culture that truly values physics, science?

Well, we can do this by having a vigorous visiting program that would initiate meaningful undergraduate research in the colleges.

In such a program, the first thing to do would be to encourage, to arrange, and to pay for a teacher in a college to visit a university or industrial or national laboratory for some kind of participation at whatever level, be it for a day, a week, a summer, or a sabbatical year. Making funds available for a teaching replacement during a leave of absence would be necessary and would be a place where NSF funds would be of great help. Once the teachers have found their way, then student visits and work periods could be arranged at the laboratories. At the same time, the scientists at the laboratories should be encouraged to visit the colleges.

The purpose of all this should be to find some kind of research effort that could be of significance and could be carried out at a particular college. NSF could help significantly by making modest funds available for this kind of research. Most useful would be funds made available to the heads of departments without the necessity of complicated proposals or of red tape, but with strict accountability after the funds have been spent.

Although it should by no means be a requirement of any NSF grant that the researchers should visit a college or inspire research at a college, it would help to ask what the researcher is doing or would propose to do to help propagate research elsewhere. NSF might even volunteer extra funds beyond the grant for this kind of activity.

Finally, if some kind of research—it might be to assist in research elsewhere—could be instituted in the colleges, then research aptitude as well as formal teaching ability might become a desideratum for the teaching job.

In this way, science—research—might become more deeply and democratically embedded in our culture, might flourish more extensively and intensively—might attract the participation of much new talent.

Attachment

Written Statement on Undergraduate Science and Engineering Education

The American Physical Society, founded in 1899, has as its purpose the advancement and diffusion of the knowledge of physics. Our 36,000 members work at universities and colleges, national laboratories, and in private industry. Most of them are research scientists, although many also teach at the graduate and undergraduate levels. It is sometimes erroneously thought that research scientists do not have a great interest in or strong feelings about undergraduate science education. This assumption is certainly not accurate with respect to the American Physical Society, and to judge by a resolution passed this year by the Council of Scientific Society Presidents in strong support of expanded NSF college and precollege programs, neither is it correct with respect to the scientific research community as a whole. The American Physical Society, through its Committee on Education, its Panel on Public Affairs, and other committees has, in recent years, made major efforts to improve science education.

This is why I am grateful for the opportunity to join my colleagues from the American Association of Physics Teachers in presenting our view on the state of undergraduate science education and in particular on physics education. Its importance in contributing to this country's scientific and technical workforce and to enhancing our strength and well-being should be more widely recognized. I am grateful also for the opportunity to join my colleagues in making specific proposals to the National Science Foundation for helping to solve serious problems in undergraduate physics education that threaten to diminish, at a crucial time, the quantity and quality of our scientific manpower.

The information and recommendations that follow come, in large measure, from a survey of the chairs of 553 U.S. physics departments, approximately five-eighths of which grant only undergraduate degrees and three-eighths of which also award master's and Ph.D. degrees.

What we learned from this survey and from a conference of chairpersons regarding the status of undergraduate physics education, as well as what can and should be done to improve it, is summarized in the joint American Physical Society (APS)/American Association of Physics Teachers (AAPT) background paper, "Priorities for Undergraduate Physics Programs." At this time I should like to highlight and comment upon two of the major findings and call attention to three recommendations to NSF.

Findings

1. The survey has found that undergraduate physics programs have experienced significant declines in the quantity and quality of students enrolled. The reasons are not totally clear but, in my view, include the following:

   - The small pool of high school graduates motivated and equipped to study science;
   - The attraction, for those scientifically and technically inclined, of programs and careers in computer science, engineering, and medicine, and even law and business;
   - The poor state of undergraduate physics laboratories and the sometimes less than inspired teaching; and
   - The dearth of undergraduate research participation opportunities and the lack of financial support for potential students in such programs.

   It is likely that if the present trend should continue, a number of undergraduate physics programs will be shut down, and, consequently, the numbers of physics majors will decline even further. Graduate physics programs will also be affected, either through closures or diminution in size, unless an ever-increasing fraction of the graduate students are from foreign countries.

2. The second finding I wish to highlight is that between chairs of purely undergraduate and graduate physics departments, there is no appreciable difference in the perception of the problem and in the recommendations for action to improve undergraduate physics education.

Before telling you what I believe the National Science Foundation can and should do to deal with the threatening situation in undergraduate physics education, I wish to make it clear that the federal government by itself cannot solve all or even most of the problems. Much of the impetus and resources for change will have to come from the states, from industry, from scientific societies such as APS and AAPT, and, most of all, from the colleges and universities themselves. In particular, the physics departments should heed the recommendations to put their best teachers in front of introductory classes and to institute more inter- and cross-disciplinary majors programs with the other sciences and with engineering.

Here, then, are steps that NSF and perhaps only NSF can take to improve undergraduate science education. Indeed, some of these programs formed part of the NSF mission in the past and have proved to be very effective. About five years ago, NSF abdicated responsibility for undergraduate science education and, indeed, for most forms of science education with, I believe, deleterious consequences. Since then, the Foundation has begun to resume a major role and instituted a number of exciting and promising programs in precollege science education. I believe that the time has come for the resumption of programs and for new initiatives in undergraduate science education.

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Recommendations

1. Because the poor condition of undergraduate laboratory instrumentation is the most significant problem now facing physics programs (and, I dare say, other undergraduate science programs as well), undergraduate laboratory equipment programs should have a high priority for NSF support. All types of institutions should be eligible, regardless of whether the highest degree awarded is a bachelor's, a master's, or a doctorate. Although the needs are huge, a significant start could be made with an annual program at the $50 million level.

2. The availability of funded undergraduate research participation programs is a strong plus in attracting bright students into physics and other sciences and for motivating and preparing them to go on to graduate study and to careers in research and development. Grants should be made competitively and should be available to support undergraduate research in universities as well as at four-year colleges. Opportunities to bring students and faculty from non-research to research institutions should also be made available. An annual program of about $20 million would make a significant contribution.

3. Special attention should be paid to the need for more minorities and women in physics and in the other sciences. This is not only a question of social equity and justice but also a matter of self-interest, in that women and Black and Hispanic minorities form the largest and mostly untapped pools for increasing the scientific and technical workforce of the nation. While the reasons for the "underrepresentation" of minorities and women in the physical sciences are complex and the problem is not totally solvable by "throwing money at it," two steps nevertheless can be taken at the undergraduate level to recruit and retain more minorities in the sciences. These students need more role models and they need more material and financial support. In both of these cases, the situation and the efforts of the government in the physical sciences contrast unfavorably to what has been achieved and is being done in the medical and health sciences, where such NIH programs as MARC (Minority Access to Research Careers) and MBRS (Minority Biomedical Research Support) have made a significant impact on producing more minority physicians and health scientists. A competitive NSF program at the level of $5 million per year would be a great help to those universities and colleges throughout the country that want to and are in a position to have special programs for producing more minority and women scientists.

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Undergraduate Science and Engineering Education

Terry L. Gildea

Technical Training Manager
Hewlett-Packard

Representing the Technology Education Consortium

I am representing an informal group of managers from major corporations that have significant dependence on high technology. We call ourselves the Technology Education Consortium (TEC Club for short) because all of us are concerned with the education efforts required in industry to maintain the technological skills of our workforce. Represented are such companies as HP, IBM, Motorola, GE, Du Pont, Ford, etc. (see Table 1). A complete list of the group's members is attached.

Table 1. Technology Education Consortium (TEC Club): Companies Represented.

Borg-Warner Corp.	IBM
Computervision	Mobile Corp.
Du Pont	Motorola
Exxon Research & Engr. Co.	New England Med. Ctr.
Ford Motor Co.	Prof. Comm Consultants Ltd.
General Electric	RCA
GMI	Texas Instruments
Hewlett-Packard	3M

Our organization is very informal: We have no bylaws, no officers, no paid staff. We meet about twice a year to discuss issues of common concern. We are here this morning because the state of engineering education in this country is certainly an issue of major concern to us and to our companies.

In your hearings so far you have heard considerable testimony that has highlighted the condition of our higher education system in this country, particularly as it applies to engineering and science education. I do not plan to argue those points again. However, you have heard mostly from educators, those who stand to gain directly from additional NSF funding for education. It seems that there is some benefit to reinforcing those educational viewpoints that those of us in industry particularly agree with.

Recap

Much excellent work is done outside of the superstar research universities. This is important for those of us in industry. As one of our group put it, "Most engineering jobs don't require a genius." Even in my own company, where we spend 10 percent of revenues in R&D—significantly above the industry norm—only 40 percent of our engineers work in product development activities. We have to ensure the health of all of our engineering colleges, not just the major research campuses.

These non-research universities and colleges are important to technology because breadth of study in engineering, and some understanding of technology by non-engineering employees, are crucial to the success of any industrial organization. Again, the research institutes are not the only important suppliers of key personnel.

We in industry continue to have problems with engineers who cannot write an English sentence, who cannot make a cogent presentation of their ideas to colleagues and management, who cannot understand market needs and factor that information into their product designs. Many engineers are seduced into spending time studying for an MBA degree because they cannot get sufficient non-engineering courses in the typical engineering curriculum. Rarely is that a good career enhancement compared to additional engineering studies. Since good management is an art, much of it has to be learned on the job. What we really need is coursework in the field of engineering management conveniently available to working engineers.

As has been often observed, we live in a technological age. Many important positions in technology are held by people who were educated in the liberal arts. As an example, the woman who runs my MIS data center has a degree in psychology. We have to encourage an appropriate level of technical education in all majors. If we are to achieve optimal usage of scarce engineering talent, we have to be able to staff some technical jobs with personnel having other training and backgrounds.

It is true that the quality of our best engineering students is exceptional and getting better each year. So, what is the problem? Why are we in industry concerned about engineering education? This country is developing a two-tier system of education. We at Hewlett-Packard do not have much trouble recruiting engineers; we are able to attract top-level talent and we only need one to two thousand per year. But, just because the quality of our top students is holding up, we should not be lulled into complacency about the quality of our educational system and its graduates in general. We must be concerned

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about the declining health of that important segment of higher education that is not composed of our premier research institutions.

Lab equipment in most of our postsecondary schools is badly in need of upgrading. From our point of view it means that we must offer considerable additional education to college recruits before they know the minimum required for success in industry. Perhaps more important, if engineering schools could have access to computer-aided design tools for teaching, the students would better understand the design concepts. The same productivity increases that we get in product design using computer-aided engineering (CAE) in industry could be had in teaching productivity using CAE on campus.

There is a faculty shortage, and, more significant, much of our current academic cadre is technically obsolete. We must find ways to upgrade and rejuvenate the vitally important teaching faculty at all of our institutions. And, upgrading faculty includes more than their learning new science. It should include improvement in their teaching. Better lecture demos, use of graphics where appropriate, and better curriculum design would all contribute to mitigating our faculty shortage by increasing teaching productivity.

Educational access by minorities and women continues to be a matter of concern. We in industry are unable to meet our minority hiring goals because of an unnecessarily small pool to draw from. The country must find ways to increase participation of these population sectors.

Only a small percentage of our colleges and universities do major curriculum development or experimentation with innovative delivery systems, for example, satellite video, computer conferencing, or interactive video disks. These activities are important to continued success in teaching engineering and science. Unfortunately, some of our friends in academia are constructing barriers to the use of these technologies. At some schools, one cannot get academic credit for courses taken by video.

How can the National Science Board solve all of these problems? Given realistic resource constraints, it probably cannot. But, you can support crucial seed programs with high-leverage potential, programs that will make it possible for all of us involved in the problem to work jointly toward solutions.

We in industry have lived with these problems on a daily basis for years. For many of us, the survival of our companies as viable institutions depends on their successful solution. From this perspective we would like to make a major policy recommendation and three supporting policy suggestions with some concrete programs that NSF could undertake to implement these policies.

Recommendations

Our recommendation is simply that NSF should allocate a significant portion of its resources to supporting improvement in teaching of science, engineering, and technology, particularly at the undergraduate level.

Research is important. In my own company, half of our revenues in any year comes from products that did not exist three years previously. We depend on research; we do not advocate any cessation of support for research. But, we think that our nation will be better served if we redress the balance in favor of teaching in our schools.

How to do this? We have three policy recommendations to make.

First, redefine undergraduate education to include lifelong learning. There are plenty of 45-year-old engineers in industry who need what are now undergraduate courses to once again become productive and current in their fields. This will require a complete change in the way our educational institutions see their mission. It has implications for accreditation, transfer of credits between schools, off-campus delivery of courses, and a host of other issues. NSF should fund programs that will lead to resolution of these issues.

Let me suggest some examples. You could fund programs that require industry/education partnerships. Only proposals submitted jointly by university/corporate consortia would qualify. Since the act of writing such proposals would be beneficial, there would be positive outcomes even from those proposals that you were unable to fund because they exceeded your resources.

Examples of such partnerships might include off-campus delivery of undergraduate degrees at the worksite, increased use of industry specialists as adjunct faculty, use of industry laboratories as teaching labs for industrial students, use of satellite video for remote delivery of lecture material, use of computer conferencing technology for distributed student-faculty dialogue, use of community college facilities near worksites in conjunction with specialized faculty at remote research universities, etc.

There are several programs of this type now available for graduate study in engineering. The most widely available one is the National Technological University, which is an outgrowth of the AMCEE program that NSF funded a number of years ago. You can justly take credit for this pioneering work. Now that we know it is successful, it is time to extend the concept to the undergraduate arena.

In addition to graduate study in science and engineering, undergraduate courses in what are usually called the liberal arts, if offered for credit at the worksite, could help broaden mid-career engineers. At this stage of their career, many of them are holding jobs with broader responsibilities. They need mastery of more than just technology. Lifelong learning means more than keeping up with engineering advances.

Many of these examples use educational technologies currently used in industry, but relatively rare in academia. Each contributes to a productivity increase in education by more efficiently using our scarce resources of people and capital, precisely the shortages that your previous guests have so eloquently detailed for you. Perhaps

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more important, proposals of these types would require us all to break out of our traditional modes and look for better ways.

Second, adopt a policy of supporting good educational technology. By that we mean not just hardware technologies. We would include improvement in teaching through good instructional design, use of proven research results in the psychology of adult learning, and, of course, use of computers and other hardware. The pendulum has swung too far in the direction of campus research; important though that may be, we need improvements in campus teaching.

Again, I would like to offer some examples for your consideration. Fund efforts of course improvement to increase the efficiency with which knowledge is delivered. With the ever-increasing amount of technological information, increased efficiency in its mastery is essential. Fund faculty sabbaticals for course development at industrial sites. Our current national lag in manufacturing technologies will only be solved if we teach our students better techniques. Doing that will require faculties that understand what good manufacturing is. Fund programs that encourge development of academic courses in a non-research environment. Very few industrial employees work in a research environment, yet, to look at our campus programs in academia, one would think that all of our university graduates are being prepared for research careers.

You could fund programs that require interdisciplinary work among academic departments on practical problems currently important in industry In many cases, the current departmental organization of a typical university is left over from the Renaissance or earlier, and it has little relevance to the kind of problem-solving going on in industry. We are preparing our students for careers that do not exist.

These proposals are in the mainstream of NSF's history of supporting educational technology. Examples such as BASIC, PLATO, and AMCEE come to mind immediately. A return to supporting such innovations would certainly be in the national interest.

Third, adopt a policy of supporting faculty development. We certainly agree with the previous comments about faculty shortages and faculty deficiencies. We certainly agree that there is an important role for NSF to play. However, our suggestions for how to accomplish this go beyond the suggestions presented by your previous guests from academia. Those recommendations tended to concentrate on opportunities for faculty to learn more current science and technology; we think that learning what technology is relevant and how to teach it should be added to the list.

Once more, I would like to offer some examples. We need to develop faculty who know both what to teach and how to teach it. The first is a question of curriculum content and relevance; the second is a matter of instructional design. NSF could fund programs that would provide faculty reward systems going beyond the current "publish or perish" system. The availability of NSF-sponsored support for good teaching would allow faculty interested in teaching to compete on a more equal footing with colleagues who attract research money to the campus.

You could fund programs that support senior industrial technical personnel who want to teach on a university campus. These would be persons, perhaps in their fifties, with major career experience in industry. The combination of early retirement benefits from their corporation, teaching income, and NSF support could attract significant new blood into our engineering faculties. As full-time senior faculty, these individuals could fully participate in the governance of the university. Unlike adjunct faculty, they would be available to serve on committees, etc. Their industrial experience and contacts would enrich the engineering faculty.

It simply is not true that a Ph.D. degree is essential for good teaching. Faculty with this kind of practical world of work experience, when combined with the research-oriented Ph.D. faculty, could revitalize the teaching of science and engineering. After all, engineering is the application of science and technology to the solution of society's problems. As such it is important that those teaching and researching have a good handle on just what society's problems are.

Another possibility is funding summer institutes in spoken English for junior faculty and teaching assistants whose command of the language is insufficient to permit good teaching. In addition to lamenting the failure to attract U.S. students to teaching, let us make good use of those foreign nationals who understand the concepts and want to teach.

Summary

It is more than appropriate, it is in the national interest, that NSF support undergraduate teaching as a vital part of its mission.

We have suggested three areas where NSF support could offer significant leverage in the struggle to improve our national competitiveness. education as lifelong learning, educational technology, and faculty development.

There is a strong community of interests between the academic and the industrial sectors. NSF can supply the leadership that encourages the necessary changes in both sectors and brings about a new and vital partnership, a partnership that will make our nation stronger and more competitive in the world economy where we now find ourselves. These ideas have not been submitted to our respective organizations for formal approval as corporate recommendations. They do, however, summarize the collective experience of our group as individuals.

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Undergraduate Science and Engineering Education

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I am honored and very pleased to have been invited to make a presentation to this Committee. It was only four months ago that I took early retirement from Oberlin College and accepted a position as Program Officer at the Alfred P. Sloan Foundation. I joined the Oberlin faculty in 1953 and I can truthfully say that I enjoyed very much the years during which I taught mathematics to bright and dedicated (and sometimes bright and not so dedicated) undergraduates. Those were also years during which I personally benefited from National Science Foundation programs, twice receiving Science Faculty Fellowships. I also participated in national studies of the changing mathematics curriculum as a member of the Committee on the Undergraduate Program in Mathematics and a number of its subcommittees. This work, extending over the years from 1963 to 1981, was supported by National Science Foundation grants to the Mathematical Association of America.

The New Liberal Arts Program

My main responsibility at the Sloan Foundation is to administer the Foundation's New Liberal Arts Program. This program aims to encourage a central place in the college curriculum for quantitative reasoning and technology as "new" liberal arts. It recognizes that a modern and quality education should produce graduates familiar with the technological world in which they live, and also experienced and comfortable in the application of quantitative methods, mathematical and computer models, and technological modes of thought in a wide range of subjects and fields.

The first grants in this program were of $250,000 to 10 of the 30 leading liberal arts colleges invited to submit proposals. Grants of $25,000 went to the other 20 colleges, some of which have by now received substantially larger grants. Other undergraduate institutions, including a number of Historically Black Colleges, have become part of the program. Grants to universities, mainly for the development of materials for the teaching of technology to liberal arts students, have also been made. A resource center has been established at Stony Brook, under the direction of John G. Truxal, Distinguished Teacher Professor of Engineering and Applied Science. A monthly newsletter, the *NLA News*, is published by the center. Summer workshops have been supported to enable faculty members from NLA colleges to interact with leading engineering educators interested and experienced in the teaching of technology to undergraduate students. A modest program of special-leave grants is in place for the support of faculty members undertaking study in a university engineering department or an industrial setting, or developing materials for a new course.

In the four years from 1982 through 1985, some $12 million will have been distributed in the New Liberal Arts Program to participating institutions, numbering about 25 colleges and 10 universities among major grantees.

What has been accomplished to date? The computer has played a central role at almost all the colleges. Workshops have been conducted for faculty members on how to make effective use of the computer in numerous courses in all divisions of the curriculum: in mathematics and the sciences, but especially in the social sciences and humanities. Data sets have been produced that form the basis for interactive student investigations in history, economics, sociology, and political science. New courses in data analysis and mathematical modeling, often involving the use of statistical software packages and computer simulations, have been introduced, primarily for social science students. More unusual courses, often interdisciplinary and taught by colleagues who have benefited from summer workshop experiences, have been introduced on such topics as medical technology, bridges and structures, and history of technology. Laboratory experiences with technology have been developed at some colleges. The word "technology" is no longer a dirty word on the NLA campuses. Presidents and academic deans are very supportive.

There is, nevertheless, much yet to be done. Experimental courses need to be revised and course materials (textbooks, modules, video tapes, computer software) need to be prepared in a form suitable for use by colleagues elsewhere. Faculty development is an ongoing activity. Much more experience is needed on how best to teach technology to liberal arts students. Additional resources must be found since the funds available within the Sloan Foundation are limited. We are neither able to extend the program beyond several more years nor can we make grants to the many additional colleges who

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would like to participate in what they see as a timely and important program.

It is with this background of involvement over many years with the teaching of mathematics at Oberlin College and now with the Sloan Foundation's New Liberal Arts Program that I turn to the mission of this Committee.

Your concerns are wide-ranging, but I intend to limit my remarks to two topics: (1) science, mathematics, and technology for non-specialists and (2) some comments on mathematics education.

Science, Mathematics, and Technology for Non-Specialists

In emphasizing this aspect of collegiate teaching, I do not for a moment minimize the importance of departmental programs designed for committed students headed for careers as scientists, mathematicians, or engineers. The research strength of this nation would soon fade if undergraduate colleges did not produce students well-prepared for specialized graduate study.

But there is a complementary aspect of our educational mission: to produce liberally educated students who can be effective citizens in our society. This society is now too affected by scientific and technological issues for citizens to be scientifically or technologically illiterate. Certainly the graduates of our colleges, the future leaders of our society, should not receive their degrees with such a debilitating deficiency.

The system of required courses in mathematics and science, whether with or without a laboratory, often does not seem to achieve our purpose. Allowing students the freedom to skip any serious coursework in science and mathematics, a freedom abused more than we like, surely does not work. I believe curriculum content requires revision, not only to make the substance more meaningful to students and capture their interest, but to incorporate new knowledge. *The greater the degree to which the sciences and technology can be integrated in the curriculum, the broader is likely to be the understanding of students in these fields and in their modes of reasoning.*

Such integrated, interdisciplinary teaching has been characteristic of more than a few college efforts within the New Liberal Arts Program. Perhaps one specific example may help make my point clearer.

Consider a module on kidney dialysis within a medical technology course. What are the biological dysfunctions that require such drastic treatment? How does the dialysis machine actually work? Who designed it and how was it developed? (A visit to a dialysis center, with a presentation and discussion led by a knowledgeable physician, would make a fascinating field trip.) What are the economic implications of dialysis on health care costs, and what estimates can one make of the costs of dialysis as the population ages over time? What political issues arose in discussions of the government's willingness to pay for kidney dialysis as part of the Medicare program, and how might these relate to current discussions about the government's policy with respect to organ transplants? What ethical issues arise if one were to limit the budget for dialysis and thus have to decide who can and who cannot receive this life-saving treatment? What societal and cultural differences account for a vastly lower use of kidney dialysis in England as compared with our country?

These are the kinds of questions that educated citizens should be prepared to discuss intelligently. Such discussions would necessarily involve some science and technology, some data analysis, estimation, and forecasting. But, one inevitably also discusses the limits of the technology, the roughness of the estimates, the assumptions behind the forecasts, the ethical dilemmas that the technology has brought to the fore, the historical development of the technology, and its lessons for the application of newer technologies. A skillful teaching team has almost an entire liberal arts curriculum within its grasp in this one topic. It is a topic likely to have some interest, even fascination, for many students. Equally important, such an interdisciplinary approach develops the capacity to adapt the analytical methods and basic factual content of conventional academic disciplines for the solution of real-world problems. It gives practice in analyzing the sort of problem that will surely face the college graduate after the degree is earned. It is a liberating approach to learning.

It would be helpful if the National Science Foundation were to find a way to supplement its traditional focus on single discipline specialties with a program that would emphasize an interdisciplinary approach and would encourage interested faculty members to develop broad scientific and technical skills. NSF needs to encourage innovation and creativity in the undergraduate curriculum. This presupposes a program of NSF support not just for research at the frontier, but also for serious professional development that would lead to renewal of the curriculum by the incorporation of recent research results and technological advances.

Leading research scientists have much to contribute in such a program. NSF should try to find a way to encourage contributions of additional efforts toward teaching, curriculum development, or preparation of course materials on the part of senior scientists, mathematicians, and engineers. Not only would undergraduates benefit directly from this increased effort directed toward the curriculum and teaching, but it would also serve to make curriculum development more respectable. A better balance between research and other teaching-related professional activities is necessary to improve undergraduate education.

Some Remarks on Mathematics

I commend to your attention the testimony given in previous hearings before this Committee by my colleagues, Lynn Steen, President of the Mathematical Association of America, and Andrew Gleason, Professor of

Mathematics at Harvard University and former President of the American Mathematical Society. They have stated the case for mathematics well enough that I need add very little.

I urge that you recognize in your report that mathematics education, so central to all science and engineering education, is worthy of special and careful attention and represents a high-leverage area for NSF action. I know that work is already under way to outline a study of resources for collegiate mathematics as part of a plan for renewal during the rest of this century. A small grant made by the Sloan Foundation to the Mathematical Association of America has supported meetings of an MAA Planning Committee to carry this effort forward. Their outline should be helpful in delineating the major problems facing mathematics education, describing what a renewal effort would involve, and suggesting the appropriate role of government in this effort.

I would like to comment about a particular technological advance and briefly discuss its potential impact on the teaching of undergraduate mathematics. I refer to symbolic mathematical computation systems (or computer algebra programs), such as MACSYMA, MAPLE, muMATH, REDUCE, and SMP, developed over the last 15 years or so and capable of performing many of the standard operations of algebra and calculus. Computers can now factor polynomials, differentiate and integrate functions, solve linear, polynomial, or differential equations, plot curves, do series expansions, etc.

These systems are used widely for research purposes. Although, until recently, large and powerful computers were needed to support symbolic computation, systems have now been modified to work efficiently on the current generation of microcomputers. I am told by computer scientists that within five years there may be handheld devices to do such algebra and calculus, just as there are handheld calculators to do arithmetic operations.

There is considerable interest in the mathematical community in ways to use the new technology effectively in undergraduate mathematics courses. Pilot projects are still few and limited in scope. There are many fundamental questions to be answered: Should the teaching of the pre-calculus and calculus courses change to make use of symbolic computation systems? If so, how should the mathematics curriculum be modified, especially for the first two undergraduate years? How much conventional material can be deleted? How does this powerful tool expand the scope of ideas and applied problems a student can explore? What will be the effect on more advanced mathematics courses and on courses in science and engineering of having students introduced early in their college work to symbolic computation? How can these systems best be modified so they are economical to use and yet powerful enough for effective use in undergraduate mathematics education?

I offer this example to illustrate the fact that curriculum review must be a continuing activity. The pace of research is too rapid and the need to bring the curriculum and our teaching techniques along too urgent. Given the magnitude of the problem, there is a clear role for the National Science Foundation in recognizing and encouraging the desired close connections among research, teaching, and the maintenance of an up-to-date curriculum in mathematics (and in science and engineering, too).

A Program to Enhance the Involvement of Historically Black Institutions in Solving a National Problem: Science and Technology Research and Training

Frederick Humphries

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National Association for Equal Opportunity in Higher Education

An effective system of science and engineering education is vital to the long-term interest of the United States as this country strives to strengthen its economy, its national defense, and the quality of life and well-being of its citizens. The centrality of science and technology to American life is a recognized fact, and it is evident that this nation's future prosperity and security are dependent upon the maintenance of a sufficient number of adequately trained scientists and engineers to respond to national needs and priorities.

One key to ensure a supply of adequately trained scientists and engineers is through continued support of research and training at the nation's colleges and universities to foster the generation of new knowledge related to national priorities and to produce a cohort of technically trained personnel. As was outlined in the article, "Federal R&D and Industrial Policy," in a past issue of *Science*, American research universities, as a group, are the best in the world and have a central role in ensuring the nation's long-term economic health. One direct and effective way to meet future needs is to take advantage of the existing mechanisms at the nation's colleges and universities that permit student participation in research as a part of their training.

The article stated further, ". . . tomorrow's industrial growth will depend on the availability of skilled technical personnel." One way to ensure the availability of skilled technical personnel is to ensure that all of our citizens have equal access to scientific and technical training and careers. With respect to Black Americans, that logically means the Historically Black Institutions (HBIs). HBIs enrolled 27 percent of the Black college students in 1980 and accounted for 34 percent of all undergraduate degrees awarded to Blacks. They produced more than 40 percent of the degrees awarded to Black students in science and technology. Based on that data, it follows that programs designed to enhance the participation of Blacks in science and technology and national priorities related to the scientific and technological enterprise must involve HBIs. Because of the underrepresentation of Blacks in the sciences, it is critical that significant and bold initiatives be taken to develop this talent pool. Tables 1 and 2 point out the deplorably low level of participation by Blacks in training programs in science and technology at all degree levels and in the science and engineering workforce.

Table 1. Science and Engineering Degrees Received by Blacks in Science and Engineering Fields, 1980-1981.

Field	Bachelor's	Master's	Doctorates
All science/engineering fields	18,811	1,787	316
Physical sciences	906	107	28
Mathematical sciences	594	67	9
Computer specialties	763	70	2
Engineering	2,449	260	19
Life sciences	2,649	244	61
Psychology	3,308	424	113
Social sciences	8,129	615	84

Source National Science Foundation *Women and Minorities in Science and Engineering*, Washington, D C , 1984

Table 2. 1980 U.S. Population, Science/Engineering (S/E) Workforce, and Doctoral Scientists and Engineers by Race/Ethnicity.

Race/Ethnicity	Population	S/E Workforce	Doctoral S/E
White	79 6	95 0	89.0
Black	11.5	1.9	1.1
American Indians	0 6	a	b
Asian/Pacific Islanders	1.5	2 8	6.6
Spanish origin	6 4	a	b
Other/no response	0.4	a	b
	100.0	100.0	100.0

Note Categories with "a" total 0 3 percent of the 1980 science engineering workforce Categories with "b" total 3 3 percent of the doctoral scientists and engineers

Source National Science Foundation *U S Scientists and Engineers, 1980* NSF 82-314

In 1980, minority group members represented only 11 percent of all postsecondary teachers while representing more than 18 percent of the total undergraduate enrollment and 11 percent of the graduate enrollment.

Among 1981 college-bound seniors, the percentage of undergraduate minority group students expressing an interest in studying science was in each case less than the percentage of all college-bound seniors expressing an interest in studying science (15 percent for all, 13 percent for Blacks, 14 percent for American Indians, 12 percent for Mexican-Americans, and 13 percent for Puerto Ricans).

In 1981, Blacks received approximately 4 percent of the bachelor's degrees awarded in the physical sciences, 2 percent of the master's degrees, and only 1 percent of the doctorates in this area.

As important as initiatives at the college and university levels are, they are insufficient to address the present problems adequately. Central to maintaining a sufficient number of scientists and engineers is to take steps to ensure that the pool of precollege students capable of and interested in pursuing studies leading to scientific and technical careers remains high.

Following World War II, with the establishment of the National Science Foundation, the federal government clearly accepted a major role in science and engineering education at the college and university levels. With the amendment of 1958, the statutory authority of NSF (the agency that has assumed the predominant responsibility for science and engineering education) was expanded to include support for science, mathematics, and engineering programs *at all levels*. Thus, a history of NSF will contain information on programs ranging from precollege education to graduate and postdoctoral research and training. Each has been recognized as an important component to developing a scientifically literate citizenry while providing support for a strong educational system for students who pursue careers in science and engineering.

To achieve its goals, NSF has supported university research efforts by awarding grants. Such awards have been made in direct support of research projects and included faculty and student support. in addition, awards were made that included funds for the construction of facilities containing research laboratories and funds to purchase major pieces of research equipment. These grants provided several avenues of funds for the development of a strong research base at a large number of universities.

One program developed by NSF for the purpose of increasing the quality of science education was the Graduate Science Facility Award initiated in 1959. These funds provided for renovation and construction of academic facilities. Through these awards, 179 different institutions received a total of $186 million to develop their science capabilities.

Two instructional programs initiated by NSF to increase the number of universities capable of conducting distinguished programs of education and research were the University Science Development program started in 1964 and the Departmental Science Development program started in 1967. Through these two programs, NSF had, by 1970, awarded a total of $201 million to 85 institutions for development of their science facilities alone.[1]

Although these programs have been phased out by NSF, they demonstrate what can be done in a relatively short period of time to address problems, provided there is a commitment to change the status quo. It should be pointed out that during this period of a great influx of funds into academia to create science and technology capability, minority institutions and minority training were overlooked. This oversight, coupled with long-term historical neglect, has produced the results described.

The enrollment of Black students in pursuit of doctoral degrees in graduate science programs has remained relatively constant in absolute numbers but declined in percentage over the past few years. The Institute for the Study of Educational Policy at Howard Univer has released data to show that Blacks comprised 5.6 p cent of all graduate students in 1978, down from 5.8 percent in 1976. In 1978, the proportion of Blacks among full-time graduate students was 4.9 percent, while in 1976 it was 5.1 percent. Blacks made up 6.1 percent of first-year graduate students in 1978, compared to 6.4 percent in 1976. National Research Council data show that the distribution of Black doctorates among various fields is uneven. In 1980, 8.8 percent of the doctoral degrees awarded in education went to Blacks, in the social sciences, 4.0 percent, but only 0.9 percent in the physical sciences and 1.5 percent in the life sciences.

When we take a retrospective look, we find that the output of Ph.D.-trained minority personnel has not changed significantly over the past 10 years. Specifically, Blacks represent less than 2 percent of the doctorates in science and engineering, Hispanics, less than 1.5 percent, and Native Americans, less than 0.6 percent. The tenor of the times is embodied in a statement contained in a report on minority students in medical education prepared by the Association of American Medical Colleges and endorsed by that organization's Executive Council. It reads as follows.

> "However, the strength of the nation's commitment to equal opportunity appears to be waning and other recent developments (financial aid cut backs, class size reductions, static minority applicant pool, rising tuitions, etc.) appear to threaten this progress."[2]

This conclusion was supported by data in the report showing that the number of minority students accepted in the first-year medical school class in 1982-83 totaled 1,451 (10.0 percent), only 45 more than the 1,406 (9.4 percent) accepted in 1974-75. It is noteworthy to observe that medical schools accepted more than 2,000 additional students between 1974 and 1982. In 1982-83, medical schools accepted 56 fewer Black students than in 1980-81.

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Examination of published data for other professions yields the following details:[3]

- In 1980, 4.7 percent of all students in law schools were Black, compared with 4.8 percent in 1972.
- In 1980, 4.4 percent of all dental students were Black, compared with 4.9 percent in 1974.
- In 1980, 5.0 percent of all full-time students were Black, compared with 5.5 percent in 1974.

Part 2 of the same report presents the following highlights:

- Traditionally Black Institutions (TBIs) still graduate over half of the Black bachelor's degree recipients in the 20 states where these institutions are located.
- TBIs graduated one-third of the Black master's and first-professional-degree recipients in these stages.[4]

In short, TBIs appear to provide training to minority students in numbers that are disproportionate to the percentage of total students that these colleges enroll. A study completed by Baratz and Ficklen of Educational Testing Services shows that graduates of TBIs obtain employment and enter graduate schools in percentages no different from Black graduates of majority institutions.[5] Black colleges continue to play a significant role in the training of students. We are asking you to support programs that will strengthen our schools and allow us to be even more effective and productive.

The College Board 1985 report, *Equality and Excellence: The Educational Status of Black Americans*, indicates the following.

- Although high school graduation rates have improved dramatically for Black students over the past two decades, college attendance and completion rates have declined for Blacks since 1975.
- Blacks are seriously underrepresented among graduate and professional school students, and Black participation rates in postgraduate education have declined since the early 1970s.
- Blacks have lost ground relative to non-Blacks at each stage of the educational pipeline. In 1972, for example, Blacks represented 12.7 percent of all 18-year-olds, 10.5 percent of all high school graduates, 8.7 percent of all college freshmen, and, four years later, 6.5 percent of all bachelor's degree recipients. By 1979, Blacks represented only about 4 percent of all professional and doctoral recipients.
- At the undergraduate level, 42 percent of Black college students were enrolled in two-year colleges in 1980. Persistence rates for two-year college students are much lower than for students attending four-year colleges, particularly for Black students.
- Although predominantly Black colleges enrolled only 27 percent of Black college students in 1980 (as compared to more than 50 percent prior to 1970) and accounted for only 34 percent of all Blacks' undergraduate degrees in 1980-81, they granted more than 40 percent of all degrees for Blacks in agriculture, computer sciences, biology, mathematics, physical sciences, and social sciences.
- In an increasingly technological society, choice of fields is an important dimension of equality. With respect to math- and science-related degrees, Blacks lose "fields" ground just as they lose attainment ground at several points in the educational pipeline. At the bachelor's degree level, the percentage of those choosing quantitative fields is 60 percent of the national average, at the master's level, 40 percent; and at the doctoral level, 33 percent. These choices are affected by two factors: parental education and early educational preparation and achievement.
- Among college-bound seniors in 1981, most Black students had taken fewer years of coursework in mathematics, physical sciences, and social studies than their White counterparts. Even where years of coursework are similar, the content of the courses varies for Black and White students. For example, Black seniors in 1980 were as likely as Whites to have taken at least three years of math, but they were much less likely to have taken algebra, geometry, trigonometry, or calculus. Thus, their years of coursework were presumed concentrated in areas such as general math or business math.
- Students in low-income and predominantly minority schools have less access to microcomputers and teachers trained in the uses of computers. Furthermore, students in predominantly minority schools or classrooms are much more likely to use computers for drill-and-practice rather than programming or concept development than students in other schools.

Overall, the evidence suggests that Black students are exposed to less challenging educational program offerings and thus not as likely to enhance the development of higher order cognitive skills and abilities compared to White students.

While there is an urgent need to increase the understanding of scientific and technological issues, science and engineering education activities are at their lowest ebb since the pre-Sputnik era. The present posture of the executive branch that the federal government should exercise a reduced role in education hastens the move toward virtual scientific and technological illiteracy and jeopardizes U.S. science and technical preeminence. The report, *Science and Engineering Education for the 1980's and Beyond* (1980), points out several deficits and problems with the science and engineering educational system in the United States. Although the report is not a consensus document, it, along with other reports—such as, *A Nation at Risk*, *Who Will Do Science?*, a special report by the

Rockefeller Foundation; *Women and Minorities in Science and Engineering*, a report from the National Science Foundation; and *Educating Americans for the 21st Century*, a report of the National Science Board Commission on Precollege Education in Mathematics, Science, and Technology—point to several deficiencies that must be addressed in an organized, concerted effort to reverse the present trends. Some highlights of these reports follow:

- There are, at present, shortages of trained computer professionals and most types of engineers at all degree levels.
- While progress has been made in increasing the representation of minorities, women, and the physically handicapped, all these groups continue to be underrepresented in science and engineering fields.
- There is an immediate problem of acquisition, retention, and maintenance of high-quality faculty to teach science, mathematics, and computer science courses at the precollege level. In a recent survey of high schools in 44 states the following was revealed:

  —95 percent of the states reported shortages or critical shortages in physics teachers,
  —86 percent of the states reported shortages of chemistry teachers, and
  —96 percent of the states reported shortages of mathematics teachers.

- Nationwide, 50 percent of the teachers in science and mathematics were unqualified and using emergency certificates.
- Between 1971 and 1980, there was a 77 percent decline in mathematics teachers being trained and a 65 percent decline in science teachers being trained.
- Decreasing priority is being given to science and mathematics in the secondary schools of the United States in marked contrast to what is happening in Germany, Japan, and the Soviet Union.

The larger percentage of our nation's youth graduates from high school with no science or mathematics beyond the tenth grade. Essentially, these students have been eliminated from opportunities for scientific and technical careers which, as a consequence, decreases the pool from which future scientists and engineers are drawn. Recent studies by NSF, the Department of Education, and the National Research Council reveal:

- Only 33 percent of the nation's schools offer more than one year of science and mathematics.
- At least half of the nation's high school graduates have taken only one year of biology and no other natural science.
- At least half of the nation's youth graduates from high school with no mathematics beyond algebra.
- Five million high school students study calculus in the Soviet Union compared to 100,000 high school students in the United States.
- Insufficient attention is given to motivating and providing an adequate education in science for nonscience majors at both the precollege and college levels.

The problems are particularly acute for minorities and disadvantaged members of the population who are located in large urban school systems. Yet, the problem extends beyond minorities. The deficits in the U.S. educational system generate a national problem, related directly to national security and defense and to the economic productivity and well-being of all the nation's citizens. The volunteer armed forces, for example, attract approximately 300,000 high school graduates annually. Increased sophistication of military hardware and computers requires an intellectual capacity based on adequate rudimentary skills in mathematics which must be taught in high school. A model program providing mechanisms for addressing the underrepresentation of minorities in science and technology follows.

An Approach to Enhance the Involvement of Historically Black Institutions in Science and Technology Research and Training

To address the issues and problems identified in the preceeding section, we need a comprehensive program extending from precollege to the postdoctorate level. The program, at a minimum, needs to address three elements at the college/university level. These elements include institutional development, faculty development, and undergraduate and graduate student development. At the precollege level, the program needs to address preservice and inservice teacher development and elementary, junior high, and high school student development.

The Resource Center for Science and Engineering (RCSE) program was a model with the potential for long-term success in addressing the problem of inadequate opportunities in science and mathematics education for minorities of the nation. Conceived to address the entire spectrum of science and mathematics education, from the precollege to the postdoctoral levels, the model had broad applicability with many features that were cost-effective and transportable.

The program was successful where other programs failed because it provided a well-defined mission with specified guidelines for proposal development; a staff completely dedicated to the operation and success of the programs; one contact point within the federal agency with which interaction was necessary; and multiple-year funding for a broad spectrum of programmatic thrusts.

The RCSE model also made provisions for the following three elements at the college/university level:

1. *Institutional development*. Support of sophisticated equipment not attached to any particular project or

principal investigator, funds to strengthen physical resources, alterations and renovation of laboratories, provision of support services, including electronics technicians, machinists, and other centralized resources.

2. *Faculty development.* Provision of up to 50 percent released time and technical support including technicians and postdoctorates.

3. *Graduate and undergraduate student development.* Research assistantships, student travel to scientific meetings, and laboratory visits.

At the precollege level, provisions were made for the following three essential components:

1. *Preservice science and mathematics teacher training program.* Opportunities for teacher development activities that focus on innovative and creative approaches in the preparation of precollege teachers of science and mathematics with emphasis on the preparation of science and mathematics specialists (K-12).

2. *Inservice science and mathematics teacher training programs/institutes.* To provide for the development of detailed, consistent, and indepth training and updating in content, technology for teaching (computers/telecommunications), and teaching methodology for the current science and mathematics teaching force at the precollege level.

3. *Student development programs.* To provide motivational and academic enrichment experiences and at the same time offer opportunities for career explorations. Programs that were developed included the Saturday Science Academy (for elementary and middle school students, grades 3-8); Summer Science, Engineering, and Mathematics Institute (for high school students, grades 10-12), and Research Apprenticeships for Minority High School Students.

Recommendation

A comprehensive model containing the elements described above is the model recommended by the Science and Technology Advisory Committee of NAFEO for adoption by NSF to provide support for science and technology in Historically Black Institutions. Further, the committee recommends that the adoption of the model be accompanied by a commitment for adequate and consistent funding for a minimum of 10 years. These actions would enhance significantly the ability of HBIs to contribute to the solution of the nation's problem in terms of science and technology manpower needs.

Notes and References

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Undergraduate Science and Engineering Education

Philip H. Jordan, Jr.

President
Kenyon College

Representing the National Higher Education Associations Task Force

Thank you for this opportunity to present the consensus recommendations of seven major national higher education associations on the priorities for NSF leadership and support for undergraduate science and engineering education. The recommendations were drafted by a special task force of college presidents, whose report (text attached) was transmitted to the members of the Committee by Robert Atwell, President of the American Council on Education, who convened the task force.

I hope you have had an opportunity to review our recommendations. I would like to say a few words about the background of the report and summarize its findings briefly.

Last August, a group of national higher education associations met with Director Erich Bloch and other top officials of the National Science Foundation to discuss the need for a greater national effort to strengthen undergraduate science and engineering education. Mr. Bloch outlined the important steps already under way at NSF, including the assessment of needs being undertaken by this Committee, and he suggested that the associations could contribute to your work by establishing a mechanism to convey to you the consensus views and priorities of the community.

Accordingly, a special task force was appointed by the American Council on Education in conjunction with the American Association of Community and Junior Colleges, the American Association of State Colleges and Universities, the Association of American Universities, the National Association for Equal Opportunity in Higher Education, the National Association of Independent Colleges and Universities, and the National Association of State Universities and Land-Grant Colleges

I had the honor to chair the task force, as the only educator in the group who was not himself a scientist (although I have been deeply interested in the topic as an undergraduate philosopher, a professional historian, and a liberal arts president). My six colleagues all had distinguished backgrounds in the sciences and engineering, and headed a variety of institutions ranging from two-year colleges and technical institutes to four-year public and private colleges and graduate institutions.

In our meeting , the task force very rapidly reached a consensus about the pressing needs of science and engineering education at the undergraduate level, and the priorities for addressing those needs. So, I can say with assurance that the recommendations of our report represent a very strong consensus within the community on the urgency of this matter and the means to address the problem.

Our first set of recommendations is organizational, urging a continued strengthening of NSF support for research activities at undergraduate institutions across the directorates. As expansion occurs in its research budget, NSF should allocate an increased share of research funds to investigators in undergraduate institutions and encourage qualified undergraduate faculty to compete for research awards according to guidelines based on realistic criteria for different kinds of institutions.

Further, we urge the Foundation to make a special effort to involve more faculty from non-doctoral granting institutions in its consultantships, peer review panels, and advisory committees. Equally important, NSF should recommend to the White House more well-qualified representatives of undergraduate institutions as candidates for membership on the National Science Board. Appointments in each of these areas have been drawn overwhelmingly from the research universities, while the wealth of experience in teaching and research at undergraduate institutions has been relatively untapped.

With respect to programmatic recommendations, the task force agreed on two overriding priorities. Our first priority is undergraduate instructional equipment and materials. The pressing needs in this area—from laboratory instruments to scientific periodicals to site preparation to special facilities for major equipment—are common to all undergraduate institutions, including community colleges. Since community colleges enroll about half of all undergraduate students, and many of their graduates go on to baccalaureate programs, the quality of science at these institutions can be an important factor in determining the quality of science at four-year colleges.

And so we urge a significant increase in the College Science Instrumentation Program, with competitive awards and the allowance of institutional expenditures for installation and maintenance as part of their matching contributions.

Our second programmatic priority is an investment in people to meet faculty and student needs. Here at the undergraduate level, research and teaching needs are conceptually inseparable. Undergraduate faculty research is a teaching tool, and research opportunities attract and keep the best teachers. But, for busy undergraduate teachers, summer stipends for released time for research and study are primary and proven means for faculty renewal.

And so we call for expanded support across the directorates for undergraduate research, including subsidized opportunities for research participation for outstanding undergraduate students, during both the academic year and the summer, and expanded opportunities for faculty renewal under existing teacher enhancement programs.

Besides those programmatic recommendations, the task force makes two other recommendations which cut across existing programs. We believe they would add new dimensions to the Foundation's leadership in undergraduate science education, enabling it to leverage scarce resources for science and integrate its activities more fully with those of undergraduate institutions and programs.

First, we recommend a new program to develop a limited number of consortial centers of instructional excellence in undergraduate science, engineering, and technical programs. Such centers of excellence would be strategically located in various geographical regions, and would gather outstanding teachers, researchers, and students from a variety of institutions—from high schools to research universities with graduate schools to corporate research programs. Through such vertical integration, the centers would provide networking to devise ways to meet regional needs. The centers would explore the pooling of science resources and facilities, the development of joint projects for cooperation with schools, projects for curriculum development, projects for the development and dissemination of instructional material, expansion of opportunities for faculty and student research, including cooperative projects with industry, and the development of technical programs in emerging sciences.

NSF could leverage limited resources through small initial planning grants to develop competitive proposals. Then, in a second round, a small number of pilot projects could be funded with local matching and built-in evaluation.

Our second additional recommendation is that NSF establish a challenge grant program for improvement of undergraduate science and engineering education. The task force had in mind the successful $20 million program conducted by the National Endowment for the Humanities. We urge the creation of a counterpart that would provide three-year grants with significant matching to leverage relatively small, short-term federal expenditures into a large-scale effort at institutional advancement. Awards would be based on detailed plans for coordinated activities to strengthen the institution's total science effort including faculty development, student needs, and facilities and equipment improvement.

To implement our recommendations, we suggest a goal in the near term of an additional $100 million for NSF undergraduate science education programs. Of this total, we would allocate 60 percent for instructional equipment and materials and 20 percent for support of faculty research and teaching. We would suggest that 10 percent be allocated for the proposed new consortial centers of excellence, and 10 percent for a new program of challenge grants for improvement of science education.

By these means, we believe that the National Science Foundation can exercise a leadership that will stimulate and sustain the strong leadership of campus presidents and help to attract funds from the private sector, especially from business and industry, to address the problems in undergraduate science education and to move forward significantly in this important area of our national life.

Attachment

National Priorities for Undergraduate Science and Engineering Education

National Higher Education Associations Task Force*

This report deals with an essential element of the developing national strategy to rebuild our human and capital resources for basic science and research. The strategy is evolving out of growing recognition of the need to strengthen America's scientific and technological capacities to increase industrial and economic competitiveness and to strengthen the national defense.

National policies for long-term investment in research and education to address this complex set of problems must be fashioned with a clear understanding of the critical role of undergraduate science and engineering education. The processes of science, engineering, and technical education and of the education of scientists, engineers, and technicians are continuous. The undergraduate years are crucial phases in those processes. They are the years when qualified students learn basic scientific concepts in sequential study and weigh career choices as professional engineers, scientists, and teachers.

The federal concern with the production of trained scientific and engineering manpower thus requires direct and appropriate investment in undergraduate educa-

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tion—research and instrumentati. ı and teaching programs—in all its settings, whether at two-year or four-year institutions or in undergraduate programs at research universities. Undergraduate institutions are a primary concern of this report because they have historically attracted high-ability science students, produce a disproportionately large number of science and engineering baccalaureates, and serve as primary feeder institutions for top graduate-level programs. Many other undergraduate institutions have a tradition of strong teaching in the physical sciences and engineering, and the potential to increase significantly their production of scientists, engineers, and technicians. Community, junior, and technical colleges have special missions and special competence in training and instruction in new technologies, and also serve as important feeder schools for baccalaureate and graduate programs.

Recently there have been encouraging signs that the role of undergraduate science and engineering education is gaining renewed recognition. In May, NSF's policy-making National Science Board appointed a Task Committee on Undergraduate Science and Engineering Education to review the agency's programs in this area. In June, an influential conference at Oberlin College was held to discuss a report on "The Future of Science at Liberal Arts Colleges." In July, the House-passed HUD-Independent Agencies appropriations bill directed NSF to "look for opportunities to expand undergraduate support and . . . report by March 1, 1986, on the Foundation's assessment of needs in the undergraduate area and the progress toward the development of programs to meet these needs."

This report outlines the priorities of the higher education community to assist NSB's Task Committee in building a carefully focused, leveraged program of NSF leadership and support for undergraduate science, engineering, and technical education. We urge that such a program be implemented as promptly as fiscal realities permit, emphasizing the importance of sustained funding and careful evaluation of program impacts over time.

Increasing Participation of Undergraduate Sector in NSF Activities

We believe that organizational as well as programmatic steps are necessary to build such a program. We urge the Foundation to strengthen its links with undergraduate institutions and programs through a comprehensive effort to involve more faculty from non-doctoral granting institutions in its consultantships, its peer review panels, and its advisory committees. Equally important, NSF should recommend to the White House more well-qualified representatives of undergraduate institutions as candidates for membership on the presidentially appointed National Science Board. Appointments in each of these areas have been drawn overwhelmingly from the research universities, while the wealth of experience in teaching and research at undergraduate institutions has been relatively untapped.

Strengthening NSF Leadership in Science and Engineering Education

We urge NSF to continue to expand its support for research activities at undergraduate institutions across the directorates. It is vital that the skills of quality researchers at undergraduate institutions be utilized as fully as those of researchers who have taken positions at research institutions, not only as grant recipients but as members of peer review panels. The Foundation's current $12-13 million investment in quality research at undergraduate institutions has begun to tap this resource. As expansion occurs in its research budget across the directorates, NSF should allocate an increased share of research funds to investigators in undergraduate institutions and encourage qualified undergraduate faculty to compete for research awards. Guidelines should be developed based on realistic criteria for different kinds of institutions and different kinds of projects to assure that meaningful opportunities are provided for all kinds of institutions and their faculties to compete for research funds.

Additional dollars invested in research at the undergraduate level have enormous leverage, in terms of strengthening both the capacity of the researchers and the education of future scientists, as well as the value of the research itself. The total amounts needed are often small in comparison to other research investments.

We commend the re-establishment of the Science and Engineering Education Directorate (SEE). Its current initiatives to strengthen precollege math and science education address the needs of students at the critical years when concepts and attitudes are developed. These activities provide a basis for future expansion to fulfill the responsibilities for supporting science education at all levels as set forth in the original NSF organic act as well as the 1983 Board resolution re-establishing SEE. For example, we believe that the two program initiatives proposed below would appropriately be administered by an expanded SEE Directorate.

In shaping our recommendations for programmatic priorities, we have focused our attention first on two critical areas: (1) tools—instructional equipment and materials, and (2) people—faculty and student needs. In addition, we propose that NSF undertake two crosscutting initiatives designed to provide needed leadership for a national effort to strengthen undergraduate programs: (1) consortial centers of excellence and (2) a program of challenge grants for the improvement of undergraduate science, engineering, and technical education.

Programmatic Priorities

Undergraduate Instructional Equipment and Materials. In our view, the primary need of undergraduate institutions is instructional scientific equipment and materials. The serious deficiencies in the research laboratories of universities are reasonably well documented. There, the obsolescence of research instrumentation is often in marked contrast with the state-of-the-art equipment of major industrial and national laboratories. As noted in the 1980 AAU report to the Foundation, *The Research Instrumentation Needs of Universities*, the equipment deficiencies of undergraduate instructional laboratories, while less well documented, are equally serious. Important progress has been made in recent years in addressing the research equipment needs of universities, but little has been done to address the purely instructional equipment needs of undergraduate institutions and programs.

The category of equipment covers an array of needs, from instruments to keep laboratories current with scientific and technical advances, to scientific periodicals for the library, to site preparation and special facilities to house major equipment, but the most pressing need of undergraduate institutions and programs is for instructional equipment.

The needs are compounded by the rising cost of sophisticated equipment and its rapid obsolescence (instruments that might have had a useful life of 10-15 years may now be outdated after 5 years due to rapid advances in the disciplines). The needs are common to all undergraduate institutions, including community colleges—and since they enroll about half of all undergraduate students, and many of their graduates go on to baccalaureate programs, the quality of science at these institutions can be an important factor in determining the quality of science at four-year colleges.

Increased NSF leadership and support for undergraduate instructional equipment are urgent because the Foundation is the only federal source for undergraduate science, engineering, and technical programs. These institutions are virtually excluded from competition for research funding by the major mission agencies. The College Science Instrumentation Program should be substantially expanded. Awards should be made competitively, and institutions should be permitted to apply their expenditures for installation and maintenance as part of their matching contributions. The Foundation should also ensure that institutions provide properly for the continuing maintenance of the funded equipment.

We also urge the SEE Directorate to (1) expand eligibility for its support for the development and application of instructional technology to improve the quality of teaching in the sciences (Applications of Advanced Technologies), (2) support programs to provide equipment for new and emerging science programs, and (3) support studies and publications that encourage technology transfer among undergraduate institutions. With such NSF encouragement, undergraduate institutions could exert enormous long-range influence on the quality of science instruction at all levels, from elementary and secondary school through graduate school. The possibility of allocating a portion of Small Business Innovation Research (SBIR) funds for such projects should be explored.

Faculty and Student Needs. It is conceptually impossible to separate teaching and research needs. Research support is the fundamental tool for enhancing the skills of undergraduate scientists and engineers. Institutions cannot attract or keep highly qualified teachers (or keep them qualified) unless there are opportunities for faculty to do research and keep up-to-date in their fields.

Summer stipends and released time for extended research and faculty renewal and study are two primary and proven mechanisms for faculty renewal. Undergraduate institutions are receiving increasing numbers of requests for released time from their faculty, and college budgets are never adequate for this purpose.

We recommend that NSF expand support for undergraduate research activities across the directorates in addition to the Research in Undergraduate Institutions (RUI) program. At the same time, we recommend that NSF expand support opportunities for undergraduate faculty renewal under the Teacher Enhancement and Informal Science Education program in the SEE Directorate. There is a clear national need to assure a sufficient supply of science teachers and researchers into the next century. To address this policy goal through federal support of graduate assistantships is insufficient because many recipients are lost to industry, and college and university student/faculty ratios cannot justify hiring more of them for the foreseeable future. Therefore, faculty research and teaching grants are potentially the most effective federal policy instrument for sustaining adequate supplies of able and committed teachers and researchers in the sciences and engineering.

Student needs, we believe, should be addressed by NSF primarily through support for equipment and faculty needs.

Just as research opportunities are essential for quality teaching, such opportunities for hands-on experience should be made available as widely as possible for outstanding undergraduate students. NSF should encourage undergraduate faculty to develop summer or academic-year research projects that include significant subsidized student participation. Such projects should be judged by separate and appropriate criteria.

NSF already has an outstanding record of commitment to the expansion of opportunities for underrepresented minorities and women at the graduate level. Any new emphasis on undergraduate support should be equally sensitive to this objective. The importance of such efforts was underlined in the NSB report, *Educating Americans for the 21st Century*:

"By 1995, there will be almost 30 percent fewer college-age students for the workforce. Furthermore, upwards of 40 percent of these young people will be Black or Hispanic, the very groups who, for no reason related to inherent ability, are now at the bottom of the educational and economic ladder. Such disparities mean that the nation continues to suffer from inadequate development and utilization of its human resource potential. The nation cannot afford such educational casualties."

Crosscutting Initiatives

The competitive instructional equipment and research programs proposed above, we believe, should form the core of revitalized NSF undergraduate activities. In addition to these initiatives we make two recommendations designed to provide an added dimension to the Foundation's leadership in undergraduate science and engineering education; leverage scarce resources of the Foundation, institutions, and others; and integrate more fully the undergraduate activities of the Foundation with those of undergraduate institutions and programs, faculty, students, and others interested in improving the quality of undergraduate programs.

First, we urge NSF to carefully develop a program to establish a limited number of consortia as centers of instructional excellence in undergraduate science, engineering, and technical programs. The centers should be strategically located to serve the various geographic regions of the country and to build on existing institutional strengths in undergraduate instructional programs.

Second, we propose a program of challenge grants, modeled after the successful National Endowment for the Humanities challenge grant program, to provide undergraduate institutions and their patrons with opportunities to examine institutional instructional objectives, articulate related needs, and develop realistic plans for strengthening the quality of their science, engineering, and technology programs.

Consortial Centers of Excellence. We believe that opportunities exist for major advances in cooperative efforts to strengthen science education on a regional basis. Such opportunities could be realized through NSF leadership in establishing a program of consortial centers of excellence.

The mission of these centers should be to bring together outstanding teachers, researchers, and students from a variety of involved institutions from high school through graduate school and corporate research programs, and through such vertical networking to devise ways to better meet regional needs. The potential for pooling science resources and facilities and for enhancing institutional strengths in research and teaching should be explored. Such centers also could develop joint projects for cooperation with the elementary and secondary schools through workshops, summer institutes, roundtables, and other programs for teacher training and faculty exchange, curriculum development; dissemination of materials for training, retraining, and in-service development in mathematics, science, computer science, and technical occupation fields, expansion of research opportunities for faculty and students, including cooperative projects with industry, and development of technical programs in emerging sciences.

Successful consortial arrangements are challenging to develop. They require careful thought, planning, and time to develop fruitfully. Seed money is an early essential ingredient. NSF could leverage limited resources and prepare for more fully developed efforts in future years by first soliciting proposals for a limited number of relatively small planning grants to be used to develop competitive proposals. Planning grants will stimulate broader national and regional interest in undergraduate concerns that will benefit all competing institutions. In the second round, the Foundation could select a small number of proposals for funding as pilot projects for a period of at least five years, with increasing local matching and built-in evaluation required in subsequent years. If the pilot projects succeed, proposals could be solicited to establish additional consortial centers of excellence in other regions of the country.

NSF should emphasize the need to involve different types of institutions in the proposed consortia, including high schools and technical colleges. Most consortia tend to be integrated horizontally among similar institutions rather than vertically to involve a mix of institutional types.

Challenge Grants for Improvement of Undergraduate Science and Engineering Education. We strongly urge NSF to establish a challenge grant program for improvement of undergraduate science and engineering education, similar to the $20 million program conducted by the National Endowment for the Humanities. Three-year challenge grants with significant matching provide exceptional opportunities for leveraging relatively small, short-term federal expenditures into a large-scale effort at institutional advancement.

Challenge grants will foster broad improvements in the quality and effectiveness of undergraduate science education. They will encourage undergraduate institutions throughout the country to identify and articulate their most pressing needs in science education. Awards should be based on detailed plans for a coordinated set of activities to strengthen an institution's total science effort, including faculty development, student needs, and important improvements in equipment and facilities. As with the NEH program, NSF will find that it will stimulate significant additional private support from alumni, corporations, and other prospective donors.

A Goal for Future Growth

We believe that the priorities outlined above should guide the Foundation in a sustained effort to achieve realistic growth of its leadership in strengthening undergraduate science and engineering education. As an immediate goal we recommend that NSF seek to expand its existing research and education activities in these areas across the directorates by an additional $100 million. Of this sum, 60 percent should be allocated for instructional equipment; 20 percent for support of faculty research and teaching; 10 percent for consortial centers of excellence; and 10 percent for challenge grants for improvement of science education.

The above recommendations represent a strong consensus of the undergraduate science community. We believe that their implementation would greatly assist the Foundation in pursuit of its statutory mission ". . .to recommend and encourage . . . national policies for the promotion of . . . education in the sciences . . . and to initiate and support . . . programs to strengthen science education at all levels."

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Undergraduate Science and Engineering Education

Timothy O'Meara

Provost
University of Notre Dame

I am Provost at the University of Notre Dame, and I am also a mathematician, my specialties being algebra and the theory of numbers. I received my doctorate from Princeton University in 1953 and was active in teaching and research from that time until I became Provost in 1978. My regular faculty appointments have been first in New Zealand, then at Princeton, and finally at Notre Dame. I am currently co-authoring a research monograph for Springer-Verlag. I have been a principal investigator on NSF research grants from 1963 until 1980 and an NSF reviewer for research grants on the national level on many occasions. As Provost, I have responsibility for the entire academic area of the University of Notre Dame. Graduate studies, research and sponsored programs, and student affairs also report to the Provost through two Vice Presidents. The Provost is the second officer of the University.

The University of Notre Dame is a private, independent university with an enrollment of 7,500 undergraduates, 1,200 graduate students, and 700 advanced students in law and business administration. The undergraduate student body is highly selective. We are in excellent financial condition. The last 30 years has marked a transition of Notre Dame from a teaching university to one that puts equal emphasis on both teaching and research. Our federal support at the present time is good, with a 37 percent increment from 1983-84 to 1984-85.

These then are the various forces that influence my testimony today. On the personal side, I have been influenced as I watched all five of our children graduate from Notre Dame, none of them in science I might say.

Appearing before you at the end of these hearings I have had the opportunity to read most of the testimony that has been presented, and I am impressed with the long shopping list of requests which, if granted, would surely solve the problems of science for years to come, perhaps forever!

From the perspective of my own university, I can relate to the movement of the best students out of science, a continuing decline in freshman interest in science, the need for laboratory modernization and computer equipment, and the continuing lack of interest in doctoral studies by domestic students. Before I am done I will add an item or two of my own.

Much of the testimony has been concerned with the public perception of science. Prestige and respect for the profession are significant factors in the allocation of resources, and also in motivating young men and women to dedicate their lives to science. This perception is related to the dual responsibility that science has to the public. Here, I am thinking specifically of education and communication.

Our research universities have special responsibility in this regard. We have performed brilliantly in the delivery of highly creative scientific research over the last 40 or 50 years. But, the problem immediately before us is one of continuity of the scientific enterprise through the development of the next generation of students. A good part of the responsibility for this crisis of continuity belongs to our research universities, which are responsible for the formation of our scientific professoriate. And, some of this responsibility must be shared by NSF, which plays an influential role in shaping the graduate faculties in these universities through its research grant mechanism. It is therefore essential that NSF take catalytic action through its research grant mechanism to influence the education of the future scientific professoriate at the very heart of its formation.

One of the cornerstones of science policy in the United States since the Second World War has been the concentration of basic research in our comprehensive universities. This is quite different from the Soviet model of highly specialized research institutes. Our model has served us well. But there are signs of drift and erosion. The impressive statistics given in these hearings on the success of liberal arts colleges make us wonder about how well our research universities are meeting the dual role of teaching and research in the formation of the professoriate. I was reminded of this concern by the low profile of research universities at these hearings to date. Personally, I do not find convincing the "some are teachers and some researchers" response given in earlier testimony. My own experience has shown that where this dichotomy exists, teachers are invariably viewed as second class to researchers. Somehow the balance must be tilted toward a greater integration between teaching and research in the education of the next generation of scientists. There is no doubt in my mind that the highly competitive nature of research proposals plays a significant role in the imbalance and in contributing to a culture that puts teaching in second place. Therefore, whether it likes it or not, and for better or for worse, NSF is already playing a significant role in science education through the vehicle of its research grants. I fully recognize the tension between education and research and the dilemma that it presents. The research component must not be sacrificed. But, NSF must think through anew its policies on *education versus research* and *breadth versus depth*. Indeed, it must do so in the long-term interest of research itself. Somehow the dual role of a university to teach and to do research must be reflected in our doctoral programs, and I urge NSF to find some kind of leverage that will accomplish this. Why not a teaching and research postdoctoral program?

The problems of education and communication within the scientific community are real. Let me take an example from an address that I delivered to the National Chairmen's Research Colloquium for the Mathematical Sciences last October. Just before the meeting, I asked my Associate Provost, an ethicist, who had interviewed all faculty members at our University over the last three years, the following question: What do *you* think of mathematicans? This was his answer:

> "They are self-contained; they presuppose that what they are doing is relevant whether or not anyone else thinks it is; they have a great tolerance for individuals; they consider neither social conformities nor appearance to be of much importance; they reach a high level of competence at an early age; after that a certain boredom sets in which seems to affect the way in which they teach."

Here is a second example. I recently asked one of our strongest research groups with outstanding federal support for a proposal for an endowed chair. The first draft of the proposal was filled with information about the number of pieces of equipment, the number of articles published, the relationships with other research groups throughout the world, and technical information on the latest results in the field. No doubt it would have qualified for an award from just about any federal agency in the country. But not from a private donor. Nowhere was the significance of the work described in simple language that could be understood by an educated layman. After pointing this out I was politely informed that, after all, research is hard. Nevertheless, I asked for a second version, but that was still unsatisfactory. Finally, after several revisions, a proposal was submitted with concrete topical examples showing how basic research done in the discipline many years ago was now having important applications in various segments of society. It concluded by speculating on future applications of the group's current research to society.

My third illustration is a lamentation about the dearth of honest mathematics courses for students in the liberal arts. We mathematicians prefer to do mathematics and not talk about it. We are simply not that interested in giving an overview of our subject. And, we are sometimes embarrassed by those who do. The purpose of mathematics in a liberal education should be to expose students to that mathematical way of thinking, to give them certain mathematical skills, and to give them an understanding of the significance of mathematics in the world. And this applies to science as well.

These are the sorts of experiences that over the years have contributed to my view that we do indeed have a problem with education and communication which is affecting the development of the next generation of scientists. I do not believe that the problem is recognized on the grass roots level. Fortunately, I see leadership emerging within the profession. The David Report—which to be sure concerns research—is a case in point. A similar report on mathematics education at the undergraduate level has been initiated under the chairmanship of Bernard Madison and should be encouraged. The key to success in these ventures, it seems to me, is the interaction between distinguished scientists from both the university and the business communities.

Before I conclude I think I should add a couple of items to the long shopping list you have already received. I think that NSF, in its program for continuing education for high school teachers and college professors, should consider reinstituting some form of the highly successful academic-year and summer institutes that it supported in the 1950s and 1960s. Thought should also be given to reinstituting some form of the NSF Science Development Centers that served many universities, including my own, so well!

In conclusion, I want to re-emphasize that NSF has played a highly significant role in the education of the scientific professoriate of American universities. Now, in the interest of the continuous generation of personnel for science, NSF must find a way of catalyzing an integration between teaching and research through its various support mechanisms including those research grants that influence doctoral education.

The Role of Science Museums in Undergraduate Science and Engineering Education

Kenneth Starr

Director
Milwaukee Public Museum

In making my presentation I first shall focus on the role of science museums in undergraduate education. Here I can speak with strong conviction, for over half a lifetime—my graduate fellowship years at Yale's Peabody Museum of Natural History, my subsequent curatorial years at the Field Museum and directorial years at the Milwaukee Public Museum—I have seen in daily fashion the way in which those and other science museums contribute to the scientific education of undergraduates, whether pipeline science majors or mainline non-science majors.

I shall confine my comments to describing in very broad way two major areas of contribution that museums make in undergraduate education. The two areas, both of which relate closely to the more formal collegiate educational system, have to do with museums, one, as important, even essential, science education resources and, two, as equally important working situations for gaining valuable practical experience in science.

Museums as Science Education Resources

Museums serve in a number of important ways as significant science education resources for both students and faculty, as the following examples will attest.

Access to and Use of Collections. The primary raison d'etre for museums of course is for the studied acquisition of objects of natural and human history, for the responsible organization and care of those objects over time, and for their effective use for purposes of scholarship and education.

Such collections are invaluable resources, the more so because they represent all forms of natural objects and human invention through space and time, and, because having been assembled over decades, centuries, and millenia, they often have become rare or irreplaceable, as objects collected today will be tomorrow. Students and faculty in the earth, biological, and human sciences draw heavily on museum collections for purposes of teaching and research, whether the collections are across the campus, the city, or, in the case of research materials, across the country and the world.

Museum Staff. The staffs of science museums also are important resources, especially the curatorial staff who in the larger museums are the equal of college and university faculty, if one is to judge them on the basis of the excellence of their training and experience, the quality of their publications, and the numbers of grants that they have won from the National Science Foundation and other public and private granting agencies.

Many curators in the larger museums hold adjunct professorships at neighboring colleges and universities, teaching both in their museums and at the schools. They serve themselves well by keeping more current in their fields, they serve their museums well by the broader perspective that they gain, and they serve the colleges or universities well by providing skills that the regular faculty might not possess, so widening and deepening the pool of knowledge and experience available to the students. In my own situation, the Milwaukee Public Museum has close relationships with the University of Wisconsin-Milwaukee which, with 30,000 students, is the second largest campus in the University of Wisconsin System. In appointing new curatorial staff we regularly sit with faculty of the concerned university department to study ways in which we can cooperate, sharing rather than duplicating our intellectual resources, thus benefiting both students and institutional budgets. Incidentally, the two institutions also share libraries, laboratory facilities, and specialized equipment, again enabling both institutions to keep costs down.

Whether adjunct or permanent, all faculty make active use of museums for instructional purposes. Many teachers in area colleges and universities rely heavily on museum exhibits to illustrate basic scientific principles, while providing their students with opportunities of seeing the actual "stuff" that composes our natural and human worlds. Enterprising faculty also arrange for their students to take behind-the-scenes tours of collection areas, laboratories, and workrooms, so providing them with opportunities for handling actual objects and for seeing and participating firsthand in the workings of science. Seeing the actual skull of a triceratops has much more impact than seeing a picture of one, and participating in the reconstruction of that skull surely beats a verbal or written description of the process.

Teachers are remiss if they do not avail themselves of every possible instructional medium at their disposal for communicating scientific information to their students, and museums are one such important medium, and a very effective and engaging one.

Otherwise, museum curatorial staff also share with undergraduates their knowledge and experience relating to bibliographic sources, provide guidance in selecting graduate schools, and write references for schools and for jobs.

Libraries. Museum libraries, particularly those in the larger museums, are especially valuable resources. Thus, as an example, the library of the Field Museum serves as a resource for more than 20 area colleges and universities, while my own museum serves in like way for the Milwaukee metropolitan area and, indeed, for the entire state. Our library is the more valuable in that it is more than a century old and holds not only specialized recent scientific materials, but also older series and individual titles that are not to be found in the libraries of newer institutions.

Museum Publications. Continuing in the bibliographic vein, I make note of the scientific and scholarly materials that science museums publish. Including both "hard-core" and "soft-core" science, those publications see regular use in undergraduate courses in colleges and universities.

Films. Other significant resources that museums offer are films, video disks, and laser disks, many of them on scientific subjects. The Milwaukee Public Museum holds what as far as I am aware is the largest collection of such audiovisual materials of any museum in the country, some 16,000 films and related materials. We also were first among museums to devise a computerized system for booking those materials, as we also do our school-class visits. Local colleges and universities make active use of these audiovisual materials.

Museums and Practical Work Experience

Having cited some of the more important ways in which museums serve as resources for undergraduate education, I move to another distinctive area of contribution that museums make, that of providing students with pertinent practical work experience.

The *study* of science represents but one aspect of science education, whether the student follows the very narrow pipeline or becomes part of the much, much wider mainline. An equally important, indeed, possibly more important aspect of science education is that of actually *doing* science. Here, science museums excel in providing opportunities for students to apply their studies and to practice science, both in the museum and in the field.

All of the larger museums actively provide such opportunities through research assistantships, work-study programs, internships, and volunteer opportunities. It also is important to note that students not only gain invaluable practical scientific experience, learning the trade firsthand, but also earn hard and often badly needed money at the same time.

In summary, through their collections, curatorial staffs, facilities, and programs, science museums make important and, in the true meaning of the word, unique intellectual and experiential contributions to undergraduate science education.

Museums and the Precollege Educational System

Having spoken of the role that science museums play in undergraduate science education, both pipeline and mainline, I now would like to speak briefly of their role in relation to the broader society and more particularly the precollege educational system.

As the subject is not relevant in the context of the present hearing, I shall not dwell on the role of museums in educating the general population in science, save to say that science museums rank high in providing informal science education, making people feel comfortable and easy with science, making them aware that science is a vital and important part of our lives and contributory to our well-being. Science museums reach segments of our population that no other educational media do, certainly not the formal educational system.

More pertinent to our purposes here today is the part that science museums play—or do not play—in precollege science education, K through 12, the grades from kindergarten through high school.

In order to come to fruition in the undergraduate and graduate years, interest in science must begin early and be fostered continuously. One cannot just catapult the young into science with little or no prior experience of a kind that lets them know that science can be satisfying, that inspires them to inquire further into the marvels and mysteries of the world around them, and that either makes them into science pipeliners or at least makes them mainliners who have a greater awareness, understanding, and appreciation of science.

As the situation has existed in the schools in the past, kindergarteners and primary-schoolers have had little and in many instances no systematic training in science. Such a situation results in the shock, the absolute cold-water shock of suddenly, violently being thrust into mathematics, physics, chemistry, and biology. Despite the passage of the years since I was in that situation, I still clearly remember the shock. Combine that with what all too often is poor and unimaginative teaching, and young students very rapidly move away from science. Far too often there is not the proper preparation in the primary grades, in consequence of which the move into secondary school math and science is akin to a traumatic and painful rite of passage, rather than a smooth and exciting transition.

By and large, the situation seems not to be a great deal better today, with little effective science education taking

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place in the primary grades, as a result of which only a relatively small percentage of secondary school students either enter the science pipeline or go into the mainline with any appreciation or understanding of science. All this being so, how can one rightfully expect that having long since passed their formative years, any greater percentage of undergraduates will take any more eagerly or successfully to the sciences? One can but hope that the recent initiatives in augmenting science education in the precollege years and in improving the quality of teaching in the primary and secondary grades will serve to create early interest in science and then nurture that interest in ways that will strengthen science education throughout the precollege years, thus providing solid practical as well as attitudinal preparation for subsequent undergraduate science education.

As I described above for undergraduate science education, so also science museums make significant contributions in the vital area of precollege science education, running the full range from kindergarten—and for that matter even younger—through high school. Science museums do so through an almost literally endless number and variety of programs whose purposes are to present math and the physical and natural sciences in ways that invite and excite and intrigue, and that please people and encourage them to learn by doing science, rather than just by looking and reading and talking about it.

One has only to scan the listings of such science museum programs to become aware of their quality and, more important, their high potential for inspiring interest in science in the precollege years, as well as in the mainline general population. It would be futile as well as overly bold to attempt to do more than cite but a few general examples of some of the kinds of highly creative programs that science museum staff present for the precollege grades and their teachers, programs that supplement and in many cases actually replace those in the formal educational system.

Among these general examples one could name the tours of exhibits that hundreds and hundreds of thousands of school children take each year; the great variety of classes that museums offer on specialized math and scientific subjects; the "hands-on" discovery and participatory learning centers; lectures and films, and the educational aids that go out on loan to schools; magnet-school programs and special programs for gifted and disadvantaged children; career days and science fairs; field trips, both day-long and those lasting for several weeks or months; camp-ins, where children camp in the museum and enjoy scientific activities; and programs for science hobbyists.

These examples serve as but a very few of the endless and endlessly changing kinds of programs that bring precollege students, both mainline and future pipeline, to science museums. Each issue of educational offerings from science museums presents new programs for bringing science to children, manifest of the creativity of museum staffs and their strong sense of mission with respect to science education.

On another level, science museums also involve themselves actively in training teachers through internship programs in cooperation with university schools of education and through in-service training programs in conjunction with local public and private school systems. All of these programs represent efforts to sensitize teachers to the ways in which they can use science museums to greater advantage as an important part of the total educational resources of their communities.

Again, I emphasize that these are but the barest few examples of ways in which science museums contribute to precollege science education, so very important in the preparation of primary and secondary students for college education.

In summary, I again stress the fact that science museums are vital and important components in the overall system of science education, whether in the undergraduate years or the precollege years that establish the patterns for undergraduate science education.

Issues in Undergraduate Science and Engineering

In his letter, Dr. Neal noted that I should feel free to discuss any issues relating to undergraduate education in science and engineering. With that suggestion as guide I shall speak briefly of what in part are issues and what in part are recommendations. Some will be general in nature, others, specific.

General Issues. As I look at the role of the National Science Foundation and more particularly that of this Committee, I see the need for a broader perspective. Two areas where such need exists come to mind:

- *Broadening and deepening the pool of resources.* There is the need to include a greater number and wider range of components in the pool of resources for undergraduate science education. Colleges and universities, agents of formal education, of course are one major component in that pool, but they by no means are the only component, or perhaps not even the most important. Many other institutions including science museums, botanical gardens, zoological parks, nature centers, corporate research and development laboratories, and a host of other non-academic institutions and organizations also offer a great deal for informal undergraduate science education.

  As I am speaking as a representative of science museums, and by logical extension for our sister institutions, botanical gardens and zoological parks, I ask that this Committee and the National Science Foundation in all appropriate aspects of its programs recognize science museums and related entities as scientific and educational institutions, and manifest that recognition in the form of funding.

  Formal learning in college or university is important, but informal learning in non-academic institutions is equally important, a hard and easily documentable fact that many in the traditional academic world do not realize or accept.

2. *Improving precollege science education.* If this Committee and the National Science Foundation truly are interested in improving science education at the undergraduate level, they will pay very serious attention to improving the quality and quantity of science education in the precollege years. As the old folk song states, "the leg bone is connected to the knee bone," and realistically one cannot expect that significant numbers of undergraduates will take science courses when they have had little if any positive association with science in their primary and secondary years.

Specific Recommendations. Apart from these general observations about undergraduate science education I have two specific recommendations:

1. *Importance of collections.* I make a plea for greater recognition of the abiding value of and the consequent need for support of collections and their care. Collections of objects of natural history and human invention are basic in science and the teaching of science, whatever the trend of the moment. Fruit flies and computer models have their inestimable value, but they also have their limitations, and so it is, for example, that paleontological collections and their associated data have their essential place in the study of the changes that have taken place in life on our planet over time.

2. *Increased opportunities for student employment.* Even more specifically I suggest that very meaningful benefits would accrue to undergraduates, their colleges and universities, and museums if the National Science Foundation were to provide students with increased opportunities and the requisite funding for working in science museums and in other science-related situations where they can reinforce their academic science with relevant practical work experience.

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III. ADDITIONAL TESTIMONY SUBMITTED TO THE COMMITTEE

During the Committee's study, the following organizations and individuals submitted written testimony:

- American Chemical Society
- American Chemical Society: Task Force on ACS Involvement in the Two-Year Colleges
- American Society for Engineering Education
- American Society of Plant Physiologists
- Association for Affiliated College and University Offices
- Council of Scientific Society Presidents
- Council on Undergraduate Research
- East Central College Consortium
- Texas Woman's University
- University of Wisconsin Campuses (Chancellors)
- Jerrier A. Haddad, IBM Corporation (retired)
- David Hart, Conference Coordinator, Student Pugwash
- John G. Kemeny, Professor of Mathematics and Computer Science and President Emeritus, Dartmouth College
- John S. Morris, President, Union College

Chemistry Education at the College Level

American Chemical Society*

The American Chemical Society (ACS) has identified a number of important needs for chemistry instruction at the college undergraduate level that require federal leadership and resources.

The American Chemical Society and Chemistry Education

The quality and quantity of college-level instruction in chemistry in the United States have been major concerns of the American Chemical Society throughout its 109-year history.

While the current quality of chemistry graduates is high and the Society continues its own supportive efforts in the field, there are major problem areas that can be addressed only through federal programs. The Society positions described below have resulted from careful consideration by ACS study groups that represent both the educational and industrial components of ACS membership.

The Society issued its latest major report on chemistry education, *Tomorrow*, in late 1984. Some 16 principal (and many subsidiary) recommendations were directed to chemistry instruction at the college level. The ACS has begun implementing recommendations directed to itself, such as one calling for new guidelines for two-year college chemistry. Other recommendations, like funding of instrument maintenance and repair, call for efforts at a federal level. Some were specifically reiterated in the recent National Academy of Sciences report, *Opportunities in Chemistry*.

The Environment of Chemistry Instruction

Several very different populations must be served by chemistry education at the college level. Each audience leaves college with knowledge and attitudes about science and scientists that are vitally important to American society. These populations include:

- Future chemists and other scientists whose command of chemistry must be comprehensive and provide the basis for future learning while having current utility in an increasingly competitive world,
- Future voters and decisionmakers who must judge between conflicting interpretations of science-related information,
- Future teachers and parents who inculcate perspectives about science in children, and
- Future non-chemistry professionals who work with chemicals and apply chemical principles as part of their professional practice.

At all levels, audiences for science education need exposure to an ever-increasing number of topics—and that exposure must be effective. In previous statements supporting federal programs, the Society has recommended that the federal government continue and expand its role as a major supporter of research and development in the use of computers and other information technologies in science education. Further, the federal government should continue and expand its role as the principal supporter of basic research in science education, especially through efforts that increase the interaction between and among natural scientists, cognitive scientists, and teachers.

Chemistry Education for Future Chemists

The education of today's chemistry graduates has been constructed with much care and with strong, but sometimes inconsistent, support from the federal government. The result is that high-quality chemists are being produced in numbers that appear reasonably satisfactory for the health and security of the nation. By no means does this imply that education of chemists can now be ignored. There are deficiencies that must be addressed now, and maintenance of current performance standards requires consistent planning and execution.

The most critical deficiency in the education of today's chemists is inadequate instrumentation for teaching. Much of the work of today's chemist requires sophisticated instrumentation, and this is unlikely to change in the foreseeable future. Many of the instruments are expensive relative to the academic budgets available for their purchase. Some colleges even lack sufficient basic equipment such as balances and pH meters. Most instruments should be considered obsolete at an age of seven or eight years, and maintenance often becomes excessive at that time. Yet, according to a recent ACS survey, that *terminal* age is actually the *average* age of *both* research and teaching instruments in academic institutions.

*Submitted by Moses Passer, Director, Education Division, American Chemical Society.

Some federal programs seek to address this matter, but they need to be expanded greatly and more colleges made eligible for instrument purchase and maintenance. One major gap is found in the fact that the two-year colleges that enroll about one-third of all chemistry students are ineligible for assistance from current programs.

The maintenance of instruments is a critical problem, particularly at smaller colleges. The ACS *Tomorrow* report recommends the addition of funding to the budgets of college instructional instrumentation programs for developing cooperative mechanisms for the maintenance and repair of such equipment.

Concepts from polymer chemistry are applied daily by the majority of industrial chemists, but are absent from many chemistry curricula. Biochemistry, computer use, probability and statistics for experimental design, communication skills, chemical information retrieval, safety, and chemical economics all impact very directly on the effectiveness of new chemistry graduates, but are frequently absent from their experience. New courses, or additions and topic replacements in existing courses, must be developed to respond to the ever-broadening environment in which chemistry is practiced in today's world.

Chemistry courses for future chemists concentrate increasingly on the principles that underlie current research and, to a lesser extent, practice. The result is a weakening of historical perspectives and humanistic values in terms that place chemistry in our culture. Unless there is better integration of science and chemistry with the totality of the intellectual enterprise, renewed emphasis on science awareness and literacy could simply widen the gap between the "two cultures." Support is needed for summer workshops and other mechanisms that bring together teachers of chemistry, natural sciences, engineering, the arts, the humanities, and the social sciences to study issues of common societal and intellectual concern so that the fruits of such study may be applied directly to the improvement and expansion of multidisciplinary instruction. Existing federal programs should support this effort and consider expansion. Additional faculty support for participation should come from their institutions and from the discipline-oriented associations.

Chemistry Education for Future Voters and Decisionmakers

Misunderstanding of science is widespread, and the public understanding of chemistry is poor. Too little science is taught in the elementary schools. Too few teachers of chemistry in high schools are well-grounded in the subject. Laboratory exercises are disappearing from the general chemistry education of students in both high schools and colleges. Applications of both information technology and discoveries about learning are occurring haphazardly. The quality of instruction and qualifications of teachers at the undergraduate level in all types of colleges are a part of this problem, their enhancement offers an opportunity to contribute significantly to the solution.

The recommendations of highest priorities that the Society makes to the U.S. government have to do with improvements in the qualifications of teachers and in the quality of instruction. A broad spectrum of in-service workshops, short courses, and institutes for teachers offers the best hope for improving and maintaining the qualifications of those who teach, at every level; these programs would usually need to be offered through colleges and universities and would be designed to meet the needs at college and precollege levels. We recommend that the direct and institutional indirect costs of such programs, as well as certain of the participant costs, be provided by the federal government at an annual level of $200-250 million. State sharing of the total costs would be expected through support of released time, additional funds for operations, etc.

Today, colleges find many students poorly prepared for college-level work—and remedial courses must be taken. At the same time, the interaction in the laboratory between nature and the student is an essential ingredient of education. The Society believes that concerted efforts are needed to increase college entrance requirements and high school graduation requirements for both laboratory science and mathematics. These efforts must be shared—any one organization or any one advertising campaign is inadequate for the job that must be done.

Laboratory science requirements for the baccalaureate degree for the general student need to increase to 10 percent of the total credits for graduation. This increase must be accompanied by steps to assure that the chemistry taught to non-scientists is sound, informative, interesting, and useful. To non-scientists, courses for chemistry majors give detail to the point of obscuring the forest with the trees. The common approach to this problem is to create "watered-down" courses that often look trivial to the student and embarrass the professor. Satisfying courses that are not condescending, patronizing, or apologetic do exist and are given at some colleges and universities. Vigorous efforts to offer such courses elsewhere at both lower-division and upper-division levels are likely to pay huge benefits in improved public understanding of chemistry. Courses that attempt to bridge the culture gap between scientists and non-scientists would be particularly effective. Support for experimentation in course designs and appropriate instructor preparation should greatly benefit society.

Clearly, the audiences described above are poorly served when pressures for efficiency drive curricula toward single approaches to chemistry instruction. Support is needed to prepare curricula and instructional materials for varied approaches to chemistry instruction that respond better to audience needs than do current materials. The availability of federal grants perhaps combining both research and instructional components would make it easier for faculty to devote more time to improving instructional quality at the college level.

Costs Versus Risks

Educational improvement costs money. Failure to make educational improvement costs much more. We cannot estimate the costs associated with less-than-well-informed citizen judgments, continued low standards of teacher certification, obsolete instruction and teaching materials, failure to assist teachers at all levels to improve their qualifications, or any of a host of consequences on inattention to the centrality of science in edu ation for contemporary life those costs are surely high.

American Chemical Society

The American Chemical Society is a congressionally chartered non-profit scientific and educational association with a membership of more than 1?5,000 chemists and ch[illegible] ngineers. Our membership includes educators and researchers at colleges and universities, scientists and engineers in government and industry, and some high school teachers and administrators.

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Undergraduate Science and Engineering Education

Task Force on the American Chemical Society's Involvement in the Two-Year Colleges*

In November of this year, the American Chemical Society sponsored an Invitational Education Conference entitled "Critical Issues in Two-Year College Chemistry." The goals of this conference were to identify the issues facing the chemistry teachers in two-year colleges and to make recommendations to the organizations capable of addressing these issues.

During the conference, it was discovered that many of the issues in two-year college chemistry teaching were also issues in the teaching of biology, physics, geology, and mathematics. The conference participants also realized that many of the issues confronting two-year colleges also confront small four-year colleges and universities.

It is the purpose of this document to convey to the National Science Board the recommendations of the conference participants relevant to the mission and objectives of the National Science Foundation. Additional recommendations will be made to other groups when the final conference report is produced in 1986.

The Two-Year College Role in Undergraduate Science and Engineering Education

Two-year colleges make a substantial contribution to undergraduate science and engineering education in the United States. The magnitude of this contribution is undeniable. For example, 55 percent of all freshmen entering college are enrolling in two-year colleges. Of all students enrolled in higher education, 33 percent are enrolled in two-year colleges. The nation's community colleges enroll 42 percent of all Black college students, 54 percent of all Hispanic college students, and 43 percent of all Asian college students. During the 1982-83 academic year, 21 percent of the University of California System graduates, 50 percent of the California State University System graduates, and 50 percent of the University of South Florida graduates had previously attended a two-year college. California and Florida may not be typical of current trends in community college transfers to senior institutions because these two states certainly have the most highly developed two-year college systems. However, because these states are in the vanguard of higher education, these trends will soon become national trends.

Recommendations

Some of the issues facing two-year colleges and other providers of undergraduate science and engineering education are of such magnitude that only the federal government, acting through the National Science Foundation in its role as the leader in science research and education, can effect the needed changes.

The participants in the 1985 Invitational Education Conference of the American Chemical Society recommend that NSF take the following actions:

Professional Growth for Faculty. NSF should:

1. Vigorously support professional growth and development for two-year college science teachers, at a minimum of personal expense, by:

   —Providing updated versions of summer conferences and institutes, Chautauqua courses, regionally oriented College Science Improvement Programs, and faculty fellowships;

   —Supporting an extension of the Institute for Chemical Education that would serve as a training mechanism for two-year college science teachers; and

   —Supporting the development and dissemination of materials that would provide in-service training to science faculty who are unable to attend conferences and institutes.

Scientific and Instructional Equipment. NSF should:

1. Modify the College Science Instrumentation Program so that two-year colleges are eligible for funds. This program should also help two-year colleges purchase the equipment necessary to offer training programs in the emerging sciences and in science-related technologies.

2. Establish a new program that provides funds to help two-year colleges purchase instruments costing less than $2,000. This program should use professional scientific societies or state two-year college agencies to administer a large fund and make smaller disbursements to individual colleges submitting proposals.

*Submitted by William T. Mooney (Chair, Task Force on the American Chemical Society's Involvement in the Two-Year Colleges), El Camino College; Harry G. Hajian, Community College of Rhode Island, Donald E. Jones, Western Maryland College, Robert A. Schunn, E. I. du Pont de Nemours & Co.; Tamar Y. Susskind, Oakland Community College, Katherine E. Weissmann, Charles Stewart Mott Community College, and E. James Bradford, ACS Liaison, American Chemical Society.

3. Support cooperative instrument repair services similar to the regionally based CHEMS program at the Georgia Institute of Technology. This program consists of a mobile instrument repair service that is utilized by a number of academic institutions in the Georgia Tech area.

4. Continue support for existing programs in the new instructional technologies, such as Project Seraphim, so that these programs remain at the cutting edge. The National Science Foundation should also establish new programs to initiate projects in the new instructional technologies utilizing compact disks, video disks, and teleconferencing. These programs should provide a delivery system to bring enhanced learning to students as well as to bring additional professional development opportunities to faculty members.

5. Establish a program that funds a number of regionally located and well-equipped science instructional laboratories to serve as models of excellence.

Programs for Students. NSF should:

1. Establish a program to support the improvement of undergraduate science education for students not specializing in science. Projects funded under this program should emphasize firsthand experience with science at a level that prepares individuals for responsible citizenship in an increasingly technological society. These projects should focus on laboratory exercises, demonstrations, and other activities that hold students' interest. The existing NSF-supported CHEMCOM (Chemistry in the Community) project is an example of what is needed. This existing project could be adapted to the needs of the first two years of undergraduate education.

2. Modify the existing Undergraduate Research Participation program, or establish a new program, to encourage student-oriented research directed by two-year college faculty. A program such as this could provide an early positive experience in science for students, especially for minority and economically disadvantaged students.

3. Establish a loan program, similar to the National Defense Education Act Loan Program, to help economically disadvantaged students earn a degree in science or engineering. These loans should be available to both two-year and four-year college students.

Articulation and Cooperation NSF should:

1. Establish and support a body to coordinate, on both national and local levels, articulation among the sciences at the lower-division level. This body could be similar in structure and mission to the Triangle Coalition that now serves precollege education. Once established, this body could operate a study center to collect and disseminate information, and to provide guidance to the federal government in adapting programs to better serve science and engineering education at the lower-division level.

2. Establish and support a body to encourage, on both regional and national levels, articulation of two-year college science programs with secondary schools, four-year schools, and industry. Cooperation of schools in close proximity is needed especially in the areas of assessment, placement, and remediation. Cooperation with local industry is needed to ensure that college programs are providing graduates that meet the industrial needs of the community.

3. Establish a program that supports consulting activities that bring the expertise of nationally known scientists to the colleges that need this service most. These consultant services could provide guidance for all types of articulation as well as serve as an external evaluating mechanism to enhance the quality of education in science and engineering programs.

Concluding Remarks

The community colleges are clearly serving a vital role in the preparation of America's next generation of scientists and engineers. We call upon the National Science Foundation to recognize the tremendous contribution two-year colleges are making in the national interest and to establish and support programs for lower-division science and engineering education at a level consistent with the task.

Letter from the American Society for Engineering Education

February 27, 1986

Dr. Homer A. Neal
Chairman
Committee on Undergraduate Science
and Engineering Education
National Science Board
Washington, D.C. 20550

Dear Dr. Neal:

The American Society for Engineering Education has under way a two-year program, the Quality of Engineering Education Project (QEEP), which is sponsored by thirty major corporate employers of engineers. Four university-industry task forces are addressing some issues of critical importance to the continued quality of the nation's engineering schools in the years ahead. Each task force produced at the end of the first year of the project a report giving its preliminary findings and recommendations. Summaries of those reports can be found in the December 1985 issue of *Engineering Education*.

Each task force is now in the process of revising its preliminary report to take into account suggestions received from the education and industrial communities at a large number of meetings beginning in October 1985 and continuing through April 1986. The final report of the project is due for publication in September 1986. There are, however, three specific recommendations directed to the National Science Foundation which will without question appear in the final report. Since these bear directly on the topic being addressed by your Committee, I am calling them to your attention now rather than later in the year in the hope that they will be considered in the report of the Committee to the National Science Board.

In the attachment I have listed the three recommendations and added a brief rationale for each. If there are questions which you or members of the Committee have regarding any of them, please call on me.

Sincerely,

W. Edward Lear
Executive Director
American Society for Engineering Education

Attachment

Attachment

Recommendations to the National Science Foundation from the ASEE Quality of Engineering Education Project

Task Force on the Undergraduate Engineering Laboratory

Charge. How to bring laboratory instruction into full partnership with the rest of the engineering education program.

Background The undergraduate engineering laboratory is beset with a multitude of problems—the well-documented obsolescence of equipment and facilities is a major one, but equally important is that the reward system and load allocation do not encourage faculty participation in laboratory development and instruction.

The task force will make some recommendations aimed at strengthening the present system, but has posed the question of whether there are alternative ways of conducting the laboratory phase of engineering education. For example, are there appropriate combinations of simulation and hands-on experience that could ease the equipment demands and at the same time present an exciting and rewarding challenge for the faculty?

Recommendation. The National Science Foundation should support some experiments in innovative approaches to laboratory-oriented studies in engineering. These could include the use of simulation, computer-aided measurement and experimentation, and the use of modern educational technology.

Task Force on Continuing Professional Development of Faculty

Charge. How to ensure technical and pedagogical currency of engineering faculty throughout their teaching careers.

Background. Present methods of faculty development in the engineering colleges are found to be ad hoc and totally inadequate for the needs of a profession in which the knowledge base is changing so rapidly. The task force is recommending that each engineering school put in place a structured program appropriate to its local situation and applicable to every faculty member.

Recommendation. The National Science Foundation should support several experiments in the design and implementation of faculty development programs which could serve as models for various types of institutions (public, private, research, undergraduate, etc.).

Task Force on the Use of Educational Technology

Charge. To recommend a viable approach to integrating appropriate technology into the engineering education process of the nation over the next decade.

Background. There seems to be little question that the use of technology, and particularly the computer, in the education process will produce some dramatic changes in the years ahead in the teaching of engineering, bringing the classroom more in line with changes taking place in engineering practice. The task force is addressing several issues that will result from such change—intellectual property rights policies, mechanisms for development and distribution of software and courseware paralleling those now available for textbooks, standardization of hardware and software, use of technology for lifelong learning, reward systems for course development in the new modes, improving the effectiveness and efficiency of engineering education, etc. Several major experiments are under way in the integration of technology into the engineering program, many of which are dependent on a large grant of equipment and services from a computer vendor. Almost all engineering schools are beginning some move into the use of technology, but there is no concerted effort that will prevent much "reinvention of the wheel."

Recommendation. The National Science Foundation should fund some innovative, model approaches to the integration of technology into engineering programs, particularly those that emphasize the maximum benefit from available technology for minimum investment and, at the same time, make the education process more cost-effective. The object would be to produce models applicable to any of the approximately 290 engineering colleges in the nation.

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Letter from the American Society of Plant Physiologists

January 1, 1986

Dr. Homer Neal
Chairman
Committee on Undergraduate Science and
Engineering Education
National Science Board
Washington, D.C. 20550

Dear Dr. Neal:

It is our understanding that the National Science Foundation is looking into undergraduate science education. The American Society of Plant Physiologists (ASPP) would like to express its support for any program that would help to strengthen, extend, and improve the quality of education in our colleges and universities. We would welcome a chance to express our views and offer our support for any of the National Science Foundation's efforts to re-establish support for undergraduate teaching or for research by undergraduate students.

The American Society of Plant Physiologists was established in 1924, and has a current membership of about 5,000. We publish a monthly journal, *Plant Physiology*, with three volumes a year, as well as a monthly news bulletin. It is our conviction that one of the roles of a professional society is to foster excellence in teaching, as well as research. We have established a Committee on Education, which will be seeking ways to encourage excellence in teaching. There was a well-attended workshop on teaching at our 1985 annual meeting; a formal session on this topic is planned for the next annual meeting.

The plant sciences are undergoing a renaissance with the realization on the part of society that the green world supports the life of the planet. We need to extend knowledge of how plants function to a larger group of undergraduates, with the hope that some of the best and brightest minds will make plant physiology a career. The principles of plant physiology extend across much of biology, biochemistry, and the study of evolution.

We look forward to learning of the outcome of the current hearings.

Sincerely,

Charles J. Arntzen
President
American Society of Plant Physiologists

Undergraduate Science and Engineering Education

Association for Affiliated College and University Offices*

The Association for Affiliated College and University Offices (AACUO) includes college and university affiliate and associate members from a broad spectrum of institutions: large and small; public, private, and church-related; undergraduate colleges and comprehensive universities. For the last two years, a universal concern voiced by these institutions has been the problem of aging and obsolete instrumentation (see attached summary of a sampling of AACUO members' instrumentation needs). A related problem in undergraduate science departments is the need for assistance to provide the time for faculty to revise curriculums to use updated equipment effectively. Further evidence of the universal need for improved instrumentation is contained in the applications submitted and awards made in the National Science Foundation's College Science Instrumentation Program. The institutions and individual faculty represented in the awards list represent a broad spectrum of American higher education.

The emphasis on need for modern scientific instrumentation has surfaced as a workable and partial solution to the frustration of faculty over lack of concern for the state of undergraduate science education and the lack of a related national policy. There has been a sustained policy to support basic research, but there has never been a policy—sustained or temporary—for the support of undergraduate science instruction that is critical to the supply of competent researchers.

It is recognized today that the college science teacher must keep up with the field and continue to pursue research. Good teaching must be based on current information and state-of-the-art laboratory methods to meet even minimum expectations of students. Undergraduate students today have a right to expect some hands-on research experience if they are to consider graduate school and/or a career in industry or academe seriously. The college science teacher cannot provide such research training without doing research. Studies, surveys, and polls abound pointing to unrest among faculty and a decline of interest in remaining in and considering a career in academe. This trend is frightening. Unless a national policy is established with commitment to the encouragement of good teaching and research in all of our colleges and universities, the scientific manpower in this decade will not be adequate to maintain national strength in scientific and technological advancement. The manpower will not be adequate to develop a scientifically literate public.

We urge the National Science Board to establish a national policy that recognizes the critical role of undergraduate science teachers in the entire science enterprise. The college teacher is the trainer of future elementary and secondary school science teachers and the producer of scientifically literate citizens and candidates for graduate school and of future college teachers and researchers. We suggest that the proper role of the federal government is to encourage and support high-ability undergraduate science teachers in all kinds of institutions: two-year and four-year colleges, technical schools, and undergraduate divisions of comprehensive universities.

We further suggest that within the framework of this policy the focus should be on support of talented individuals rather than institutions. The emphasis on providing support for individuals as opposed to institutions is analogous to the present debate over the support of "big" science through such mechanisms as centers and the sustained support of individual scientists which has proven to be productive in the past. We are not suggesting one approach at the total exclusion of the other. We do suggest that the first priority should be for the support of the talented individual. The National Science Foundation has a proven track record of managing a peer review process to ensure quality. Thus, the "star" in a small, relatively unknown or regional institution will be recognized. The faculty in institutions with a long history of productivity in the sciences will also be represented in the selection process.

We suggest that the place to start implementation of a national policy is with a broadening of the instrumentation program in the following manner:

1. Open the competition to science faculty in all undergraduate-level programs in accredited institutions.
2. Provide funds to be used for a combination of instrumentation, faculty time, and student assistance.
3. Limit the cost-sharing requirement of such a program to the instrumentation component.
4. Seek and/or provide substantial support for the program.

This support mechanism would become the teacher-researcher's version of a scientific research grant. To justify concentration on this broadened instrumentation pro-

*Submitted by Flora Harper, President, and Julia Jacobsen, Vice President, Association for Affiliated College and University Offices gram further, we suggest that none of the goals for improved science instruction and research in undergraduate settings can be achieved without modern instrumentation, and, quoting from the present College Science Instrumentation Program guidelines, "Students in science and engineering courses—majors and non-majors alike—must have experience with suitable, up-to-date equipment in order to become involved in the work that is at the heart of scientific understanding and progress."

If and when equipment is replaced, the institutions are faced with the problem of making effective use of the new equipment. Instead of performing old experiments in the same way on new equipment, faculty need to devise new experiments to take advantage of the additional capabilities and increased efficiency of the new equipment. This requires revision of curriculum, courses, and related laboratory work.

In summary, we need a national policy committed to sustaining a strong undergraduate science infrastructure in all institutions of higher learning for preparation of future scientists, engineers, teachers, and leaders in business and government. The initial mechanism for implementation of this policy should be through support on a competitive basis of instrumentation and faculty time to attract the most talented and highly qualified science teachers in this country.

Attachment

Instructional Scientific Equipment Needs in Undergraduate Institutions

Telephone interviews were conducted with deans and grants officers in a sample of 11 colleges and universities, all of which are members of the Association for Affiliated College and University Offices, in an effort to identify instructional equipment needs in undergraduate institutions. A summary of the responses shows the following.

1. The age of vital instructional scientific equipment in these institutions ranged from 5 to 20 years old.
2. The most frequently mentioned need was microcomputers. NMRs, electron microscopes, mass spectrophotometers, and thin slicers were the next most frequently mentioned equipment needs.
3. No school had found significant innovative ways to finance instructional scientific equipment. Several had made one-time deals with local industry.
4. The largest single source of support was the National Science Foundation and its College Science Improvement, Local Course Improvement, and Instructional Scientific Equipment programs, which have been defunct for five years. The current College Science Instrumentation Program was perceived to be too competitive and not open to undergraduate schools with a Ph.D. program in any science.
5. Private support was limited and sporadic.
6. The sources mentioned most frequently for one-time support were:
   —Camille and Henry Dreyfus Foundation (chemistry equipment),
   —Exxon Education Foundation (microcomputers),
   —Pew Memorial Grant (mainframe computer), and
   —ARCO Foundation (miscellaneous equipment).
7. The effects of these equipment needs on students entering graduate school are hard to determine; the respondees provided no significant information.

Undergraduate Education

Council of Scientific Society Presidents*

At the December 4, 1985, meeting of the Council of Scientific Society Presidents (CSSP), the important question of the quality of undergraduate education was discussed extensively, in the context of the recent review of this matter undertaken by the National Science Board. These deliberations resulted in the preparation of the following statement setting forth the views of CSSP:

> "The Council of Scientific Society Presidents endorses the initiative of the National Science Board in undertaking a study of undergraduate science, mathematics, and engineering education. The undergraduate years are a crucial period in the education of all who are headed for careers in mathematics, science, or technology. As was well-documented by earlier testimony to the Board, signs of weakness abound in science and mathematics programs at the undergraduate level. Because of severely inadequate funding levels for undergraduate education, the National Science Foundation has been unable to provide national leadership and resources to help bring about necessary improvements. Therefore, we strongly urge the National Science Board and the National Science Foundation to restore strong support for collegiate science, mathematics, and engineering education."

Attached is a statement providing information on the membership of the Council and the participating societies, which represent a total membership of nearly 500,000 scientists.

Attachment

What Is CSSP?

Members of CSSP are the presidents-elect, presidents, and immediate past presidents of about 30 supporting societies (listed below) with a combined membership of over 500,000. In addition, the members of the Executive Board (also listed below) are members of CSSP. The Council, a non-profit organization, is supported by voluntary contributions of the supporting societies.

The Council was founded in 1973 and, quoting from the bylaws, has the following purposes:

"To facilitate coordination and cooperation between the various scientific disciplines and to provide a forum for the exchange of information and viewpoints;

"To consult and work with government and private agencies to improve the free flow of scientific information and to determine which scientific disciplines can be of the greatest assistance in given areas;

"To develop points of view through meetings or study groups and issue reports representing its conclusions. Said reports shall deal broadly with science and technology-related problems or policies of a national or international scope."

The CSSP has become a voice for science that is listened to by both the executive and the legislative branches of government. It has been addressed by the science advisors to both Presidents Carter and Reagan, as well as by legislators interested in science. The Council also has taken the initiative in a number of important issues affecting science.

The Council established the CSSP Award for Support of Science in 1983. The first recipient was Congressman Don Fuqua, long-time Chairman of the House Science and Technology Committee, and the second was Dr. Frank Press, President of the National Academy of Sciences.

The Council has two meetings of one and one-half days duration each year; both are held in Washington, one in the spring and one usually after Thanksgiving. The meetings are customarily attended by not more than 40-50 participants. In this intimate setting, the Council conducts its business and hears timely presentations on issues of science and science policy by invited speakers from the legislative and executive branches of government, academe, and the private sector. In addition, council members are, on occasion, asked to present organizational and public policy concerns of their own societies.

Beyond the formal program, attendance at the meetings affords an opportunity to get acquainted with fellow presidents and to exchange views and experiences on an informal basis.

The Executive Board, elected at the fall meeting, is made up principally of past presidents of supporting societies, people who can give some time to CSSP affairs. The Executive Board meets in conjunction with the semiannual meetings of CSSP and on two other occasions to organize those meetings and address issues as they arise.

*Submitted by Eric Leber, Administrative Officer, Council of Scientific Society Presidents.

Periodic briefings are intended to keep the membership informed on timely issues of science policy.

CSSP Officers and Membership 1985

Executive Board

Robert P. Williams, Chairman
Warren D. Niederhauser, Chairman-Elect
Joe P. Meyer, Secretary
James D. D'Ianni, Treasurer
Richard D. Anderson, Member-at-large
Tomuo Hoshiko, Member-at-large
L. Manning Muntzing, Member-at-large
Stephen S. Willoughby, Member-at-large
Eric Leber, Administrative Officer

Members

Kurt M. Dubowski
American Association for Clinical Chemistry

James A. Purdy
American Association of Physicists in Medicine

Anthony P. French
American Association of Physics Teachers

Ellis K. Fields
American Chemical Society

Robert E. Newnham
American Crystallographic Association

Edd R. Turner
American Geological Institute

Willard Marcy
American Institute of Chemists, Inc.

Irving Kaplansky
American Mathematical Society

Joseph M. Hendrie
American Nuclear Society

Arthur R. Mlodozeniec
Academy of Pharmaceutical Sciences

Robert R. Wilson
American Physical Society

Robert Perloff
American Psychological Association

Daniel Branton
American Society for Cell Biology

Rita R. Colwell
American Society for Microbiology

Edwin Krebs
American Society of Biological Chemists

Joe H. Cherry
American Society of Plant Physiologists

Adele Goldberg
Association for Computing Machinery, Inc.

Seymour Parter
Conference Board of the Mathematical Sciences

Joe W. Grisham
Federation of American Societies for Experimental Biology

William F. Prokasy
Federation of Behavioral, Psychological & Cognitive Sciences

William J. Bair
Health Physics Society

John D. C. Little
Institute of Management Sciences

Lynn A. Steen
Mathematical Association of America

F. Joe Crosswhite
National Council of Teachers of Mathematics

Alice J. Moses
National Science Teachers Association

Michael E. Thomas
Operations Research Society of America

Robert R. Shannon
Optical Society of America

Gene H. Golub
Society for Industrial and Applied Mathematics

Paul De Weer
Society for General Physiologists

W. R. Schowalter
Society for Rheology

Reccmmendations on Undergraduate Science and Engineering Education

Council on Undergraduate Research*

Several studies show that decreasing numbers of the most able students in the United States are choosing careers in the sciences. Recently, the important role of the predominantly undergraduate colleges in motivating and preparing undergraduates for scientific careers has again become more widely understood. For example, the report of the National Research Council's Committee to Survey Opportunities in the Chemical Sciences, chaired by George Pimentel, states, "In fact, the key role of the four-year colleges in meeting our national technical manpower needs must be recognized." The close partnership of faculty and students in classes and research projects in four-year colleges plays an important role in this regard. In addition, good science often results from undergraduate research. There are important benefits to the nation and to the fabric of science education in maintaining strong science programs at predominantly undergraduate colleges.

The Council on Undergraduate Research (CUR) has been active for several years in understanding the roles of and encouraging research in the undergraduate environment. In order to maintain and strengthen the nation's science infrastructure, CUR recommends that the National Science Board consider the following critical areas in the NSF role in science and engineering education:

1. That the successful Research in Undergraduate Institutions (RUI) program and Regular Program Support (RPS) for research at predominantly undergraduate colleges be continued and strengthened.
2. That the College Science Instrumentation Program (CSIP), which has begun to meet the great need for up-to-date instructional equipment in the undergraduate colleges, be expanded at least to include eligibility for all colleges and universities that are eligible for the RUI program. This would require an expansion from $5 million to $10 million in the program. A strong case could be made to make this outstanding program available to the research universities as well, with an appropriately increased budget.
3. That a program to promote undergraduate research, akin to the successful Undergraduate Research Participation (URP) program which was discontinued in 1982, be established to support research in departments where it is not yet possible to meet the stiff competition of the RUI program or regular program support.
4. That an expanded program of professional development be established for the science faculties of four-year colleges. This is a natural area for partnership betwe NSF and the four-year colleges. Faculty sabbaticals now provide for part of an academic year at most. An NSF grant program for research leaves (expanding the role of the Research Opportunity Awards) or for the development of projects in science and engineering education could pay handsome dividends.
5. That ways be developed to assure good coordination between the research divisions and the Science and Engineering Directorate at NSF. As good teaching and research go together in the undergraduate sector, good coordination between the research and education wings of NSF will provide the greatest effectiveness for programs in the undergraduate area.

*Submitted by Jerry R Mohrig, Chairman, Council on Undergraduate Research.

References

The Council on Undergraduate Research, brochure

A proposal to the National Science Board on Support for Undergraduate Research, December 1982.

"The Education of Scientists The Future of Research at Undergraduate Colleges " Delivered at a Conference at Colgate University, July 1985, by Robert H Edwards, President of Carleton College, Northfield, MN.

"Undergraduate Research Gaining a Higher Profile," *Chemical and Engineering News*, August 19, 1985.

Statement to the Panel on the Health of U S Colleges and Universities, White House Science Council, September 20, 1984, by Harlan F. Foss, President of St Olaf College, Northfield, MN.

Statement on Undergraduate Research from the *CPT Newsletter*, Committee on Professional Training, American Chemical Society, Summer 1985

Undergraduate Science Education

East Central College Consortium*

We are here representing the East Central College Consortium (ECCC), a group of eight small undergraduate liberal arts colleges founded in the mid-1800s. The member colleges are Bethany College, West Virginia; Heidelberg College, Hiram College, Marietta College, Mt. Union College, Muskingum College, and Otterbein College all in Ohio; and Westminster College in Pennsylvania. All are within a 200-mile radius of each other. The consortium was founded in 1966 to further the interests and to strengthen the individual colleges through consortial sharing and consortial action.

We wish to present briefly three recommendations to the National Science Board for the development of National Science Foundation programs in science education to meet the needs of undergraduate science instruction.

That undergraduate instructional scientific equipment is a major need of all institutions has been presented to the National Science Board in eloquent terms. We join the litany. We recommend steady and enlarged NSF support for instructional scientific equipment for the following reasons:

- Scientific equipment costs have escalated beyond the reach of even the most affluent small college budgets. Increasingly, college budget balancing is achieved by excluding purchase of the new and sophisticated scientific equipment that first-class training in science demands.

- Donations from industry often consist of equipment of short life and prohibitive repair costs. Such donations, however well-intentioned, cannot be relied upon as an adequate and steady resource for undergraduate colleges.

- Foundation support sounds better in theory than it materializes in fact. Few foundations are even interested in considering the support of instructional scientific equipment, and no single foundation has emerged that is able to provide a steady national program for this purpose.

For these reasons, then, we think that NSF is the only feasible resource to which colleges may turn for essential instructional scientific equipment. We recommend expansion of the program with awards determined as they are now, and have been in the past, through open competition judged by peer review.

Because we believe that teaching and research constitute a continuum, our second recommendation is to ask for an enlarged program of support for individual investigators who may be pursuing their research in an undergraduate setting. We recognize that these are times of national budgetary difficulties, and we suggest that available funds be concentrated on a program to support individual investigators rather than to support institutions. If a choice has to be made (and in present conditions it may be necessary), we recommend support of the individual rather than the institution. Through support of the individual, the students will inevitably gain and so will the institution.

Undergraduate colleges typically emphasize flexibility in programs and facilities. We urge that the NSB keep this same principle in mind. We are in colleges where the faculty of the institution should be regarded as competitive for research—not merely the institution itself. To have any list of "research colleges" is misleading. It will change from year to year, and, in all honesty, any school not on a list could muster evidence to indicate that it should be on the list.

In the ECCC colleges, we all have faculty members who have pursued original research with government grants. Where our faculty members have been recipients of basic research grants from NSF and NIH, the grants were awarded because of individual initiative and planning—not that of the college or a professional grant writer. To have faculty at the typical liberal arts college excluded or stifled from government-funded research would be a mistake indeed. Research at our colleges involves students as integral research partners. This ought to continue as an ideal that we can offer to the most prestigious institutions.

Our third and final recommendation is for the continued and strengthened support of NSF programs in precollege education. The need for upgrading the knowledge of existing elementary and high school science teachers has been well documented. ECCC colleges have been steadily involved with regional and local educational agencies and have contributed services in addition to staffing workshops and seminars funded by the National Science Foundation and the National Endowment for the Humanities.

In summary, we are recommending additional support for three broad programs that will result in substantial

*Submitted by Sherrill Cleland, President, Marietta College, for the East Central College Consortium.

ERIC

strengthening of science education at the elementary, high school, and undergraduate college level. We advocate that support be open competitively to the many different kinds of institutions of higher education that form the healthy mix, the diversity, that is the strength of higher education in the United States.

We attach a description of one of the premier research programs in one of our colleges.

Attachment

Innovative Research at Private Liberal Arts Colleges: The Heidelberg College Water Quality Laboratory

While private liberal arts colleges are known primarily for their emphasis on teaching, significant, innovative research programs can also develop within such institutions. These research programs can begin as original responses to local situations and evolve into programs with national significance. The research programs of the Water Quality Laboratory at Heidelberg College provide an illustration of this type of development.

In 1967, instructors in the introductory biology and chemistry courses at Heidelberg incorporated analyses of water samples from local rivers into the laboratory portions of their courses. The instructors subsequently initiated faculty research programs in which they specialized in studying the transport of agricultural pollutants in streams and rivers during runoff events and floods. This research program was among the first in the country to provide quantitative data on the magnitude of agricultural nonpoint source pollution.

The academic freedom within private liberal arts colleges coupled with the absence of a structured research program allowed the Heidelberg faculty to develop a program to address information needs as they observed them. They noted that neither land-grant universities nor government agencies were adequately examining the impacts of intensive agricultural land use on regional water quality, i.e., the water quality in streams, rivers, and lakes. For example, there were no systematic studies of the occurrence of currently used herbicides in streams, rivers, or even drinking water.

In 1980, the Water Quality Laboratory initiated a study of currently used herbicides in streams and rivers. They observed that during runoff events in May and June, high concentrations of many pesticides were present. They also observed that these herbicides passed directly through water treatment plants and consequently were also present in the finished tap water of several cities in northwestern Ohio. In 1984, when the U.S. Environmental Protection Agency's Office of Pesticide Programs initiated its special review of the herbicide Lasso, the Water Quality Laboratory was the source of 70 percent of the data on drinking water contamination and 60 percent of the data on surface water contamination by Lasso available in the entire country.

The programs of the Water Quality Laboratory represent the closest approach in the United States to a large-scale, long-term comprehensive study of the impacts of intensive row crop agriculture on regional water quality. Since 1974, the laboratory has analyzed more than 50,000 water samples from area rivers. The EPA is now relying on these data to calibrate and validate pesticide runoff models that are the basis for both regulatory and policy decisions. Large-scale agricultural nonpoint source pollution control programs are now being launched in these regions. The baseline data collected by the Water Quality Laboratory provide unique opportunities to evaluate the effectiveness of these programs.

The Water Quality Laboratory currently has a staff of seven full-time researchers. Its programs are funded entirely by grants from government agencies, industries, and foundations. The uniqueness of the laboratory's programs is reflected, in part, by an absence of counterpart funding programs. That there should be a dearth of programs addressing such fundamental issues as the relationship between food production and regional water quality does not speak well for relying solely on large research institutions and government programs. Private liberal arts colleges can be the source of research programs that respond in unique and original ways to local, regional, and national needs.

Women's Underrepresentation in Science

Texas Woman's University*

A career in science demands an unusual dedication to the profession. Because the information pool is continuously changing and expanding, it is never possible to complete the training process. Individuals committed to teaching and/or practicing the discipline of science must continuously remain students of the field. This requires a constant reading of the literature within one's specialized discipline. However, it is also essential that the scientist remain abreast of current technical developments in peripheral fields.

Careers in science may be conveniently divided into two categories: (1) careers where individuals practice and/or relay already acquired skills and (2) careers where individuals are actually engaged in the art of science. The first category of job descriptions might include teachers, technicians, or science journalists and, while underrepresented by the female sex, has traditionally captured more of those females trained in science than has the second career category. The second career category has traditionally been most discriminatory to the female. Such discrimination has been both overt and covert, and, while such overt actions have been reduced in recent years, the less tangible discriminatory practices are still in place.

Because of the rapid rate at which scientific knowledge changes, it is impossible for an individual to lose contact with the field for one or two years and hope to re-enter the scientific professions successfully. Success as a scientist requires the continuous publication of research findings and the consistent interaction with scientific peers. Since scientific research requires specialized equipment of costly nature, excellence in research requires adequate funding from both federal and university levels. Federal funding is difficult to achieve under the best of circumstances and requires evidence of continued productivity. Therefore, one or two years without publication leads to a vicious circle. In order to obtain federal or private funding, it is essential that the individual be able to demonstrate: (1) ability to ask important questions, (2) knowledge of current problems and techniques in the field, (3) evidence of consistent research productivity, and (4) location in an environment that is sympathetic to the pursuit of scientific research. Grant funds cannot be obtained when an individual has low productivity, and productivity cannot be achieved without grant funds.

*Submitted by Carolyn K. Rozier, Acting Vice President for Academic Affairs, Texas Woman's University

The ability to remain competitive in the scientific professions is therefore difficult for any individual. For women, however, this commitment to excellence in science requires sacrifices not forced on the average male. As a consequence, fewer women than men actually enter scientific careers. In 1983, women comprised only 13 percent of all employed scientists and engineers, compared to about 44 percent of all employed persons. Of those who do begin a scientific education, fewer women survive as practicing scientists. This higher dropout rate reflects the continued existence of covert discriminatory practices by academic, scientific, and societal mores. Such discriminatory practices operate at two levels to reduce the number of women in science: (1) few women choose a career in science and (2) of those who do, few women remain in science.

Early Rearing Practices

Listed below are several factors that reduce the probability that women will enter scientific careers:

1. The female sex is traditionally viewed as less competent in scientific disciplines.
2. Perpetuating the female's lowered aptitude is the discriminatory practice in early training both in home and in the classroom.
3. Little girls are encouraged to participate in indoor activities (e.g., playing with dolls, engaging in craft and/or sewing activities, and assisting with the preparation of meals).
4. Little boys, on the other hand, are encouraged to "rough and tumble" in the outdoors, to participate in competitive games, and to accompany their parent(s) on hiking and/or other nature-related activities.
5. As a consequence of early discriminatory training, girls receive less knowledge about the world around them and are given less opportunity to query their parents about the environment in which they live.
6. Girls are expected to follow normative behavior, while boys are encouraged to be aggressive, investigative, and inquisitive. These latter attitudes to question and to consider alternative explanations are the very attitudes needed in scientific research.
7. The practice of science involves the act of viewing relationships between variables in the environment

and the art of asking questions about these relationships. Female children are given less opportunity to observe these relationships and therefore have less incentive to address questions about these relationships.

8. Reduced familiarity with objects leads to a reduction in curiosity about these objects and hence a reduced interest in science.

9. During early education, these early rearing practices are accentuated. The biological sciences require dissection of dead animals and/or exposure to insects or other creatures. The reduced familiarity by females with these creatures reduces their willingness to engage in these exercises.

10. Throughout the female's primary and secondary education, she is exposed to role models that reinforce the early training. Most successful scientists are male, and therefore the developing female is taught that women cannot enter these professions.

Several practices could be initiated to overcome these biases partially. A few of these are listed below.

1. Eliminate stereotypical treatment of children.

2. Teach questions and excitement of science prior to the introduction of dissecting procedures; in short, science teachers must be aware of the potential problems young women may have and attempt to overcome these with training and sympathy rather than with ridicule.

3. Encourage young girls to participate in science exercises. Since males are often more eager to engage in these procedures, it is possible for girls to avoid scientific contact throughout their early years. This reinforces their lowered familiarity with procedures, concepts, and questions and reduces their curiosity.

4. Successful female scientists should be introduced to girls in the early grammar classes, and this practice should be continued throughout the primary and secondary educational levels. Such exposure to successful role models could reduce the belief that women cannot succeed in science.

University Practices

By the time females have entered higher education, they have already been subjected to 16-20 years of social prejudice regarding the ability of women to succeed in science. However, they are also the victims of an educational process which inadequately prepares the female for university science instruction. As a consequence, the female has a lowered probability of success in science in the educational setting. The tragedy is that this reduced success stems from poor training rather than from poor aptitude. The university faces a particular difficulty, therefore, in educating women in science. Not only must the university recognize the need to inform women actively of their potential in scientific careers, but the university must also be willing to commit faculty to remedial training programs to accommodate the often reduced practice level of entering women. This remedial necessity is even more apparent when the university trains large numbers of "returning" students, where the women received their initial education 10-20 years earlier when sexual prejudices were both overt and covert. However, it is not sufficient to simply offer courses for women. The university must recognize that by college entry, the female has accepted the sexual biases and believes herself to be unable to compete effectively in scientific fields. Therefore, the remedial training must be both educational (fact finding) and psychological, thereby overcoming the prejudices the female has herself developed. Female role models can be valuable, but not sufficient, in this regard.

Professional Practices

Among employed women scientists, only 15 percent hold doctorates, compared to 23 percent of all men. Even when women successfully reject societal prejudices and are able to enter and complete a scientific education, several obstacles make it less likely that they will remain active members of the scientific profession. The reasons for the female dropout rate were discussed earlier but will be listed again below:

1. Success as a scientist requires total commitment to the profession. This is especially true in early years when scientists must establish their own laboratory and develop a record of scientific productivity. The course of scientific research cannot be completed within an 8 a.m.–5 p.m. day. Research questions cannot be solved within the confines of a traditional day. Sometimes it is necessary to perform research endeavors at midnight, at 9 p.m., or at 5 a.m., and it inevitably requires greater than an 8-hour day. In short, it is impossible to pursue a scientific career and lead a regular schedule. Men are much more successful in maintaining these irregular schedules because societal values enable the male to be away from the home, while the female is expected to participate in meal planning and rearing of children. Consequently, women must reject these traditional values and either choose not to marry and rear children or select a mate who is also immune to the traditional sex role typing.

2. It is not possible for a scientist to take one or two years off to produce and rear a child and then return to the scientific profession. By this time, the individual will have fallen so far behind scientific progress that the individual will no longer be competitive in the profession. Women in science must therefore choose either to avoid having children or to commit the children's rearing to a foster parent. Male scientists do not have to face this sacrifice because they are able to continue

in the practice of science while their wives take responsibility for education and rearing of the children.

3. Success in a scientific discipline generally requires a minimum of a Ph.D. and often two or three postdoctorate positions before an individual actually settles down to a first job. This usually necessitates two or three relocations between the Ph.D. and the first "real" job. Consequently, unless female scientists formulate relationships with males who are willing and/or able to relocate, there is a low probability of a long-term relationship. Women are therefore forced to choose between marriage and children or their career. Such choices are seldom faced by male scientists. Consequently, fewer women remain in scientific careers even though they may obtain the Ph.D.

4. Finally, practices within the scientific discipline itself reduce the probability that females will survive a scientific career. Various factors operate to produce a successful scientist. These include (1) quality research, (2) high visibility within the scientific community, and (3) production of quality graduate students. These accomplishments are much more difficult for women than for men. As mentioned above, continued production of quality research usually requires external grant funding, and, because of all the other factors alluded to in this statement, this is more difficult for women than for men. A recent NSF report indicates that women who apply for NSF funding are as successful as men in obtaining funds. However, considerably fewer women than men actually apply for these funds. Production of quality graduate students requires the female's location in a quality graduate program and accessibility to competent students. Because women do not have the same positions in the scientific community as are held by men, women will generally not be as competitive in attracting the top students in the country. Finally, visibility within the scientific community results not only from publications but from invited presentations, presence on scientific review boards, etc. The individuals in positions of power who are involved in selection of membership in such endeavors have not actively sought to include women as representatives. This is currently changing so that the number of women in positions of power is continuing to increase. However, even when women are selected to positions of power, there remain subtle discriminations that reduce their visibility within the community. Considerable scientific interchange and consequently scientific insight derive from dialogues between individuals in informal settings. This type of dialogue is more difficult for a male and a female than it is for a male and a male. Consequently, males and females engage in scientific discourse in a manner quite different from the comfortable interaction evidenced between two males. This places the female at a distinct disadvantage in the scientific community.

During the past five years, women in science have made a substantial improvement in some of the covert barriers to success. These have included the formation of women's organizations which have attempted to develop "old girls networks" to compete with the practices of the "old boys networks." In addition, women who have obtained positions of notice and/or power have attempted to include other women in those positions. Finally, the success of women who have entered scientific careers has forced male colleagues to accept these women as equal participants in the search for new knowledge. The presence of these successful women in science has not, however, been successfully communicated to the grammar and secondary educational levels.

TWU's Potential

Although no one institution alone can overcome all these barriers to the success of women in science, Texas Woman's University (TWU) plays a substantial role in reducing the educational biases toward women. TWU already participates in a science education program where faculty go to area schools and discuss science. Because of TWU's unique commitment to the education of women, the university is innovative in its encouragement and re-education of women to the potential opportunities in science. As such, we have some suggestions to encourage women in scientific careers.

Recommendations

1. Explicitly recognize that women have some insecurities about the entry into scientific disciplines This insecurity is well-known but largely ignored. Consequently, rather than facing and overcoming the prejudices, many women simply avoid any interaction with science.

2. Encourage the visibility of science instruction not only to the college student, but also to the secondary school student.

3. Encourage summer programs for women that enable high school students to work in science laboratories and hence overcome much of their fear about a career in science. This program would also foster excitement about scientific fields of inquiry.

4. Actively promote women-in-science programs, where the general student body is exposed to speakers from various disciplines.

5. Actively encourage female students to participate in science courses. This could be part of the orientation program. Science should not be singled out as more difficult than other courses. This must be discouraged because it reinforces the stereotypes already formulated by the majority of women students.

6. Establish special scholarships and/or recognition programs for women enrolled in science courses. Because

of the reduced preparation of women for science courses, women who choose to stay in these professions will by definition have lower grades than women who choose to major in more traditional "female" areas. Thus, women who have majored in the sciences are given little encouragement for their perseverance and dedication to a career for which they have been inadequately prepared by the traditional educational system.

7. Actively recruit college-bound women into scientific fields. This could be accomplished through the regular college recruitment programs or through special programs for high school students interested in science. One procedure might be to have an annual science fair where females are encouraged to spend a few months in a college science laboratory and then report their research endeavors in a competitive fair. The most valuable assets would be the visibility of science faculty to interested students and encouragement of female students to become science majors. In addition, each student participant would hopefully take an enthusiasm back to the school environment so that the excitement of science would infect other individuals.

Undergraduate Science and Engineering Education

Chancellors
University of Wisconsin Campuses*

The National Science Board is to be applauded for initiating hearings on improving undergraduate science and engineering education. It is well-known that primarily undergraduate higher education institutions in the United States have long been one of the principal providers of well-qualified students who, after completion of graduate education, are major contributors to the scientific workforce of the United States. After a period of substantial support for undergraduate science education in the 1950s and 1960s, subsequent years saw a steady decline and eventually the virtual elimination of support for science education at the National Science Foundation.

While those institutions with both undergraduate and large graduate research programs have had some flexibility to compensate for this decline—their undergraduate programs, for instance, profit indirectly from research support and the indirect overhead funds it generates—the primarily undergraduate institutions do not. We believe that the current level of support represented by the Research in Undergraduate Institutions Program, the College Science Instrumentation Program, and Research Opportunity Awards has moved in the right direction but is not yet sufficient. More important, the National Science Foundation does not have the organizational ability to focus its attention on the particular needs of primarily undergraduate institutions.

There is no organizational structure within the National Science Foundation that is particularly cognizant of the strengths and needs of science education at primarily undergraduate institutions. As a result, there is no systematic attention to these issues, and both NSF and the primarily undergraduate institutions tend to concentrate energies on the desirability of particular program initiatives, rather than on the current and potential contribution of undergraduate science education to the health of the nation's overall science effort. Therefore, we would strongly suggest the creation within NSF of such an organizational unit with particular responsibility for analyzing and supporting research and science education at primarily undergraduate institutions.

We suggest that the function of this unit should be to:

1. Work with organizations such as the American Institute of Physics and the American Chemical Society to analyze existing data and, as necessary, collect additional information to measure the effectiveness of current programs and to suggest the development of new programs.
2. Initiate programs that would provide opportunities for faculty renewal through cooperative industrial relationships as well as strengthen existing programs through the national laboratories and large graduate research programs.
3. Initiate various faculty recognition programs for primarily undergraduate higher education institutions. These programs could parallel those already in existence for the precollege area and the graduate programs.
4. Consider the reinstitution of support for undergraduate student research projects.
5. Consider the creation of a challenge grant program to support selected departmental revitalization.

We make these recommendations because we think it is vitally important that undergraduate science education should not be viewed by the National Science Board either as an unimportant add-on to otherwise more importantly defined science activities, nor simply a rallying point for institutions with primarily undergraduate science programs to lobby for particular programs. A complete national science effort requires coordinated excellence at all levels, from elementary school through specialized research laboratories. There is no question that good science is done at primarily undergraduate institutions. The National Science Board, through formal recognition of their contribution, can ensure that good science continues and prospers at these institutions and that they can be utilized more effectively as a valuable component in national science policy.

*Submitted by Gary A. Thibodeau, Chancellor, University of Wisconsin-River Falls, and endorsed by the Chancellors of the University of Wisconsin campuses at Eau Claire, Green Bay, La Crosse, Oshkosh, Parkside, Platteville, Stevens Point, Stout, Superior, and Whitewater

On Engineering Education

Jerrier A. Haddad

IBM Corporation (retired)

Engineering is a very diverse profession. It is diverse from the standpoint of discipline, from the standpoint of type of activity, and from the standpoint of industrial sector. For instance, consider the employers of engineers. They range from government to academe to industry. Industry is by far the largest employer, but industry is a very diverse set of companies. Companies range from the outfit that employs one general-purpose engineer to the so-called high-tech companies, some employing thousands of scientists and engineers. Engineering jobs, therefore, run quite a range of functions. An engineer in industry may have a job that calls for the very latest in technical knowledge, e.g., applied research or advanced development, or a job that calls for skill at design and knowledge of manufacturing processes. The engineer's job may involve mundane detail work that could just as easily be done by an engineering technologist, or could involve facets of responsibility that require fairly deep knowledge of things like finance or law or marketing. There is a very large range of engineering functions. Similarly, there exists a set of engineers having a range of capabilities and interests willing to fill these jobs.

Thus, all engineers are not alike. Not only do engineers have different field specialties, but they hold jobs within those specialties that are quite different in function and in what they require of an individual in knowledge and expertise.

This, then, raises the question, "What is the precise goal of engineering education?" A very good question. Is it to educate the individual for a particular job in a specific field? Is it to educate for a variety of jobs in a specific field? Is it to educate for a particular job irrespective of field? One should also ask whether or not it is the goal of engineering education to educate for any particular job or, even, for any specific field. There is also the perennial question of whether or not it is proper to focus the four undergraduate years so heavily on technical matter to the detriment of a broader education that will allow the student a richer life regardless of career choice.

Thus, we are brought to a discussion of the structure of engineering education. Why is it the way it is? How and why did it get here? To consider these questions we need to take into consideration not only the *assumed* benefits to the students but additionally:

- The desires of the students;
- The desires of their parents, or whoever is paying for their education;
- The effect on potential employers in terms of starting salaries, on career chances, and on the general desirability of the graduate;
- The effect on the faculty and college administration in terms of motivation, opportunity, challenge, growth, and competitive success; and
- The effect on the nation in terms of its engineering infrastructure, its international competitiveness, its defense capabilities, and its public safety, health, welfare, and tranquility.

First, it is all but impossible to prove that a liberal or general education is a worthwhile thing in terms of dollars and cents, or any other measure. One can make the case for a liberal education only in terms of faith and very broad experience over generations of graduates. There are incongruities! An employer that would not dream of hiring a non-college-graduate (liberal arts, most likely) for general non-professional employment, thinks nothing of hiring graduates for technical-professional jobs who have little or no general education in addition to their technical education. Evidently, industry presumes that the technical-professional, having spent four years in an academic institution, is "educated." On the other hand, it is held that one who has not been an undergraduate for four years is presumed to be "uneducated." This logic makes the assumption that a substantially technical education is somehow miraculously the equivalent of a liberal education but not vice versa.

For that matter, even many of the technical subjects that are studied cannot have their value assayed. Experience and logic give us faith that our *judgment* is correct in laying out a curriculum. That is the best we can do. We use our wisdom and our judgment.

The potential employers of engineering graduates have professed not to value education beyond the "practical" technical courses in terms of the general desirability of the graduate or in terms of starting salary. At the same time, they complain that these graduates are deficient in terms of their ability to communicate, their knowledge of our economic system, their knowledge of business practice, and their familiarity with cultures other than our own. This attitude seems to be changing. At a recent convocation of industrialists held by the Accreditation

Board for Engineering and Technology (ABET), the industrialist majority was outspoken in stating its need for a broader non-technical education for engineers.

The Forces on Engineering Education

In the years since World War II, the engineering curriculum has had a significant increase in the amount of basic science and mathematics. This resulted from the realization that the most noteworthy technical advances during the war largely had been the result of work by physicists rather than engineers. The late Frederick Terman said, "Most of the major advances in electronics were made by physicists and people of that type of training rather than the engineers." The famed Grinter report published in 1955 added fuel to the fire. It strongly recommended that engineering science be increased in the engineering curriculum. Terman wrote an article shortly after this in the *IRE Student Quarterly* entitled "Electrical Engineers Are Going Back to Science!" In this article he warned that if the engineering fields that "lie between pure science and traditional engineering" were not recognized as engineering, then "colleges of applied science will develop on the campus and insulate engineering from pure science while taking over the interesting and creative areas."[1]

Not only is the greater emphasis on science and mathematics necessary to enable the engineering graduate to practice the profession properly, it would be essential in today's world if for no other reason than it allows practicing engineers to re-educate themselves as the need arises. A practicing engineer in mid-career may need to switch specialties or fields due to the maturation of an industry or the effect of the progress of technology. The ability to read the literature, take advantage of symposia, communicate with peers, take special courses, and participate in other educational activities depends heavily on the individual's academic base. This academic base is very largely the knowledge and understanding of fundamental science and mathematics.

At the same time, there arose a clamor for heavier doses of the liberal arts and the humanities in the various four-year curricula for engineers. In an effort to contain the traditional engineering subjects along with the newly desired ones, attempts were made to effect a five-year undergraduate program. This also had the desirable feature that it allowed a more appropriate scheduling of prerequisites. However, a five-year program resulting in a bachelor's degree just could not compete with a four-year program with fewer of the non-technical subjects that resulted essentially in the same degree. Employers were not prone to increase starting salaries for this fifth-year graduate enough to compensate for the expense of the fifth year and the concomitant loss of earnings during that year. The five-year bachelor program failed.

In the years since, engineering alumni who were polled on their judgments regarding the effectiveness of their education quite uniformly replied the following. The alumni of up to 10 years favored more and deeper technical training along with some courses in business practices such as accounting and cost accounting. The 10-year to 20-year alumni favored more courses in business management and administration. Those alumni more than 20 years out favored more study of economic systems, more humanities, and more social sciences. All alumni, regardless of age, strongly condemned the new graduates' inability to communicate, i.e., to write, to make oral presentations—in short, to be convincing.

Additionally, the technology has progressed such that courses are now necessary that just did not exist 30 years ago. Servomechanisms and signal processing are two good examples. There is now the need to study numerical methods for using computers in addition to studying analytic forms of mathematics in order to understand concepts.

The march of technology has also led to a proliferation of engineering fields. Forty years ago we had civil, mechanical, electrical, chemical, and mining and metallurgical engineering fields—pretty much what the five founder societies focused on. Of course, there were "subfields" such as electronics or illumination. However, these were not reflected in the curricula except as an expression of optional courses at most. It is quite the opposite today. Now, there are close to 30 engineering professional societies, each representing at least one field of engineering and many representing numerous subfields as well. While no college can hope to offer all these fields, much less all the special courses they imply, there is a school of thought that a well-educated engineer should at least be broadly familiar with these fields and courses if not exactly adept at the detailed subject matter. Even this is impossible in the present situation.

In former years, rudimentary courses were given on shop subjects such as foundry, woodworking, machine shop, drafting, etc. These are largely gone today for two principal reasons. First, the pressure to accommodate courses in the humanities, etc., has forced hard decisions on eliminating the more marginal technical subjects. Second, shop practices in engineering in the real world are changing very rapidly, and now involve extremely sophisticated processes. An exposure course in patternmaking has little real relevance to today's petroleum engineer, and an exposure course in forge or foundry has little relevance to today's semiconductor circuit designer. Certainly, it can be argued that these courses exposed the engineer to valuable insights even if they were not necessary in a day-to-day sense. They were good training in that they established a feeling for the character of engineering. Yet, this kind of background can be acquired in other ways, such as summer employment. The modern engineering college simply cannot waste the time of "higher education" on this class of study. This argues strongly for some formal type of interning for the student.

Another force affecting engineering education is that due to accreditation requirements. Accreditation has become a necessity! Accreditation is now part of the law of the land in most if not all states, in that unless you hold a degree from an accredited program, you do not qualify to take the professional engineer's first part examination. While one can still become a professional engineer with a license, the path to such a license takes much more time than with a degree from an accredited program. Most institutions recommend strongly that new graduates seek registration and licensing even if they plan on careers that would not seem to require it. First of all, the laws could become more strict, and, further, there is no sense to limiting one's future options.

While the foregoing forces have been shaping engineering education, the number of credit hours necessary for graduation and a B.S. degree has gone down, on average, the equivalent of about four solid courses (around 20 credit hours). Clearly, something has had to give. There is only so much educators can do to accommodate these forces in a four-year program, and the limit would seem to have been reached, if not exceeded.

The Present Engineering Education System

The main concern of many engineering educators today seems to be the quality of engineering education. They fear it has slipped badly for a number of reasons. The American Society for Engineering Education (ASEE) has shifted the focus of the former "Engineering Faculty Shortage Project" to the broader concern of "The Quality of Engineering Education." To indicate the depth of feeling and the priority given to this effort, they have assigned W. E. Lear, the executive director of ASEE, as the principal investigator. A curious situation exists, in that most industrial employers are not nearly as concerned as are the educators. Generally, the industrial people perceive the quality of the new graduates to be high, with the exception of their desire for better communication skills. In turn, the educators have concluded that the industrial perception is focused on the short term and due to the high quality of the present students, while academe is more concerned with the longer term.

Who is right? I side with the educators. I think that academe has had to react to too many forces in recent years. It is my belief that a new hard look at the engineering education system is warranted. Before discussing possible changes to the system, we should first outline the difficulties that now exist:

1. There is too much expected from the four-year curriculum. We have tried to pack too much into it. As a result, much of value has been dropped.

2. The liberal arts, humanities, and social sciences additions while better than nothing, are still a long way from allowing engineering graduates to claim that they have been educated beyond minimal vocational requirements. For truly well-educated engineers, there should be more required than the present four-year programs will allow.

3. A great deal of the generality has been squeezed out of engineering programs in the effort to deal adequately with the minimum specialization deemed necessary for each particular field. Thus, electronics majors do not study enough about energy equipment; civil engineers do not study enough chemistry; mechanical engineers do not study enough electronics; etc. Many college advisory councils are disturbed that the various fields of engineering are increasingly unable to talk to each other. Each field seeks to delve into its specialty subjects deeper and deeper to the detriment of broader subjects. To the degree that this is true, we are seriously eroding the ability of practicing engineers to shift fields in mid-career, and making it harder to develop broad system engineers who have the knowledge and ability to lead complex projects.

4. There is still much of value that must be added to engineering programs to cover business practices such as accounting, cost accounting, recordkeeping, patent and copyright law and procedure, publication, scheduling, budgeting, program planning, and on and on. What is being outlined here is not business administration or business management. Also, it is clearly inappropriate to dedicate an entire course to each subject. On the other hand, each of these topics can be woven into other courses, or grouped into multi-topic courses as the faculty sees fit. The important consideration is to have enough time to be able to diverge from the focus of a course in order to be able to cover these important areas without short-changing the host subject.

5. State-of-the-art equipment in industry or in the field is extremely costly and has a very short life as the technology is progressing very rapidly in many areas. For any but the very wealthiest of engineering schools to have even the last generation of equipment on campus is all but impossible. This is a bad enough situation for the undergraduate, but for the graduate student it is a matter of life or death, academically speaking.

6. Given more time, engineering faculty would re-introduce practice courses, which have had to give way to engineering science in the past two decades. While there is not universal agreement that academe is the proper place to acquire practice skills, there is little question that engineering education should contain some reasonable element of it.

7. Engineering faculty is all but exclusively Ph.D.'s and heavily focused on engineering research. Research is felt to be the elixir that keeps the faculty intellectually vibrant. It is hard to argue with this formula, since it has seemed to be so successful. On the other hand, practicing engineers, in the main, do not do engineering research. Rather, they develop, design, manufacture, service, and operate. Therefore, the faculty

is not a set of role models for any but those graduates who do go into engineering research in industry or government, or into academic careers. Further, while the "Mr. Chips" type of professor is greatly appreciated and even revered, to become tenured he must show his determination and ability to do excellent research.

8. The demise of "shop" courses, the lack of other than research role models, and the shortage of up-to-date equipment make some sort of industrial interning desirable. Interning has the added advantage of enriching and focusing the classroom learning experience. It gives perspective and motivation to the regular academic courses.

9. It has been proven by the demise of the five-year program that merely requiring more credit hours for a B.S. degree in engineering will not work if it requires more than four years. Industry and government are only too happy to accept the four-year B.S. as the professional entry level, and there is little or nothing that can be done to change that fact.

10. Heretofore, a great many students desiring an engineering education have been impatient with non-engineering courses. It would seem that they desire, most of all, a vocational education in the shortest possible time On the other hand, of late, engineering education has been attracting a greater number of students who have very broad interests and who are really very bright as evidenced by their high verbal and mathematical SAT scores They may not make up the majority as yet, but they are an appreciable fraction and increasing A good number of them are women.

11. There has been a great deal of dissatisfaction in the ranks of practicing engineers with the respect they are accorded in comparison to other professions such as medicine. There are complaints that they are not treated as professionals, and that their compensation is low relative to tradesmen and craftsmen. As a result, many feel that the effort involved in a difficult and expensive education is not worthwhile.

12. Enrollment in the various engineering fields has been very uneven. Because of the slump in construction, civil engineering enrollments have been down. Because of the booming computer industry, enrollment in electrical engineering is up (but not in the power option). Chemical engineering and petroleum engineering have been on a roller-coaster as the prospects for the oil industry have changed. Computer science, which is part of the engineering school in many colleges yet is not related to engineering in many other institutions, is enjoying high enrollments wherever it is.

    This is putting a great strain on the engineering schools. It is not easy to balance faculty loads, especially given the fact of the tenure system. All sorts of mischief are being done to space allocations, laboratory and equipment requirements, and faculty assignments.

13. The B.E.T. (earned at schools of engineering technology) is creating graduates who in many instances have the ability and education to be able to satisfy requirements for jobs hitherto considered engineering jobs. In any event, since job requirements are being changed every day due to the computer revolution and other advances in technology, it is reasonable to expect that th demarcation line between engineering jobs and technologist jobs will shift There is little that anyone can do to affect this. In the last analysis, industry will assign personnel as high as the Peter Principle will allow, or as low as necessary in order to match skill to requirement.

The Goals of a Restructured Curriculum

The broadest goals of a restructured curriculum should be to educate the student as a whole person: To prepare the student for entry to any and all engineering functions, from research to manufacturing to sales; to prepare the student for a lifetime of continual education, in formal classes or self-education; to prepare the student for a particular discipline or field, yet pave the way for the student to move into an adjacent discipline during his or her career with a minimum of effort: to prepare the students in such manner that their greatest potential is achievable for their benefit and the benefit of the nation.

The one largest problem is the overambitious four-year B.S. program. It no longer contains all the technical content that a well-rounded engineering education should have. The four-year program is still deficient in engineering science and mathematics, regardless of how much better it is compared to 30 years ago.

The content of liberal arts, humanities, and social sciences is much greater than a few years ago. However, it is still not enough to allow one to say that we are sufficiently educating engineering students in comparison to what is done for physicians, lawyers, and other professionals. More important, in our increasingly global economy, engineers of the future will need to be more involved in the social consequences of their work, and more aware of and empathetic toward the cultures of other nations and the effect that this should have on products and services.

A more universal approach to interning would greatly benefit both the school and the student. While co-op programs are better than nothing, they have disadvantages that discourage academics from seeking to apply them more generally. A new approach is needed.

At the same time, more breadth and more depth are needed in the technical content of engineering education Without the breadth, graduates will be so specialized that they will have difficulty following technological trends in their careers. Increasingly, they will be unable to profit from gains in disciplines other than their own that may or should have an impact on their own fields. Paradoxically, that very advance of technology and engineering practice methods demands ever more depth of study in the specialty.

As the world's economy becomes ever more dependent on the fruits of engineers and engineering, the nation needs higher and higher caliber people in the engineering profession. It is necessary to attract to engineering study those broadly educated, bright people who not only will develop into leaders of the engineering profession, but leaders in business and government. There are many signs that this type of person is now being attracted to engineering school. We should revise the curriculum to develop these people to the limits of their intellectual interests and abilities. Anything less than this is not in the best interest of the nation.

A new or restructured curriculum that takes more than four years will need to have more attractions than the curriculum itself, in order that the extra time and money will not prove too large a disincentive. Preferential admission, liberal loans, scholarships, and other incentives should be developed. Since the nation will profit from the development of these bright people, the nation should somehow be expected to shoulder part of the burden.

However, no authority exists for effecting a restructuring by any means other than voluntarily. Additionally, state education departments and regents would need to be involved. Last, the accreditation agencies would need to bless the result. Clearly, then, it is unlikely to the point of impossibility to contemplate a single sweeping restructuring that would substitute for the present system even if one assumes that it would be desirable. I conclude that it is not a desirable objective for a number of reasons. The most important is that we now enjoy a diversity of engineering education programs that satisfy a significant fraction of the market for engineering education. We should preserve what we have and add to the present diversity other programs that would enrich the mix. These new programs should stand on their own feet. They should create a market of their own, if successful, and benefit the institutions that offer them.

Recommendations for the Immediate Future

1. We should not seek a universal solution, i.e., a solution intended to satisfy all students or be acceptable to all engineering schools or both. The present range of programs offered by engineering schools satisfies many if not most engineering students. In turn, the job market is quite satisfied with these graduates in most cases. What we need now is a set of programs that will prove attractive to the more able students. Until a new curriculum proves itself over time as satisfying a reasonable fraction of the students and filling a needed niche in the job market, we should not seek to replace what we already have. *Any new program should supplement our present programs.*

2. A restructuring of the curriculum should be the result of consensus among a few leading institutions and should be developed in cooperation with ABET. Each institution should be encouraged to implement the new programs differently according to the bent of its faculty. The important thing is to agree on broad principles and goals. *The National Science Foundation would seem to be the most appropriate agency to support and encourage this effort.*

3. The extended time for the new programs should result in a new degree or set of degrees. Rather than dual degrees, I would recommend a new approach such as Bachelor of Arts and Science in Engineering, Master of Arts and Science in Engineering, and Doctor of Arts and Science in Engineering. Of course, the degree could be more specific and name the field or discipline, e.g., Master of Arts and Science in Mechanical Engineering. *It is important to have a new degree*, whether or not it is the one I am recommending, in order to differentiate between the graduates of our present programs and those who invest more effort and time and money in the new programs.

4. *An important element of the new curriculum should be the requirement to intern for academic credit to qualify for the degree.* Interning should be a standard requirement for all students in the program. Preferably, it should come prior to heavy coursework in engineering specialties. The interning part of the program should be negotiated with industrial concerns and government agencies in such manner that the jobs held by the students would always be filled throughout the year. In other words, as one student's time is up, another student would be ready as a replacement. Also, it would be highly desirable to enlist some of the company's staff as adjunct professors and make them responsible for assuring that the work experience fulfills the expectations of the school's faculty.

5. The early years (probably the first three years) should be considered a *preprofessional education*. Properly structured, they would be the years of learning science and mathematics, liberal arts and the humanities. They could be taken at the same university as the succeeding engineering courses, or they could be taken at another college or university as long as the engineering college had an agreement with the other institution. There are many such arrangements today in the form of dual degree programs of the three/two variety.

6. The professional education should contain engineering science that not only satisfies the requirements for the specialty of the student's choice, but is broad enough to enable the student to "slide" into an adjacent discipline. There should be heavy emphasis on courses that will enable the students to self-educate themselves later in their careers as technology advances and as industries wax and wane. Together

with a reasonable amount of field specialization, this will probably result in a three-year engineering curriculum after the preprofessional curriculum of three years. It may very well be that the minimum degree for this program should be the master's degree. This is something that can be judged only after enough work has been done on the curriculum.

7. The success of this program should be judged on the basis of the quality and success of the graduates over a reasonable time. If as many as 10 or 15 percent of the engineering students opted for this program, then it would seem a very desirable thing. We should not expect that a majority of entering students would prefer this program over those now extant.
8. Student aid will be a very important element in making this program successful. Schools will not be ecstatic about the increased student aid that will be necessary due to the longer curriculum. However, the objective here is to create graduating engineers that the nation needs. Some creative financial work will need to be done to make this program acceptable to the student and to the engineering school.
9. The program will need to be promoted in order to attract the brightest students. Similar programs in existence today owe their lack of popularity to the fact that few students are aware of them. Advisors at both the secondary school and college levels must be made aware of the desirability of the new programs and not hesitate to recommend them to students where appropriate. High school PTA groups should have film strips or video tapes describing the programs available to them. Nothing new will succeed on an optional or voluntary basis if it is unknown.
10. Preference given to entering students in these programs would be a significant indication of the high esteem the institution placed on them. It would go a long way to lend attractiveness to the new curricula.

Postscript

The field of medicine has been able to go this route universally, because licensing requires the M.D., and the M.D. can be obtained only from a medical college. In turn, the medical college requires pre-med competence for entry and this implies most, if not all, of a four-year undergraduate pre-med B.S. degree.

The new curriculum should be developed as an experiment. Certainly, this experiment will take a long time to develop and perform. On the other hand, a significant departure from tradition such as this cannot be expected to be adopted without a trial and after a great deal of planning and refining. Most changes in engineering education have evolved rather slowly and incrementally, over a period of years and with a few institutions stepping forward carefully and deliberately. We should expect no faster results here.

Reference

1. Taken from an insert by Michael McMahon of Philadelphia in an article on Terman by Effie Bryson in *IEEE Spectrum*, March 1984.

The Need for Social and Ethical Issues in the Undergraduate Science and Engineering Curriculum

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Student Pugwash (USA)

Thank you for the opportunity to submit my views on the state and future of undergraduate science and engineering education. As a recent student and in my position at Student Pugwash, I have had the opportunity to observe higher education in science and engineering and to meet with outstanding students in these fields on a regular basis. I urge you to seek a diverse range of student opinion during your deliberations; students have a unique interest in education, one that is far too often overlooked in the making of policy. I do not claim to speak for all students today, but I believe I speak for a significant number, particularly those who feel that science and technology are the central forces shaping modern society. My testimony will focus on the way that science and engineering curricula do and should treat social and ethical issues.

Let me supply a bit more background about myself and Student Pugwash. I attended Princeton University for two years, where I took physics and math (among other things), and then transferred to Wesleyan University, where I developed my fascination with genetics. I won the top award the university bestows on undergraduates for my senior thesis for the Science and Society Program on "Patent Policy for Industrial Genetic Engineering." Upon graduation, I attended the 1983 Student Pugwash International Conference, spent a year working for a contractor on nuclear waste disposal facility site selection, and then took the job of organizing the 1985 Student Pugwash International Conference on "Science, Technology, and Individual Responsibility," which was held at Princeton's Woodrow Wilson School in June.

Student Pugwash is a non-partisan, non-profit organization devoted to motivating and supporting students working toward a more value-conscious science and technology decisionmaking process. Our work thus has a very broad scope; a typical international conference includes working groups on defense, health, information, energy, and environmental issues as well as general sessions on such topics as university/industry relations and secrecy in academic science. The name comes from Pugwash, Nova Scotia, where, in 1957, eminent scientists met at the behest of Albert Einstein and Bertrand Russell to discuss the role of science in world affairs. The senior Pugwash Conferences continue on an annual basis, but we have no formal connection with them nor do we share any of the political positions taken by them. We do take our inspiration from the interdisciplinary and international dialogue they foster and from their focus on the social and ethical dimensions of science and technology.

The International Conference that I organized was Student Pugwash's fourth. Ninety students from 25 nations participated along with senior decisionmakers, such as NSF Director Erich Bloch, OSTP Deputy Director John McTague, CRAY Computers Chief Executive Officer John Rollwagen, MIT physicist Philip Morrison, and others. Each student submitted a paper on one of five key issues in the world of science and technology and spent the week in a small group with other students and senior participants discussing that issue. The conference, which lasted one week, was supported by NSF's program in Ethics and Values in Science and Technology (EVIST), the Carnegie Corporation, the Sloan Foundation, and other foundations and corporations.

Another key Student Pugwash activity is the coordination of 22 chapters at campuses across the country. These chapters raise significant issues of local interest; for instance, our Cornell chapter organized a convocation on secrecy in science at Cornell with the participation of President Emeritus Dale Corson, who chairs the Research Roundtable at the National Academy of Sciences, and Rosemary Chalk, head of the Committee on Scientific Freedom and Responsibility at the American Association for the Advancement of Science. Like our conferences, our chapter activities strive for balance, to create an unbiased forum on issues that too often generate more heat than light. We also publish *The Technology and Society Internship Directory* and a thrice-yearly newsletter. Past participants in our conferences and other activities work in a wide range of science and technology institutions (many around Washington, not surprisingly), where they are moving into positions of responsibility.

As I see it, there are two overarching reasons why the federal government is involved in undergraduate science and engineering education. First, the United States needs a technical workforce that is more than competent; given the competition in military and commercial matters, it must be exceptional. Second, we need an in-

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formed citizenry capable of making good decisions on issues of national policy that involve science and technology. These issues have been taking up more of the national agenda and placing more demands on the electorate each year.

Both of these reasons for federal support imply a need for an undergraduate science and engineering curriculum that explicitly relates the subjects to society and explores the ethical dimensions of decisions about science and technology. A failure to create social cognizance among scientists and engineers will cause a failure to meet the needs of society effectively and to meet the competition in the marketplace. Lack of public acceptance, product liability suits, environmental hazards. all of these stem, in part, from an inability by technical personnel and their management to perceive the societal environment into which technology is introduced. A failure to educate the general electorate about the social structure of science and technology can cause poor decisions, based on unreal expectations. The demand that evolution be "proven" is a simple example of this phenomenon.

Yet, the standard science or engineering curriculum leaves the relationship of science, technology, and society and the subject of professional responsibility almost entirely to the imagination of the undergraduate.

For an undergraduate, there are three major reasons to be involved in science and engineering education. One is intrinsic interest in the subjects as a central focus of study. The second is to improve one's job possibilities. It has become clear to all of us that many of the jobs of the future will demand some sort of technical skill (although I think most people are quite hazy on the specifics). Finally, many undergraduates take science and engineering courses because they are required to take them for graduation and for no other reason.

For each of these types of students, an understanding of the social and ethical dimensions of science and technology should be an important part of their work. Those who have an intrinsic interest typically excel in introductory courses (and I am excluding pre-meds here—that would need an entirely separate, though related, treatment). As they move to advanced courses, it becomes increasingly difficult to get a broad education, due to the demands of the course sequence and peer pressure. As a result, they often graduate innocently into a real world that can shock them. Alan Westin of Columbia University reported at my conference that about 10 percent of the engineers in his survey had encountered moral dilemmas on the job during the past two years; a standard engineering education leaves the engineer completely unprepared.

For the student who wants the skills to improve his or her marketability, the curriculum can be a real trap. Without a conception of the larger picture of the application of those skills, the graduate may wind up in a dead-end job, because, in almost every job above entry level, something more than simply technical know-how is required. More than this, many skills appear to be on the road to being automated out of existence. What is needed is an ability to learn, to recognize opportunities—in short, to understand the context of one's work.

Finally, students who take science or engineering to fulfill requirements are in my estimation the vast majority. Their experience is generally a sour one. The subject matter is presented—usually intentionally—in an intimidating manner to "weed out" the non-majors. These courses do not cultivate interest and are viewed as something to be endured, not enjoyed. A look at the way that the subject fits into society would spice up the course—and, if you believe as I do that fun and learning are directly correlated, improve dramatically what is retained. Moreover, broader courses would pose to the undergraduate non-major exactly the sorts of questions that will be posed to him or her as a member of the body politic. I do not think these kinds of courses have to water down the technical material in a significant way; my own experience in learning genetics is a testimony to that.

Over the past 10 to 15 years, a community has evolved to fill this niche—I am a product of it. We see "Science, Technology, and Society" programs and courses scattered across the country, but it has yet to penetrate the standard curriculum. I believe one reason it has not is massive resistance on the part of science and engineering departments. The hierarchy in these departments is unable to face the fact that they are now training students to contribute in a highly regulated universe, with public funding and public impact. For junior faculty—apart from having the disciplinary blinders of their own training—the time demands of developing a broader type of course (not to mention departmental politics) are simply impossible to meet because of the need to do research.

The situation requires a push from the top. University administrators have been able to provide this push with a little money, as the Sloan Foundation's "New Liberal Arts" program has shown. However, far too often, administrators pay lip service to the program, but knuckle under to the realities of faculty politics.

The National Science Foundation can make a difference through its support of science and engineering education. I urge you to devote significant funding to this kind of curricular development—a large enough share to serve as a signal to academia to overcome some of the institutional barriers I have mentioned. The Ethics and Values in Science and Technology program in the research initiation area of NSF, which has supported Student Pugwash and related educational and research projects, is sorely threatened. This action is sending out exactly the wrong signal. I would like not only to see EVIST continue, but see a similar sort of program established in the science education area.

The other specific suggestion I have is for you, both as individuals and as a body, to speak out more on the importance of social and ethical issues in the curriculum. Your vocal support can help break down some of the resistance I have alluded to.

It is critical that support for education about the ethical and social implications of science and engineering increase. It not only meets the needs of the students—it meets the needs of the nation.

Undergraduate Science and Engineering Education

John G. Kemeny

**Professor of Mathematics and Computer Science
and President Emeritus
Dartmouth College**

Thank you for inviting me to submit testimony. I have elected to limit my testimony to a single area where I have most expertise, the use of computers in mathematics and science education.

Dartmouth College began to use computers for educational purposes on a large scale in the fall of 1964. I can testify that the impact of computers can be enormous and highly positive. This impact is possible in many different areas, but it is particularly significant in mathematics, the physical sciences, and engineering.

Let me first describe what I consider the most important uses of the computer in education. Most of the software available provides "drill" or attempts to present text materials in a different medium. I consider these to be of limited usefulness. A computer is a poor substitute for a teacher and a questionable substitute for a textbook. While such materials may be useful for remedial purposes or in subjects that require a great deal of memorization, they are least useful in mathematics and the sciences.

Instead, I have advocated the following uses of computers. First, a computer is a powerful computational tool. It allows one to remove a good deal of drudgery from a course and to allow students, even beginning students, to tackle serious practical problems. Second, personal computers have powerful graphics capabilities which are invaluable for the teaching of mathematics and science. We are just beginning to exploit these capabilities. Third, and most important, I believe that computer programs will become an important part of text materials studied by students Since this point is not obvious, I would like to expand upon it.

In mathematics we teach two kinds of material: theorems and algorithms. I have taught mathematics on the college level for 40 years; I still teach theorems very much the way I taught them 40 years ago, but I have completely changed my attitude toward the teaching of algorithms. As mathematics is an ideal language for the expression of theorems, computer programs written in an easily readable language are ideal for the teaching of algorithms. Furthermore, once the student understands the computer program, that same program can be used for the solution of problems or for experimentation with alternate procedures. A particularly effective pedagogical tool is to have students themselves write programs for a given algorithm. It is a variant of the old adage that "the best way to learn a subject is to teach it." Students, by trying to teach the algorithm to a computer, learn an enormous amount and can achieve a depth of understanding not previously possible.

While my own experience has been limited to teaching of mathematics, it is quite clear that similar remarks are applicable to the sciences and engineering; many of my colleagues here and elsewhere have effectively used the computer to enliven and enrich the content of science and engineering courses.

Problems

While I have not attempted to conduct a survey, I have spoken at a number of other institutions and at professional meetings. I therefore have a fairly good idea of the state of the use of computers in undergraduate education. My impression is that it is highly sporadic and that the major impact of computers still lies in the future. Why has progress been so slow?

During the 1970s, the limiting factor was the availability of hardware. This has changed dramatically with the coming of personal computers. My opinion is that the three outstanding problems now are (1) the lack of good educational software, (2) the difficulty of showing computer output in the classroom, and (3) that most college professors still feel uncomfortable in using the computer in a classroom setting.

I am afraid that a great deal of available software is written either by faculty members who are amateur programmers or by computer experts who have no experience in teaching the particular subject. I believe that the analogy to textbooks is a good one: The best textbooks are written by faculty members who are experts in their field, who have substantial experience in teaching the particular subject matter, and who are good writers. First-rate software should ideally be written by faculty members who are expert in their field, have considerable experience in teaching the subject, and are first-rate programmers. A second, though less satisfactory, solution is collaboration between the expert teacher and a professional programmer.

A second major cause of lack of good software is the problem of "portability." A great deal of highly useful educational software has been written at many different academic institutions. But, typically, the programs run only on one type of mainframe and are dependent on the particular operating system of the institution. One would hope that with the availability of personal computers it would be much easier to port software. But, unfortunately, there are entirely new obstacles. With the rapid advance in computer technology, we are confronted by a bewildering array of incompatible hardware. Manufacturers go out of their way to make the next generation of personal computers incompatible with previous generations. If they succeed, it represents a significant business advantage to them, but it has a highly negative impact on higher education.

There is a way of overcoming the hardware problem, namely by having computer languages that are portable from one computer to the other. This means that a program written in language X on one computer will also run in the same language on another computer. Unfortunately, the commercial enterprises that implement computer languages seem to have little interest in making the languages portable.

Twenty-one years ago my colleague Thomas Kurtz and I invented the language BASIC, to be used specifically for educational purposes. It has become the most widely used computer language in the world. But, its history on personal computers has been a sad one. The implementations tend to be of poor quality, leading to ugly computer code not suitable for educational purposes. Even versions of BASIC written by the same software house for different computers are incompatible in major ways. Similar remarks can be made about most other commonly used languages. (For more details, see our book, *Back to BASIC*, Addison-Wesley, 1985). This makes the porting of good software from mainframes to personal computers a significant task. And, typically, the software then runs on only a single personal computer (or one family of personal computers.)

The problem is so bad, that for the past two years I have devoted a significant portion of my time to trying to alleviate it. I have been involved in bringing out a modern, easy-to-use version of BASIC that closely follows the proposed national standard (ANSI) and that will be portable from computer to computer (True BASIC [tm]). We are also using this language to try to produce examples of truly first-rate educational software. Clearly, no one group has both the expertise or the time to fill the vast need for educational software, and a great deal more effort is needed. Frankly, this is not how I planned to spend my life after stepping down from the Presidency of Dartmouth, but no one else seemed to be addressing a serious national need.

The second problem is the difficulty of showing computer output in the classroom. Colleges generally make the mistake of allocating a great deal of money for hardware and almost no money for software. In spite of this, there is one major hardware area in which the solutions available tend to be unsatisfactory. For effective classroom use of a personal computer, it is necessary to be able to show the output of that computer to a class. If the class is too large to see the output on the screen of the personal computer, and most classes are too large, the available solutions tend to be unsatisfactory. I have given demonstrations on a wide variety of campuses, and no one seems to have a truly satisfactory solution. Devices that will produce high-quality output from a personal computer, particularly in color, tend to be very expensive and "touchy." This touchiness often requires that an operator be present during each class in which computer output is shown. This significantly increases the cost of teaching and is a severe deterrent against the kind of widespread use of computers that I advocate. The problem is not made any easier when a manufacturer comes out with an otherwise popular computer (the Apple Macintosh) whose output is incompatible with standard television sets. At Dartmouth it has taken an enormous expense and a regrettable amount of time on the part of faculty members to try to come up with acceptable solutions to this problem. And, I believe this experience is being duplicated on hundreds of campuses.

Finally, I see as an overwhelming problem the fact that most college faculty members are still uncomfortable with the use of computers, particularly uncomfortable with their use in the classroom. The problem will be alleviated as a new generation of college faculty members, who grew up with the computer, come along. But, in the interim, there is the need for substantial help to existing faculty members. They may need help in acquiring at least rudimentary programming skills, advice on how to use the computer in the classroom, and—most important—advice on how the computer can enrich mathematics and science teaching. During a visit last year to a well-known university of high quality, I was asked repeatedly by members of the mathematics department how Dartmouth could make such wide use of computers in the teaching of mathematics. They were hungry for ideas of what the computer could be used for, and suggestions—even ones that seemed absolutely obvious to me—seemed to be entirely novel ideas to members of the department.

Recommendations

I should like to make some recommendations to the National Science Foundation, one for each of the problem areas that I have identified:

1. That NSF encourage the development of high-quality educational software useful in the undergraduate mathematics, science, and engineering curriculum. That such support should be given to individuals who can combine subject matter expertise and expertise in programming. And, that such support should require that the software be produced in a form in which it is portable to a variety of personal computers and has a

chance of being portable to the next generation of personal computers.

2. That some of the hardware budget of NSF be spent to help solve the problem of classroom demonstration of computer output. I am not an expert on such hardware, therefore I cannot make a detailed recommendation. But, I can testify to the great frustrations that we all experience.

3. That programs of summer institutes and visiting lecturers be encouraged to spread expertise on the classroom use of computers. Such programs should help faculty members not yet comfortable with computers. But, they should also have as a purpose the stimulation of discussions on the way computers can be used to enrich the undergraduate curriculum, on appropriate uses in the classroom, and on uses by students outside the classroom.

The potential benefits are enormous. I regret that progress during the last 20 years has been so sporadic. With appropriate help from the National Science Foundation, progress in the next decade could be spectacular.

Undergraduate Science and Engineering Education

John S. Morris

President

Union College

Union College of Schenectady, New York, welcomes the opportunity to have its views presented to the Committee, and we are pleased to note the interest shown in undergraduate education by the National Science Board.

We are a college of slightly less than 2,000 undergraduates, most of them residing on the campus during the academic year. Founded in 1795, we have a long and proud tradition. Our curriculum is somewhat unique in that we offer the B.S. in civil, electrical, and mechanical engineering along with the traditional liberal arts and science. We claim to be the first, in 1845, to offer engineering in the liberal arts context. The College also maintains a small graduate and continuing education program, mainly providing master's-level courses in business administration and engineering for local industry (primarily General Electric). A Ph.D. in business administration is offered also; about two Ph.D. degrees are awarded annually.

Since we are one of the four dozen or so private liberal arts colleges described by President Starr of Oberlin in his testimony before this Committee, it should come as no surprise that we endorse his views and urge you to consider his proposals with the utmost seriousness. Rather than reiterate the points he has put so clearly, we wish to add a few comments from our own particular perspective that may be useful to you in your deliberations.

First, we call your attention to studies conducted about every five years by the Office of Institutional Research of Franklin and Marshall College, compiled from data of the Board on Human Resources of the National Research Council. These studies tabulate the baccalaureate sources of Ph.D.'s, that is, the numbers of Ph.D.'s in all fields are given according to the institutions from which the Ph.D. received the undergraduate education, drawn from almost 900 four-year, private, primarily undergraduate institutions (defined as IIA or IIB institutions by the American Association of University Professors). It is remarkable that the liberal arts colleges that President Starr referred to in his remarks are so prominently at the top of these lists, especially in the sciences. These data add additional support to the claim that the strong liberal arts colleges excel at science education.

Second, we believe that federal support for undergraduate education has been inadequate, and this has resulted in unwholesome competition for the meager funds made available for this important aspect of our national effort in ensuring a healthy supply of advanced students in the basic sciences. A personal anecdote will help illustrate the point we wish to make.

About a year ago, Union submitted a proposal under the College Science Instrumentation Program (CSIP) requesting NSF help in acquiring apparatus for use in our science and engineering departments. We were declared ineligible to apply for CSIP funds because we offered the Ph.D. (recall that we award about two per year on average) in a field that could, in principle, receive support from some other program of NSF. Never has such support been sought, incidentally, but the fact that our business program is very quantitatively oriented means that some of the Ph.D. theses are essentially statistical in nature, and these could conceivably be eligible for support from other programs within NSF. We hasten to add that a very sympathetic program officer within NSF, responding to our request that this decision be reviewed in view of the fact that our Ph.D. program is so small, carried our case forward, carefully and patiently trying to negotiate the guideline that made us ineligible. After several months, voluminous correspondence, and many phone calls, he reluctantly had to inform us that we could not compete for these funds, while commiserating with us on the apparent foolishness of the rule for our circumstances.

We appreciate the motivation for such a rule; that is, it may be unreasonable to expect the small colleges to compete effectively for funds against the major research universities; therefore, defining eligibility in terms of Ph.D. production makes some sense. But, surely the intention cannot have been to eliminate from the program colleges such as Union, given its primarily undergraduate character and its long history of accomplishment in undergraduate science and engineering education. Our interpretation of the situation is that, given scarce funds allocated for the program, some way was sought to limit eligibility for the sheer convenience of reducing the number of potential applicants. We also understand that there was considerable lobbying by some undergraduate institutions for the rule. This is the unwholesome competition to which we referred earlier. Our sister institutions found themselves advocating a bureaucratic rule to help solve a problem of insufficient resources which arbitrarily eliminated schools such as Union from a program through which, by all reasonable standards, they should have been eligible to apply for help from NSF. More support must be provided for undergraduate science and engineering education so that the institutions that have been so successful in providing scientists and engineers for our society can obtain the support they so desperately need to continue their efforts in excellence.

Third, we read the overwhelming advice from both industry and education presented to this Committee to represent an unqualified consensus among those in a position to comment knowledgeably on these matters, that more resources must be devoted to the support of undergraduate science and engineering education if we are to sustain a national posture of excellence and leadership at the cutting edge of research and application. The need for instrumentation, faculty research support, student research support, and other ways to enhance the quality of undergraduate science and engineering education is urgent if we are to attract the best students to careers in these fields.

IV. CORRESPONDENCE FROM FEDERAL AGENCIES

During the course of its study, the Committee requested views from the Department of Defense, Department of Education, Department of Energy, National Aeronautics and Space Administration, and National Institutes of Health. Although not an inclusive list, these were considered to be primary agencies with interests related to undergraduate science, engineering, and mathematics education. For reasons of space economy, the following pages contain only the agencies' responding correspondence. Requests for reports referred to in some of this correspondence and for other information on their activities should be directed to the relevant agency.

The following letters are included:

- Letter to Agencies from Homer A. Neal, Chairman, National Science Board Committee on Undergraduate Science and Engineering Education
- Department of Defense, Chapman B. Cox, Assistant Secretary of Defense for Force Management and Personnel
- Department of Education, William J. Bennett, Secretary of Education
- Department of Energy, Alvin W. Trivelpiece, Director, Office of Energy Research
- National Aeronautics and Space Administration, Russell Ritchie, Deputy Associate Administrator for External Relations
- National Institutes of Health, James B. Wyngaarden, Director

Letter to Federal Agencies from Committee Chairman

November 14, 1985

Dear Administrator:

The purpose of this letter is to request your assistance with the work of the National Science Board's (NSB) Committee on Undergraduate Science and Engineering Education.

As you may know, this Committee was established to study the status and condition of college-level education in the sciences, mathematics, and engineering, and to recommend an appropriate role for the National Science Foundation in this important area. The Committee is to provide a report to the full NSB in January that will form the basis for a report to be submitted to the Congress by March 1, 1986. A copy of the Committee's charge is attached.

I write therefore to ask if you would inform us on the activities of your agency, both under way and planned, that would be of relevance to the Committee's efforts. We would also welcome your thoughts on the status and trends in undergraduate education nationally, especially as they impact on the sciences, mathematics, and engineering.

Your views and information will be of great assistance in our study and will help to assure that your agency and the National Science Foundation neither duplicate each other's efforts nor overlook significant needs and opportunities. We will of course share our report with you and your staff as soon as it is completed.

I would greatly appreciate it if you could provide us with the information by December 15, 1985, to facilitate preparation of our report. If your staff has questions, I suggest they direct them to Dr. Robert F. Watson, Committee Executive Secretary, at (202) 357-9577.

Thank you for your attention to this very important matter.

Sincerely,

Homer A. Neal
Chairman, NSB Committee
on Undergraduate Science
and Engineering Education

Response from the Department of Defense

February 4, 1986

Dr. Homer A. Neal
Chairman
National Science Board
Committee on Undergraduate Science
and Engineering Education
Washington, D.C. 20550

Dear Dr. Neal:

Thank you for your letter regarding the work of the National Science Board's Committee on Undergraduate Science and Engineering Education. I am enclosing four documents which will be useful to you: the *Report of the DoD-University Forum Working Group on Engineering and Science Education;* a summary booklet describing the range of DoD educational programs and interests; a report on our specialized skill training; and a booklet of military careers.

I suggest that as your study proceeds, you remain in touch with Ms. Jeanne Carney at (202) 694-0206 of the Office of the Under Secretary for Research and Engineering and with Colonel William A. Scott at (202) 695-1760 of the Education Directorate in my office. It would be useful to have the draft report reviewed by them so that any appropriate DoD observations could be available for your review prior to publication of the report.

Sincerely,

Chapman B. Cox
Assistant Secretary of Defense for
Force Management and Personnel
Department of Defense

Enclosures:

1. Office of the Under Secretary of Defense for Research and Engineering. *Report of the DoD-University Forum Working Group on Engineering and Science Education*. Washington, D.C.: Department of Defense, July 1983.
2. Office of the Assistant Secretary of Defense for Force Management and Personnel. *Education Programs in the Department of Defense*. Washington, D.C.: Department of Defense, November 1985.
3. Office of the Assistant Secretary of Defense for Manpower, Installations and Logistics. *Military Manpower Training Report FY 1986. Volume IV: Force Readiness Report*. Washington, D.C.: Department of Defense, March 1985.
4. "Basic Facts Edition." In *Profile: A Guide to Military Careers*, Volume 29, Number 3, January 1986.

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Response from the Department of Education

January 14, 1986

Dr. Homer A. Neal
Chairman
Committee on Undergraduate Science
and Engineering Education
National Science Board
Washington, D.C. 20550

Dear Dr. Neal:

Thank you for your letter requesting information about activities in the Department of Education related to undergraduate education in the sciences, mathematics, and engineering.

The Department has, over the years, been involved in a great many activities related to college-level education. Most of these activities have taken place within the Office of Postsecondary Education (OPE) and the Office of Educational Research and Improvement (OERI). In many cases, the primary concem has been with the status and condition of undergraduate and graduate programs for teacher education, including the areas of science, mathematics, and technology. On the other hand, a number of programs have attended to broader issues of undergraduate education.

Within OPE, multi-year funding for 42 computer education projects has totalled $9 million since 1983. Of this total, $5 million was supported by the Fund for the Improvement of Postsecondary Education (FIPSE) and the rest by the Division of Institutional Development, which implements Title III of the Higher Education Act. Many of these projects are focused on mathematics and the sciences. For example, one FIPSE grant to Oklahoma State University will produce learning modules in applied mathematics. The Title III grants are used to strengthen the scientific capability of small and minority colleges. A project at Atlanta University provided computer science coursework through the University's resource center for science and engineering. A complete listing of the abstracts of these projects is available in *Computer Education. A Catalog of Projects Sponsored by the U.S. Department of Education*, which is available from the Government Printing Office.

Another program within OPE with interests in this area is the Historically Black Colleges and Universities Program which has funded the Minority Institutions Science Improvement Program (MISIP) to strengthen science programs in these institutions. Currently, the staff is planning a conference on science and technology to examine undergraduate science education at Black colleges and universiti

The Office of Educational Research and Improvement has had a long history of involvement in higher education. The ERIC Clearinghouse on Higher Education is a continuing resource for information. The Center for Statistics gathers and reports data at all levels of education. The 1985 edition of *The Condition of Education* contains a valuable chapter on higher education which includes data on enrollments, degrees, resources, faculty, and other factors affecting colleges, including information related to mathematics, science, and engineering.

The recent report of the NIE Study Group on Excellence in Postsecondary Education initiated an active debate on postsecondary curricular issues. The Department continues to be concerned about the issues raised in that report regarding the content of programs of study, involvement of students in their education, and expectations of student performance.

Among the research centers recently announced for funding by OERI is the Center to Improve Postsecondary Learning and Teaching at the University of Michigan. One of the Center's programs of research will be focused on Curricular Integration and Student Goals. This program will examine specific content areas such as science and mathematics. In addition, it will study the

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integration of coursework in the liberal arts and in professional areas such as engineering. The five-year program of research at this center is expected to have wide-ranging impacts on undergraduate education across the country.

The status of and trends in undergraduate education have been identified in recent national reports, including those from the Department. There has been a decline in the quality of American higher education, including falling student achievement, over-specialization in undergraduate curricula, and lax entrance and graduation requirements. It has been estimated that as many as 30 percent of the courses in colleges and universities are remedial.

The curriculum must be renewed to reflect a clear vision of the knowledge and skills that an educated person should possess. Newly discovered ideas in the sciences and mathematics, and the impact of technology on those fields and engineering, suggest changes in content and programs for undergraduates. Too many resources of mathematics and science departments are devoted to remedial courses, rather than to revitalizing the curriculum in the light of future needs of students.

Standards and expectations of academic performance must be raised and better ways of appraising educational quality, student achievement, and institutional performance must be developed. Work in the sciences, mathematics, and engineering should reflect the integrative thinking skills necessary to apply knowledge in a variety of contexts, rather than focusing on unrelated, abstract concepts that are poorly learned by many students. Results of international studies have indicated significant deficits in comparison with other developed countries. Problem-solving skills in mathematics, science, and engineering are critical to regaining American leadership in these areas.

I hope this information is useful to your Committee. If you have further questions, please contact Mr. Gerald Kulm, Senior Associate, Office of Research, at (202) 254-5766.

Sincerely,

William J. Bennett
Secretary of Education

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Response from the Department of Energy

December 26, 1985

Dr. Homer A. Neal
Chairman
Committee on Undergraduate
Science and Engineering Education
National Science Board
Washington D.C. 20550

Dear Dr. Neal:

We are pleased to respond to your request for information on educational activities at the undergraduate level sponsored by the Department of Energy. The current status and condition of undergraduate science education are also real concerns to us. Although the Department does not have a direct statutory responsibility to help improve undergraduate programs, we do support a number of activities, principally through our national laboratories, which directly benefit and involve undergraduate students and their institutions.

As you may be aware, the Department has nine multiprogram national laboratories, as well as over 40 other single-purpose and contractor facilities. These laboratories conduct a range of basic science and technology-oriented research programs and operate a number of state-of-the-art research facilities and scientific instrumentation. For over 30 years, the Department and its predecessor agencies have made the facilities and resources at these laboratories available to university and college faculty and students for research participation, education, and information exchange. The following is a list of the specific undergraduate-related activities conducted through our laboratories:

1. Undergraduate Research Participation

   Through our University-Laboratory Cooperative (Lab Coop) Program, we provide support for summer research appointments at the laboratories for undergraduate students with majors in the sciences or engineering. Based upon a review of their qualifications and career goals, student applications are referred to an appropriate research program office at the laboratory for final selection. This ensures a more suitable match between student and scientist. Appointments are normally in the summer for a period of 10 to 12 weeks. Stipend levels are $175-200 per week. Travel to and from the laboratory is also provided.

   During the past fiscal year, we had over 3,000 applicants. One thousand appointments were made with approximately 40 percent coming from small colleges and universities. Grade point averages for all these students have been about 3.5 or better.

2. Regional Instrumentation Sharing Program

   This Program makes available to faculty and students research and analytical instrumentation not normally found on smaller college campuses such as mass spectrometers, scanning and transmission electron microscopes, X-ray diffraction equipment, etc. This equipment, as well as technician assistance, is made available at no cost to the faculty or student researcher. I am enclosing a description of the Argonne National Laboratory's regional instrumentation sharing effort. Similar efforts are supported by the Brookhaven National Laboratory and the Oak Ridge National Laboratory.

3. Visiting Scientists and Lecturers

   Colleges and universities can request visits of laboratory staff scientists to lecture or consult with students or faculty on a variety of topics from career opportunities to special guidance in the scientists' field of expertise.

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4. Faculty Summer or Sabbatical Research Participation

   Each year, about 180 to 200 faculty from the smaller undergraduate institutions spend varying periods of time at a Department laboratory. These faculty members generally participate in an ongoing laboratory research program working alongside laboratory scientists. These summer assignments which are mostly made through the Lab Coop Program often lead to follow-on subcontractor or consultant support for the faculty participant from the host laboratory.

The Department, through the national laboratories, will continue to provide access to state-of-the-art research facilities and instruments for faculty at undergraduate colleges. As part of this process, the National Science Foundation might want to consider the possibility of linking this laboratory experience with a campus-based research project that would significantly strengthen undergraduate science education and research.

My principal concern with the current status of undergraduate science education is the low proportion of undergraduates who go on to pursue advanced degrees in science and engineering. The Nation will need increasing numbers of well-educated and well-trained scientists and engineers to meet both current and future needs. While a student's decision not to go on to graduate school is partly economic, I believe also that it is partly due to the lack of firsthand exposure to advanced research and a related lack of information on the exciting future opportunities and needs in the sciences and engineering. Those students who participate with us in our summer programs at the laboratories receive this exposure and are better able to determine whether to pursue a career in advanced research. We note that over two-thirds of the undergraduate students who spend time at our laboratories do go on to graduate school and receive advanced degrees. Your study should address this issue and suggest some possible approaches to encouraging more students to pursue graduate study.

I hope this information will assist you in your study. Please let me know if we can provide any additional information on the reported activities.

Sincerely,

Alvin W. Trivelpiece
Director, Office of
Energy Research
Department of Energy

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Response from the National Aeronautics and Space Administration

December 16, 1985

Dr. Homer A. Neal
Chairman
Committee on Undergraduate Science
and Engineering Education
National Science Board
Washington, D.C. 20550

Dear Dr. Neal:

Your letter of November 14, 1985, has been referred to this office for response. The National Aeronautics and Space Administration (NASA) is vitally interested in the quality of undergraduate education and in the future supply of well-trained engineering, science, and technology graduates. We conduct several programs that directly involve science and engineering undergraduates and faculty; the following paragraphs describe some of these programs.

Our most intense direct involvement with the undergraduate population is through the cooperative education program. This program gives NASA the opportunity to hire and train students early in their college careers and it provides course enrichment to the students and their schools. We are the third largest employer of co-ops in the country, employing over 1,200 co-ops each year. Our students come from more than 150 different schools and represent a variety of engineering and scientific disciplines and talents. NASA's co-op students are an integral part of the NASA workforce, participating in tasks essential to mission accomplishment. High priority is given to retaining co-ops after they graduate; nearly 70 percent of our new college graduate hires last year were graduating co-op students.

In October 1981, NASA's Educational Affairs Division introduced a new education program to bring a better understanding of the agency's research and development activities to college and university engineering and science students. The program, called CLASS for College Lecturers on Aeronautics and Space Sciences, is designed to (1) provide in-depth discussions of NASA's current research projects and objectives, (2) create an awareness of its aeronautics and space science programs, (3) point out career opportunities in the aerospace field, and (4) distribute up-to-date materials related to current aerospace research.

At present, there are four lecturers in the CLASS program with expertise in biology, physics, engineering, and science education. Their on-campus schedules include colloquia or classes for science and engineering students and faculty, seminars and lectures for the student body, and meetings with campus chapters of professional organizations. Informal meetings with students and faculty offer information on aerospace careers, graduate programs in aeronautics and astronautics, and NASA's postdoctoral and visiting scientist programs.

The NASA/University Advanced Design Program was begun in January 1985 and is now entering the second phase of a two-year pilot. In this program, an objective of which is to help improve the quality of university engineering design courses, NASA advanced projects are adopted by interested universities as topics for a senior engineering design class. Each university receives a small grant and is aligned with a field center that provides guidance, data, and lecturers during the academic year and 10-week center work assignments for three students during the summer. Nineteen universities are currently involved in this project, which we expect to evolve into a continuing program.

The Summer Faculty Fellowship Program provides opportunities for university faculty members to spend 10 weeks working directly with scientists and engineers at NASA field centers on research or systems design projects of interest to both the agency and the university. The research

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projects are designed to further the professional knowledge of faculty members, to stimulate an exchange of ideas between participants and NASA, and to enrich the research and teaching activities of the participants' home institutions. The systems design projects are designed to give participants experience and techniques to enable them to organize and conduct multidisciplinary engineering systems designs at their universities. Both of these activities are operated through the American Society for Engineering Education (ASEE). Based on program evaluations conducted by ASEE, university faculty have added new courses and altered existing curriculum because of the experience. We have hosted 5,100 faculty members over the 21 years of this program.

In addition to these agencywide efforts, several of our field centers conduct programs for undergraduates in conjunction with local colleges and universities.

The Joint Institute for Aerospace Propulsion and Power, for example, is a cooperative undertaking of the NASA Lewis Research Center, the University of Akron, Case Western Reserve University, Cleveland State University, and the University of Toledo. Its purpose is to promote efforts among these institutions in the pursuit of advancing propulsion and power technologies for aeronautical and space applications. The efforts undertaken include research, academic instruction, and information dissemination. In the conduct of research, emphasis is given to working arrangements that bring university faculty and students to the Lewis Research Center for extended periods. Close working relationships with center staff and the use of center facilities are attractions for university participants. Other activities include formal and informal course offerings, symposia, and conferences, both at the center and at the universities.

Lewis Research Center also maintains, through its College Internship Program, arrangements with several local colleges through which school-year internships may be arranged. Some of these programs, such as the Baldwin Wallace College Field Experience Program, involve students volunteering their services on a part-time basis for one school term to satisfy a graduation requirement. Others involve paid full-time experience for a limited work period.

The Spa e Life Sciences Training Program is a 6-week program at Kennedy Space Center which involves the preparation of an actual life sciences experiment to be flown aboard the Space Shuttle. The students (qualified life sciences, medicine, or bioengineering undergraduates) learn how to develop and conduct the test protocols, perform some experiments with themselves as controls, plan and execute a Shuttle crew training session, design and test preflight and postflight procedures, ground test hardwar and equipment, and analyze and evaluate postflight data.

The curriculum involves lectures, experimental design and evaluation, practical laboratory workshops and special training, tours, and films on the Kennedy Space Center and space flight operations. Five semester credit hours are offered to program participants without tuition charge.

Finally, short-term projects involving undergraduates are sponsored from time to time. A recent example co-sponsored by Headquarters, Ames Research Center, and Johnson Space Center and administered through the American Society for Engineering Education was a Spacesuit G ove Design Competition. The challenge was the design of a spacesuit glove which would allow astronauts maximum flexibility at 8.0 p.s.i.d., the pressure at which pre-breathing requirements for extravehicular activity can be reduced. An announcement of opportunity was prepared and 10 university proposals were submitted. From these proposals, four schools (Kansas State University, Massachusetts Institute of Technology, the University of Oklahoma, and Worcester Polytechnic) were selected to compete. Each design class worked independently from September 1984 to May 1985 and designs and prototypes were presented. The competition was won by the University of Oklahoma after a day of very difficult deliberations.

In addition to programs aimed at the university level, NASA has implemented a number of "feeder" programs aimed at elementary and secondary teachers. We appreciate the opportunity to contribute to your work and look forward to receiving your report. Further information on educational programs can be provided by Elaine Schwartz, University Program Manager, at (202) 453-8329.

Sincerely,

Russell Ritchie
Deputy Associate Administrator
for External Relations
National Aeronautics and
Space Administration

Response from the National Institutes of Health

January 10, 1986

Dr. Homer A. Neal
Chairman
Committee on Undergraduate
Science and Engineering Education
National Science Board
Washington, D.C. 20550

Dear Dr. Neal:

This is in response to your request for information concerning the National Institutes of Health's (NIH) efforts regarding college-level education in the sciences.

I understand that, because of the time constraints imposed upon him, Dr. Robert Watson of the National Science Foundation contacted the NIH Research Training and Research Resources Officer earlier in November on this subject. Dr. Doris Merritt has supplied him with information concerning the National Institute of General Medical Sciences (NIGMS) Minority Access to Research Careers (MARC) program, and the Division of Research Resources (DRR) Minority Biomedical Research Support (MBRS) and High School Apprenticeship (HSAP) programs.

You may know that the NIH training emphasis, responsive to its authority to support research in the biomedical and behavioral sciences, is primarily focused on the postbaccalaureate population. We are, however, very sensitive to the needs for education in sciences and mathematics at all levels. We plan to continue our support for the MARC, MBRS, and HSAP programs for the foreseeable future.

I hope this information is helpful. Please let me know if I can be of any further assistance.

Sincerely,

James B. Wyngaarden, M.D.
Director
National Institutes of Health

Attachments

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Attachment 1

Minority High School Student Research Apprentice Program

The Division of Research Resources (DRR), National Institutes of Health (NIH), currently plans to continue the Minority High School Student Research Apprentice Program in 1983. Eligible institutions are those that were awarded grants during federal fiscal year 1982 from either the Biomedical Research Support Grant (BRSG) program or the Minority Biomedical Research Support (MBRS) program, both of which are administered by DRR. Only one application for the Apprentice Program can be submitted by the recipient of both the BRSG and MBRS awards. Support will be provided at a level of $1,500 for each apprentice position allocated, funds for which will be provided as a separate award and accounted for and reported separately. No indirect costs will be paid. Funds not required for apprentice salaries may be used to enrich the research experience, add additional apprentices, or extend the period of research participation. The funds can be used only for costs of the apprentice program and for no other purpose.

The purpose of the apprentice program is to provide meaningful experience in various aspects of health-related research in the expectation that some of the apprentices will decide to pursue careers in research related to health. Direct support to the apprentice must be as salary; *stipends are not allowable.*

Each institution to which apprentice support is awarded will be responsible for designation of a Program Director. The Program Director is responsible for recruitment and selection of the apprentices and assignment of each to an investigator. Additionally, the Program Director must assure that the students are paid promptly. The submission of a report from the Program Director is required by May 31, 1984.

Each apprentice must be offered a minimum of eight weeks full-time experience. Salaries shall be at the prevailing scale for comparable work and in no case less than the federal minimum wage.

A high school student, for purposes of this program, is one who is enrolled in high school during the 1982-1983 academic year. Students who will graduate from high school in 1983 are eligible. Minority students are those who identify themselves as being Black, Hispanic, American Indian or Alaskan native, or Pacific Islander/Asian. A student who participated in the program in 1982 may participate again in 1983 provided the person is still at the high school level.

Selection of students for the program should take into account factors such as ability and scholastic accomplishment. No socio-economic constraints are placed on the eligibility of the students.

Assignments should be made to investigators involved in health-related research who are committed to developing in the high school students both understanding of the research in which they participate and the technical skills involved. Many of the successful assignments made in 1982 resulted in a continuing participation of the students in the same laboratories following the summer experience sponsored by this program.

If you wish to accept students for the 1983 summer program, send a letter stating the number of students you request, but not more than three. Limited funds and increased requests for such student "slots" may limit the final allocations by the program to less than three. Include with your written request an original and three copies of the application face page copy enclosed. Address the request to:

Biomedical Research Support Program
Division of Research Resources
National Institutes of Health
Building 31, Room 5B36
Bethesda, Maryland 20205

The firm deadline for receipt of applications in this office is December 1, 1982. Awards will be effective March 1, 1983, contingent upon availability of appropriated funds.

For further information, contact Dr. Thomas G. Bowery at (301) 496-6743.

Attachment 2

Minority Access to Research Careers Program
(Public Health Service Act, Section 301 and Title IV, Parts E and I)

1985 Current Estimate	1986 Estimate		Increase or Decrease
	Authorization	Amount	
$7,694,000	Indefinite	$7,694,000	—

Budget Mechanism	1985 Current Estimate		1986 Estimate		Increase or Decrease	
	No	Amount	No.	Amount	No	Amount
Training:[1]						
Individual Award	50	866,000	48	663,000	−2	−203,000
Institutional Awards	413	6,828,000	420	7,031,000	+7	+203,000
Total	463	7,694,000	468	7,694,000	+5	—

[1] Numbers are full-time training positions

Purpose and Method of Operation

The underrepresentati of Blacks (over 11 percent of the U.S. population) and otner minority groups (over 5 percent of the U.S. population) in scientific f ds continues to represent a significant loss of potential talent from important segments of our society. For example according to a recent report by the National Science Foundation, in 1982, Blacks acc nted for over 9 percent of total U.S. employment and over 6 percent of all professional employment, but only 2.6 percent of all employed scientists and engineers and only 1.3 percent of all employed Ph.D. sc tists and engineers. In 1982, Hispanics represented almost 5 percent of all employed persons and almost 3 percent of all professional workers, but acc unted for only 2.2 percent of all employed scientists and engineers and 1.5 percent of all employed Ph.D. scientists and engineers. The number of minorities being trained in these areas also is correspondingly small. For example, in 1981, Blacks earned only about 2 percent of the doctoral degrees and received only about 1 percent of the postdoctoral appointments in science and engineering, whil Hispanics earned 1.6 percent of the doctoral degrees and received 1.2 percent of the postdoctoral appointments in these fields.

One of the goals of the National Institute of General Medical Sciences (NIGMS) is to bring about an increase in the number of minority professionals in the various scientific disciplines essential to progress in biomedical research. Accordingly, in 1975, the NIGMS established the Minority Access to Research Careers (MARC) program. This program is designed to provide special research training opportunities and incentives in the biomedical sciences to attract and retain minority students with research career potential. Four mechanisms are used to implement this program. These are: (1) the MARC Honors Undergraduate Research Training Program; (2) the MARC Predoctoral Fellowship Award: (3) the MARC Faculty Fellowship Program; and (4) the MARC Visiting Scientist Award.

The MARC Honors Undergraduate Research Training Program was established in 1977 at the suggestion of the Congress, based on recommendations of institute consultants and staff. It emphasizes the value and importance of providing biomedical research training at the undergraduate level in minority institutions. Its objectives are to help minority institutions develop strong undergraduate science curricula and to increase the number of well-prepared minority students who can compete successfully for entry into graduate programs leading to the Ph.D. degree in the biomedical sciences. Under this program, highly qualified minority institutions receive support to teach and provide research training for honors undergraduates who are in their third or fourth year of college and who plan to obtain the doctorate degree (Ph.D.) in an area of biomedical science. Fifty-two minority institutions around the country have received support under this program. At these institutions there are now approximately 50 percent more science majors than there were prior to the receipt of NIGMS support.

Eligible students are selected on the basis of both their academic achievements and their commitment to seek graduate training. In 1984, the Honors Undergraduate Program had a total of 207 graduates, bringing the total number of graduates since 1978 to 650. To date, approximately 85 percent of these graduates have gone on to either graduate or professional schools. It is hoped that, through this program, there will be a progressive increase in the p ol of qualified minority scientists who are available to compete successfully for research grants and to serve as mentors and role models for new generations of minority biomedical investigators.

The MARC Predoctoral Fellowship Award provides support for outstanding graduates of the MARC Honors Undergraduate Program to pursue doctoral degrees in the biological sciences. Established in 1982, this relatively new award mechanism gives a further incentive to graduates of the Honors Undergraduate Program to obtain research training in the nation's very best graduate programs. Awards are conditional upon acceptance into an approved doctoral (Ph.D.) degree or combined degree (M.D.-Ph.D.) program in the biomedical sciences. In 1984, 44 minority students received financial support under this program.

The MARC Faculty Fellowship Program provides opportunities for advanced research training to selected faculty members of four-year colleges, universities, and health professional schools in which student enrollments are drawn substantially from ethnic minority groups. These institutions may nominate faculty members for MARC Fellowships in support of a period of advanced study and research training in graduate departments and laboratories, either as candidates for the Ph.D. degree or as investigators obtaining postdoctoral research training in the biomedical sciences. When the period of training is completed, fellows are expected to return to their sponsoring schools to do research and teaching. Since its inception in 1972, 180 individuals have received support under this program, including 96 predoctoral and 84 postdoctoral award recipients. Of those who have completed their training period, approximately 82 percent have returned either to their original home institution or to another minority institution. The research training sites have included universities, research laboratories, and federal institutions in 32 states and 5 foreign countries. The home institutions also are broadly representative, including 68 universities in 23 states and the Commonwealth of Puerto Rico.

The MARC Visiting Scientist Award provides support for outstanding scientist-teachers to serve in the capacity of visiting scientists at four-year colleges, universities, and health professional schools in which student enrollments are drawn substantially from minority groups. The primary intent is to strengthen research and teaching programs in the biomedical sciences for the benefit of students and faculty at these institutions by drawing upon the special talents of scientists from other, primarily majority, institutions. Due to the necessity for considerable advance planning on the part of both the host institution and the prospective visiting scientist, only 14 applications have been received and eight awards made since the inception of this award. However, concerted staff efforts to advertise and encourage applications are being made, and both the MARC Review Committee and the National Advisory General Medical Sciences Council strongly support continuation of this award mechanism.

In addition to the above, the MARC program has sought to provide advice and technical assistance to minority students, colleges, and universities wherever possible, and to encourage discussion regarding the obstacles that continue to hold the number of minority scientists in the country to a relatively low level. In 1984, for example, the NIGMS sponsored the fourth MARC Undergraduate Scholars Conference, at which MARC-supported college seniors made poster presentations of their research and met with graduate school faculty and scientist representatives of the NIH to discuss opportunities in graduate education.

Rationale for the Budget Request

The 1986 budget estimate for the MARC program is $7,694,000, the same level as 1985. This level will provide for 468 trainees, an increase of 5 trainees over the 1985 estimate.

To date the MARC program has been remarkably successful in achieving its major objective, i.e., gaining, for highly qualified minority students, entrance into top-flight doctoral programs in the biomedical sciences. Indeed, Stanford University President Donald Kennedy, while testifying last year on behalf of the Association of American Universities and the National Association of State Universities and Land-Grant Colleges before the Committee on the Republican Platform, stated that, with regard to the "serious underrepresentation of minority students in science and engineering graduate programs," the MARC program "has proven to be highly successful in encouraging talented minority students to pursue careers in biomedical research," and that "similar early intervention programs should be developed by the other mission agencies."

Evidence of the success achieved by MARC and other similar programs can be seen by the fact that from 1973 to 1981, the number of Black Ph.D. scientists and engineers in the United States, while still remaining relatively low, increased almost 35 percent, while the number of Hispanic Ph.D. scientists and engineers increased almost 250 percent. In addition, the interest expressed in MARC trainees by research laboratories throughout the country (as indicated by offers of short-term research training experiences) has been highly encouraging. Of importance in coming years will be the ability of MARC program graduates to compete successfully for research grant funds from the NIH and other sources.

For further information, contact Ms. Delores Lowery at (301) 496-7941.

Attachment 3

Minority Biomedical Research Support
(Public Health Service Act, Title III, Section 301)

1985 Current Estimate	1986 Estimate Authorization	1986 Estimate Amount	Increase or Decrease
24,951,000	Indefinite	24,951,000	—

Budget Mechanism	1985 Current Estimate No.	1985 Current Estimate Amount	1986 Estimate No.	1986 Estimate Amount	Increase or Decrease No.	Increase or Decrease Amount
Other research	83	24,951,000	79	24,951,000	−4	—
Total		24,951,000		24,951,000		—

Purpose and Method of Operation

Although ethnic minority groups comprise more than 18 percent of this country's total population, they make up less than 2 percent of the Ph.D. science and engineering workforce. While employment of Blacks in science and engineering (S/E) increased over 85 percent from 1976 to 1981, the representation of this group in S/E jobs in 1981 was only 2 percent. Blacks represented about 7 percent of those in all professional and related jobs but only 2 percent in S/E. Persons of Hispanic origin are also underrepresented in the doctoral S/E workforce (about 1.4 percent in 1981), even though the number of Hispanics in S/E has doubled since 1977. (Data from *Science Indicators, 1982*, published by the National Science Board, 1983.) In a special report published by the Rockefeller Foundation *Who Will Do Science* (November 1983), the data show that the ratio of Ph.D. degrees to population is still disproportionately low for minorities, with the exception of Asian-Americans: Blacks, 0.41; Hispanics, 0.31; American Indians, 0.66; and Asians, 1.33. This represents an average of 0.46 for non-Asian minorities, compared to 1.11 for Whites.

The Minority Biomedical Research Support (MBRS) program, begun in 1972, was established to increase the number and quality of minority biomedical research scientists. The program focuses on the current investigator groups (the faculty) and on the future potential investigator groups (the students).

A typical MBRS grant consists of a discrete set of research projects and a program director who administers the entire program. Each discrete project is headed by one or more faculty members. There may also be a technician involved in the project either supported by the MBRS program or from other funds. Undergraduate and/or graduate students participate as junior or apprentice investigators with the faculty member and the staff within that laboratory. Typically, the level of MBRS support to each project depends on the type of institution and on the level of other research support that the faculty member may have.

Investigators are supported in the MBRS program for biomedical research spanning the portfolio of NIH research activity. There are projects in clinical areas, basic biological studies, diabetes, nutrition, hypertension, arthritis, disease prevention in the area of immunology, and basic research in development of drugs by organic chemists. Research projects in the social and behavioral sciences, environmental health sciences, and alcohol and drug abuse are also supported through this program.

The funding mechanisms used in fiscal year 1984 involved the regular MBRS grant as described above, with an additional set-aside for supplemental grants for shared instrumentation.

The subprojects in each parent grant can be co-funded by other institutes at NIH and ADAMHA. In 1984, an additional $9.9 million for 260 subprojects was provided from these sources.

In 1985, two new program activities were announced: the MBRS Thematic Project Grant program and the Minority Biomedical Research Support Grant for Undergraduate Colleges.

The MBRS Thematic Project Grant is a new program initiative for 1985, intended to be responsive to significant changes in some MBRS institutions. Certain of these institutions with developing graduate programs have by now acquired a critical mass of biomedical research faculty, expanded and updated research equipment, and other biomedical research resources. They are now capable of developing increased faculty and interdepartmental collaboration around specific research themes or disciplines. The Thematic Project Grant is intended as another transitional step toward regular NIH grant support.

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The Undergraduate College Program, also begun in fiscal year 1985, provides more flexibility than the regular MBRS program awards for faculty and students at small undergraduate schools. The principal objective is to enrich the environment at eligible undergraduate institutions in order to provide increased awareness among students of the possibilities for pursuit of biomedical research careers, and to provide faculty members with the opportunity to participate in biomedical research.

Support is provided for one or more of the following:

- Biomedical research enrichment activities (e.g., seminars, scientific meetings, workshops, off-campus research experiences) for the benefit of both faculty and students;
- Pilot studies for research initiation by faculty, and
- Research projects for faculty.

In fiscal year 1984, the MBRS program supported 1,020 undergraduate students, 388 graduate students, and 736 faculty involved in 645 research projects at 81 institutions. Research accomplishments were reported in 777 scientific papers published by MBRS faculty and students, and in 726 faculty and 879 student presentations at scientific meetings. Of the 586 MBRS students who graduated in 1983 (the latest data available), 143 reported acceptance into medical schools, 21 reported acceptance into dental schools, 191 reported acceptance into graduate schools, and 135 pursued health careers at other schools (such as public health, pharmacy, medical technology). In ongoing studies designed to determine the career choices of former MBRS students, a total of 118 have been identified as having been awarded Ph.D. degrees from all institutions that award Ph.D.'s in the United States. A significant number of these were awarded by the few MBRS institutions that award the Ph.D. degree. Additional studies are under way to identify the numbers who received health professional degrees.

Student participation at some institutions has been particularly active, for example, at Catholic University of Puerto Rico, 193 undergraduates have participated in the MBRS program since 1972. Of these, 153 have received baccalaureate degrees, mostly in chemistry (81) and biology (56) As of May 1984, 35 had reported acceptance into medical school; 32, graduate school; and 30 were employed as chemists and 20 as medical technologists. Sixteen have received the M.D. degree, 3 are dentists, and at least 9 have received Ph.D.'s or are in Ph.D. programs.

The MBRS program at Xavier University in New Orleans, begun in 1972, exemplifies the impact of MBRS support on student development. Data available as of January 1, 1983, indicate that 244 students have participated. The graduates include 22 physicians, 7 dentists, 2 Ph.D.'s, 1 optometrist, and 19 medical technologists. Additionally, 5 students were awarded the master's degree, and 26 students are currently enrolled in graduate or medical school (18 are candidates for the M.D., 2 for the D.D.S.; 5 for the Ph.D., and 1 for the L.L.D.)

At the 12th Annual MBRS Symposium on April 10-13, 1984, in Washington, D.C., some 1,500 MBRS student and faculty members participated. The students presented 570 scientific papers and poster displays. Both faculty and students engaged in workshops on electron microscopy and high-performance liquid chromatography. Lectures and mini-symposia on "Nutrition and Aging," "Hypertension," and "AIDS" also were well-attended by interested students and faculty.

Examples of research accomplishments by MBRS faculty and students in fiscal year 1984 follow.

The MBRS program at the University of Hawaii is one that provides students the opportunity to work with investigators who are well-established as independent biomedical research scientists. This allows each student the opportunity to become familiar with the research process that is being used by the faculty mentor as a specific research question is being pursued. A typical example of this type of MBRS student research experience involves the isolation, purification, and characterization of the hormone relaxin by one of the investigators at this university. Working in this laboratory, students are able to understand the important role that relaxin plays in the rapid delivery of the fetus. Relaxin increases the rate of thinning of the cervix in women induced to labor, and thereby decreases the number of contractions necessary for the delivery. The use of this hormone obviates the need for a caesarean section in many women.

MBRS investigators at New Mexico State University have been studying how the bacterium, *B. subtilis*, accomplishes and controls intracellular protein degradation at the molecular level. They have developed a chemically defined growth and sporulation medium for *B. subtilis* which results in very high rates of intracellular protein degradation. In searching for a regulatory mechanism to explain this phenomenon, they have identified a protein inhibitor which has physical properties comparable to calmodulins. Calmodulins have previously been found in eukaryotic and gram-negative bacteria. The discovery of calmodulin in *B. subtilis* is a very significant finding because it is believed to be the first time that calmodulin has been found in a gram-positive bacterium. An MBRS undergraduate student conducted the initial work that led to this discovery.

In research at the Florida A&M University College of Pharmacy, an MBRS-supported pharmacology professor and graduate student have found preliminary evidence that suggests that diabetes adversely affects the nervous system in rats by interfering with the production of two enzymes, acetylcholinesterase (AChE) and choline acetyltransferase (ChAT). Both of these enzymes regulate the action of acetylcholine, a chemical responsible for transmission of nerve messages in the body. AChE breaks down acetylcholine, while ChAT stimulates its production. In rats with drug-induced diabetes, the investigators detected abnormal levels of these enzymes in the brain. Diabetes apparently stimulates the production

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of both enzymes. The animal system attempts to maintain a normal level of acetylcholine, but, after a few days, the balance between the two enzymes is no longer maintained and the acetylcholine level becomes exceptionally high.

These studies are significant because other studies in humans have linked high levels of acetylcholine to depression. Some investigators also reported a relationship between diabetes and depression.

The long-range goal is to find a drug therapy that can reduce the production of the cholinergic (ChAT) enzyme and alleviate some of the adverse effects that diabetes has on the nervous system. If such a drug is discovered through this research in rats, it may eventually lead to clinical trials in humans.

Rationale for the Budget Request

The 1986 budget request for the MBRS program of $24,951,000 is the same level as in 1985. At this level of funding, the program will be able to maintain support to 79 MBRS awards, four fewer than in 1985. The Thematic Project Grant initiative and the Undergraduate College Program, both of which are beginning in 1985, will be continued in 1986 at the same level as in 1985.

Efforts will be continued in 1986 to address needs for research equipment at MBRS institutions. The 1986 request includes $1.0 million for supplemental awards, to be awarded on a competitive basis, for new research instrumentation.

Funds provided through co-funding arrangements by the categorical institutes of the NIH as well as by the National Institute of Mental Health in 1986 will continue to help expand the number of research projects that can be supported. In 1986, the categorical institutes of the NIH have budgeted $10,050,000 for co-funding support of the MBRS program, thus bringing the total anticipated funding level by NIH in 1986 to $35,001,000, an increase of $132,000 over the 1985 current level.

For further information, contact Dr. Ciriaco Gonzales at (301) 496-6745.

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VI. Subject Index

This index provides broad subject access to the wealth of material presented in the testimony to the Committee. References indicate the author and the first page number of the testimony.

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