NSB 86-100

Undergraduate Science, Mathematics and Engineering Education

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
March 1986

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NATIONAL SCIENCE BOARD
WASHINGTON, D.C. 20550

March 20, 1986

Dr. Roland W. Schmitt
Chairman
National Science Board
Washington, D.C. 20550

Dear Roland:

I am pleased to transmit to you the final report of the National Science Board Task Committee on Undergraduate Science and Engineering Education. In pursuing your charge to the Committee we have kept clearly in view the responsibility entrusted to the National Science Board to promote research and education in science and engineering in the United States.

In this report we state our conviction that the National Science Foundation must both assume a leadership role and provide highly leveraged program support for undergraduate science, mathematics and engineering education in order to successfully meet critical needs that affect the health of the Nation.

The Committee consulted widely across the Nation and within the National Science Foundation in the conduct of its business. At public hearings and through submitted testimony we heard from leaders representing academic institutions, industry, government, and professional societies. There were also numerous interactions with members of the National Science Board and NSF staff. The issues we dealt with are complex and often interactive and as such are not easily resolved. Their proper treatment will require carefully developed plans and sustained efforts by many sectors.

We are greatly heartened that many members of the Board, and others as well, are expressing strong support for a meaningful leadership role for NSF in undergraduate science, mathematics and engineering education. The Committee is appreciative of the Director's genuine interest and active participation in its work, and we are grateful for his input to the development of this report.

I would like to thank the members of the Committee for the deep sense of responsibility that they brought to this task. In addition, many members of the NSF staff, from the Board Office, and from several Directorates, were quite helpful and made significant contributions to our work.

We commend your foresight in establishing the Committee. We are available for further consultation as may be needed. The Committee is very hopeful that this report will trigger the necessary action that we urge upon all sectors concerned with the quality of undergraduate education in science, mathematics, and engineering. As announced since establishment of the Committee, the report is to be distributed widely and we urge that it be made available to appropriate individuals and organizations.

Sincerely,

Homer A. Neal

Homer A. Neal
Chairman, NSB Task Committee
on Undergraduate Science and
Engineering Education

Members of Committee:

Jay V. Beck
Rita R. Colwell
Thomas B. Day
James J. Duderstadt
Norman C. Rasmussen
James L. Powell, Advisor
Lester G. Paldy, Consultant
Robert F. Watson, Executive Secretary

National Science Board Resolution *re* Report of the Task Committee on Undergraduate Science and Engineering Education

RESOLVED: The National Science Board hereby accepts the Report of the NSB Task Committee on Undergraduate Science and Engineering Education and thanks the Task Committee for its efforts.

Further, the Board requests that the Director, in close consultation with the NSB Committee on Education and Human Resources, prepare a plan of action to respond to the report focusing on new and innovative program approaches that will elicit creative proposals from universities and colleges, and submit such plan to the Board as part of the National Science Foundation FY 1988 budget process.

March 21, 1986

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IV. APPENDICES

References to oral and written testimony, (Wxy), are listed in Appendices B.1-B.3. Bibliographic references, (Bxy:ab), are listed in Appendix B.4.

INTRODUCTION

This report is the outcome of a year-long study conducted by the National Science Board Task Committee on Undergraduate Science and Engineering Education. The Task Committee was established because there were numerous signs that U.S. undergraduate education was developing serious problems; and because of our perception of the responsibility shared by the Board and the National Science Foundation for the health of U.S. academic science and engineering. Although the Committee's principal original charge was to consider the role of the NSF in undergraduate education, this was extended appropriately to include consideration of the needs for action by other sectors as well.

This report provides an analysis of the current condition and trends in U.S. undergraduate education in the sciences, mathematics and engineering. It contains suggestions for actions to be undertaken by academic institutions and their governing bodies, the States, the private sector, and other Federal agencies, as well as by the National Science Foundation.

During the course of its study, the Committee received information from many sources. 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 statements and reports from a number of concerned individuals and organizations. We are most appreciative of the time and efforts expended by so many people in contributing to the report. In particular, we acknowledge the outstanding work of the Committee and its chairman, Dr. Homer Neal.

The report contains much useful information and reflects strong opinions of a broad cross-section of persons knowledgeable of U.S. science and technology about a serious national concern. We hope the report will be of interest to and serve as a basis for discussion by those who are actively concerned with the quality of the Nation's colleges and universities and our country's long-term economic health.

In its response, the Foundation will prepare a plan emphasizing new and innovative approaches with reference to the information and recommendations contained in the report. This Plan will have to be devised in the context of severe budgetary pressures and large competing demands. Thus, its implementation poses a great challenge to all concerned with the quality of higher education. But, we must all take action or suffer the consequences of an ever diminishing quality in the education of the Nation's future scientists and engineers.

Roland W. Schmitt
Chairman
National Science Board

Erich Bloch
Director
National Science Foundation

ACKNOWLEDGMENTS

Many individuals and groups contributed to the work of the Task Committee leading to this report. The individual witnesses and those who spoke to the Committee as representatives of organizations are listed in the Appendices. We are grateful for their statements, ideas, and cooperation.

We are especially grateful for the continued staff efforts by members of the National Science Foundation: Peter E. Yankwich, who served as co-principal writer with the Task Committee's Executive Secretary Robert F. Watson, and their assistants—Myra J. McAuliffe, Judith M. Glover, Saundra F. Lesesne, and Sadie R. Jones.

The source of much of the data contained in the report is the Division of Science Resources Studies. William L. Stewart, Charles H. Dickens, Mary J. Golloday, Felix H. Lindsay and Penny Foster reviewed the entire manuscript of the report. Special data were provided by Peter W. House and Rolf F. Lehming, Division of Policy Research and Analysis.

Data presentation was developed by Janell C. Walker, Division of Administrative Services, assisted by Marie M. McIntosh and Chris J. Gordon.

Thomas Ubois, Executive Officer of the National Science Board, and Catherine M. Flynn, Staff Assistant, smoothed the path of the Committee in many ways.

A particular debt of gratitude is owed to Alexandra M. Wolman of the NSF Staff, assisted by Patricia A. Burbank, Sherrie Sykes (Office of the General Counsel), and Kimberly Gibson, upon whom fell the seemingly endless task of preparing the drafts and redrafts of the text of this report.

Finally, we express special thanks to Bassam Z. Shakhashiri, National Science Foundation's Assistant Director for Science and Engineering Education.

Homer A. Neal

Homer A. Neal
Chairman
National Science Board
Task Committee on
Undergraduate Science and
Engineering Education

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 1980's - 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 nation-wide 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.

A. 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 nation-wide 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 very few opportunities and incentives for faculty to contribute and compete on a national basis for support of scholarly and creative activities related to teaching as 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 18-19 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 9 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.*

B. 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; and 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.

- *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 fifteen years from 0.43% to 0.68% 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 *Department 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.

C. 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 which 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:

- 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;
- timely and responsive consideration by legislatures of recommendations for improvement of undergraduate mathematics, engineering, and science education in two- and four-year colleges and in universities;
- 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);
- careful long-range planning for the renewal of facilities, equipment, and other physical resources; and
- 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:

- 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;
- development of both short-range and long-range plans for modernization of undergraduate instructional and research equipment;
- careful long-range planning for the renewal of facilities, equipment, and faculties;
- strong support of faculty efforts to update and upgrade courses and curricula designed to meet the needs of both majors and non-majors;

- 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;
- joint efforts with other institutions to improve the school-to-college, two-year to four-year college, and undergraduate-to-graduate transitions; and
- expansion of partnerships in education with industries and other organizations in the private sector.

To the Private Sector:

- greater and more stable support for undergraduate education in mathematics, engineering, and the sciences;
- expanded partnerships with colleges and universities in efforts to improve pre-professional education; and
- increased corporate efforts to improve the public understanding of science and technology.

To Mission-Oriented Federal Agencies:

- 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.
- Those agencies also should consider providing incentives to contractors and grantees for appropriate inclusion of undergraduate components in their work.
- 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.
- 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 nation-wide.

D. Recommendations to the National Science Foundation

Current national policy and federal strategy recognize that education in science, engineering and mathematics are 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*.

1. 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:

- 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;
- implement new programs and expand existing ones for the ultimate benefit of students in all types of institutions;
- actuate cooperative projects among two-year and four-year colleges and universities to improve their educational efficiency and effectiveness;
- stimulate and support a variety of efforts to improve public understanding of science and technology;

- 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;
- bring its programming in the undergraduate education area into balance with its activities in the precollege and graduate areas as quickly as possible;
- expand its efforts to increase the participation of women, minorities, and the physically handicapped in professional science, mathematics, and engineering;
- 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; and
- 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.

2. 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.

- Laboratory Development .... $20 million
  (supporting development projects to improve the laboratory component of science and engineering instruction)
- Instructional Instrumentation and Equipment .... $30 million
  (encouraging and supporting joint efforts to remedy the serious deficiencies of instructional instrumentation and equipment)
- 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)
- Course and Curriculum Development . $13 million
  (encouraging and supporting efforts to improve the ways in which technical knowledge is selected, organized, and presented)
- 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)
- 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)
- Minority Institutions Program .... $ 5 million
  (strengthening the capability of minority institutions to increase the participation of minorities in professional science, mathematics, and engineering)
- 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 United States 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 FY 1988*; attainment of a total of *$100 million in new funds by FY 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 detailed in later sections 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 *nation-wide* effort that can *solve* these problems.

NSF Budget Estimate		*Recommended Funding Above FY 1987 Budget Estimate*	
FY 1987. $13	Program (short title)	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 considered carefully 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:

- *Increased Participation of Women, Minorities, and Physically Handicapped.* The NSF should actively seek this goal in implementing the above recommendations, including program management and proposal review, and the projects that are supported.

- *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.

- *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 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.

E. 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. FINDINGS

"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 is dependent upon the maintenance of a sufficient number of adequately trained scientists and engineers to respond to national needs and priorities." Frederick Humphries, President, Florida A&M University (W24).

A. Background

1. Undergraduate Education. . .

Nowhere else in the world have Nations succeeded in creating a system of higher education that reaches such a broad cross section of citizens as in the United States. The quality we strive for and the standards we establish for this enterprise are sensitive measures of our aspirations for the American future.

There are nearly 3,300 institutions of higher learning in the U.S., two- and four-year colleges, master- and doctoral- granting universities, and specialized institutions; 2,700 of these have courses of study in science and engineering (Table A) (B1:266). In the Fall of 1984, these 3,300 institutions enrolled over 12,300,000 students, of whom 10,700,000 were undergraduates. Enrollment trends since 1970 and projections through 1993 are shown in Table B (B2:98) and Chart 1 (B2:99).

Undergraduate programs build on the experiences of students accepted from our Nation's diverse precollege school systems, ranging from those flourishing in affluent locales to others struggling in inner city blight and rural poverty. Reciprocally, challenging and well-conceived undergraduate education can help to elevate the quality of precollege programs across the Nation.

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 (B3). Partly in consequence of the alarm sounded by the Commission's 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 (B4).

Graduates of the four-year colleges and universities enter business, industry, and government, or continue their education in graduate or professional programs. Graduates of two-year colleges and technical institutes provide an important human resource for industry and a steady stream of transfer students for four-year colleges and universities. American technological competitiveness in the international arena in the future will be influenced by these sometimes overlooked programs.

A significant fraction (31%) of college and university students graduate today with majors in scientific and technical areas, and these students constitute the scientific and technological leadership pool that must support American innovation and discovery for nearly half of the next century (B5).

Attention has not yet been focused on the essential bridge between the schools and the national apparatus for research and development: undergraduate education in mathematics, engineering and the sciences. A few states (e.g. Kentucky, Tennessee, New Jersey and California) have taken significant steps to improve the quality of instruction in those fields in the colleges and universities they support. However, appropriations for higher education in most states are not increasing rapidly enough to correct the effects of erosion by inflation during the past fifteen years (B6).

The same concerns that led to recent school-oriented educational improvement efforts 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. In the main, those steps have been directed at the graduate education level. Industry has given some increased attention to the research coming from graduate education, though its direct support of such activities is still a small fraction of that provided by the State and Federal Governments (B7).

The Nation counts on its diversified population of college graduates to provide leadership in business, government, education, agriculture, media, and the arts. The quality of their undergraduate contacts with science, mathematics, and engineering will be reflected in many forums in the future. The knowledge and training of these graduates and their ability to continue to learn, more than any other tangible resource, constitute the future wealth of the Nation.

TABLE A

Institutions of higher education and institutions awarding S/E degrees, by highest degree awarded: 1960-84

Year	Total higher education institutions	Four-year institutions						Two-year institutions
		4-year institutions	Granting S/E degrees (highest degree)				Not granting S/E degrees	
			Total	Bachelors and first professional	Master's	Doctor's		
1960	2,021	1,446	1,056	735	180	141	390	575
1961	2,034	1,441	1,090	748	189	153	351	593
1962	2,050	1,464	1,112	745	212	155	352	586
1963	2,106	1,476	1,125	754	209	162	351	630
1964	2,146	1,509	1,147	757	218	172	362	637
1965	2,189	1,532	1,165	754	233	178	367	657
1966	2,247	1,565	1,178	745	246	187	387	682
1967	2,347	1,592	1,217	752	271	194	375	755
1968	2,392	1,603	1,223	746	281	196	380	789
1969	2,503	1,636	1,254	756	292	206	382	867
1970	2,544	1,654	1,274	762	292	220	380	890
1971	2,573	1,681	1,276	760	287	229	405	892
1972	2,626	1,689	1,362	795	319	248	327	937
1973	2,689	1,772	1,396	815	318	263	376	967
1974	2,744	1,737	1,400	802	327	271	337	1,007
1975	3,012	1,871	1,420	813	340	267	451	1,141
1976	3,026	1,898	NA	NA	NA	NA	NA	1,128
1977	3,046	1,905	NA	NA	NA	NA	NA	1,141
1978	3,095	1,925	1,445	804	359	282	493	1,170
1979	3,134	1,925	NA	NA	NA	NA	NA	1,209
1980	3,152	1,934	NA	NA	NA	NA	NA	1,218
1981	3,231	2,007	1,447	793	361	293	560	1,224
1982	3,253	2,039	1,457	797	365	295	582	1,214
1983	3,280	2,074	NA	NA	NA	NA	NA	1,206
1984	3,284	2,012	NA	NA	NA	NA	NA	1,272

Note: NA = Not available.

SOURCE: National Science Foundation: Science Indicators, 1985

2. . . .and The National Science Foundation

The National Science Foundation (NSF) has statutory authority to support undergraduate education via Section 3(a) of the National Science Foundation Act of 1950 (as amended) which states that "the Foundation is authorized and directed:

> *"(1). . .to initiate and support basic scientific research and programs to strengthen the mathematical, physical, medical, biological, scientific research potential and science education programs at all levels . . ."*

Throughout the 1960's and early 1970's, the National Science Foundation had an extensive program of support for undergraduate research participation, faculty development, laboratory instrumentation, and development of new curriculum materials.

An average of approximately $30 million per year ($100 million in 1985 dollars) was channeled into these important activities. However, questions about the proper role in education of the Federal Government, issues associated with perceptions of program focus, effectiveness, and financial exigency caused NSF undergraduate program support levels to be reduced severely in later years.

The history of NSF's support for graduate, undergraduate, and precollege education through its Science and Engineering Education Directorate is depicted in Chart 2 and Table C. Chart 3 compares these data for education support with the history of total NSF funding since 1960 (B8:39, updated).

The following listing is a brief description of some of the major undergraduate support programs formerly conducted by NSF.

Students:

- *Undergraduate Research Participation Program (URP)*—Operated from 1959-1981, this program provided summer full-time support, sometimes coupled with part-time academic year activities, for undergraduate students to work with faculty on *specially designed*

TABLE B

Past and Projected Trends in Total Enrollment in Institutions of Higher Education, by Control and Type of Institution and by Level of Student: United States, Fall 1970 to Fall 1993

(In Thousands)

		Control of Institution		Type of Institution		Level		
Fall of Year	Total Enrollment	Public	Private	4-Year	2-Year	Undergraduate and Unclassified	Graduate and Postbaccalaureate Unclassified	First-Professional
1970	8,581	6,428	2,153	6,358	2,223	7,376	1,031	175
1971	8,949	6,804	2,144	6,463	2,486	7,743	1,012	194
1972	9,215	7,071	2,144	6,459	2,756	7,941	1,066	207
1973	9,602	7,420	2,183	6,590	3,012	8,261	1,123	218
1974	10,224	7,989	2,235	6,820	3,404	8,798	1,190	236
1975	11,185	8,835	2,350	7,215	3,970	9,679	1,263	245
1976	11,012	8,653	2,359	7,129	3,883	9,429	1,333	251
1977	11,286	8,847	2,437	7,242	4,042	9,714	1,318	251
1978	11,259	8,784	2,475	7,232	4,028	9,684	1,319	257
1979	11,570	9,037	2,533	7,353	4,217	9,998	1,309	263
1980	12,097	9,457	2,640	7,571	4,526	10,475	1,343	278
1981	12,372	9,647	2,724	7,655	4,716	10,754	1,343	275
1982	12,426	9,696	2,730	7,654	4,772	10,825	1,323	278
1983	12,465	9,683	2,782	7,739	4,726	10,846	1,339	279
					Projected*			
1984	12,345	9,645	2,700	7,600	4,745	10,715	1,345	285
1985	12,247	9,591	2,656	7,437	4,810	10,551	1,398	298
1986	12,162	9,533	2,629	7,358	4,804	10,447	1,413	302
1987	12,136	9,518	2,618	7,317	4,819	10,410	1,424	302
1988	12,141	9,528	2,613	7,303	4,838	10,417	1,424	300
1989	12,161	9,548	2,613	7,306	4,855	10,439	1,425	297
1990	12,093	9,498	2,595	7,264	4,829	10,371	1,427	295
1991	11,989	9,419	2,570	7,195	4,794	10,266	1,430	293
1992	11,810	9,284	2,526	7,071	4,739	10,096	1,422	292
1993	11,676	9,185	2,491	6,968	4,708	9,968	1,418	290

*For methodological details, see *Projections of Education Statistics to 1992-93*, 1985.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Higher Education General Information Survey, *Fall Enrollment in Colleges and Universities*, various years; *Projections of Education Statistics to 1992-93*, 1985, and unpublished tabulations (December 1984).

research projects. One goal was to induce faculties to incorporate this type of activity into the regular curriculum for majors. In 1966, the program supported 6,500 students with a budget of $6.8 million, with proposals requesting support for over 30,000 students.

Curriculum and Materials:

- *Instructional Scientific Equipment Program (ISEP)*—Operated from 1961-1981, this program provided matching funds for instruments to implement instructional laboratory improvement and development plans. ISEP was open to all institutions.

- *Science Curriculum Improvement Program (SCIP)*—Operated under this name from 1958-1972, with name changes thereafter, the activity supported curriculum and course research and development activities. In the 60's SCIP supported the commissions (eg., Commission on College Physics); was responsible for such projects as the creation of computer language BASIC, and noted educational materials and films such as the film "Powers of Ten." Later projects in the 70's included creation of AMCEE (Association for Media-based Continuing Education for Engineers) and the CAD/CAM (Computer-Assisted Design/Computer-Assisted Manufacturing) Engineering Project, a consortium of major engineering schools to develop and disseminate CAD/CAM materials and curricula.

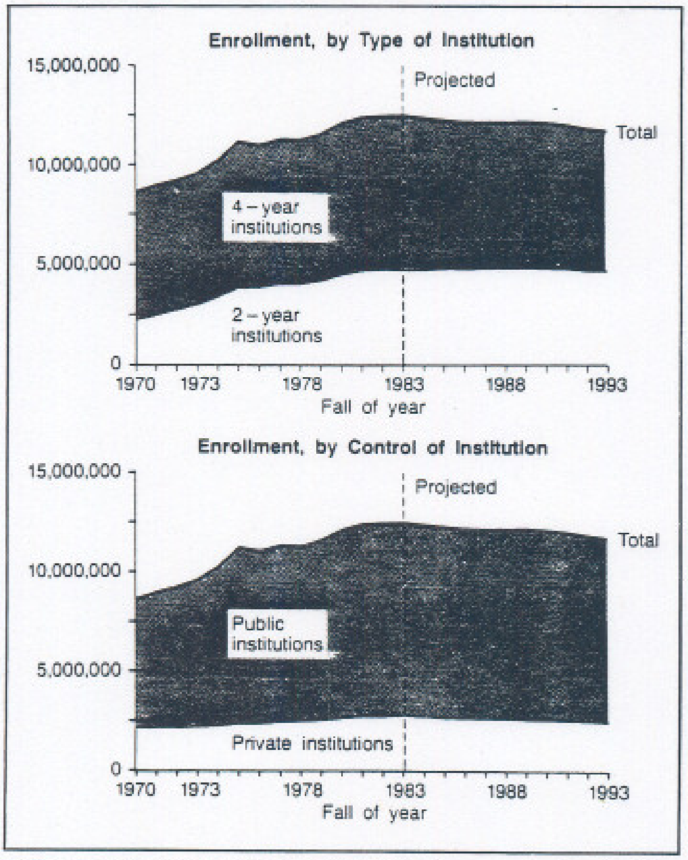
- *Local Course Improvement (LOCI)*—Focused course development projects by individual faculty or small groups; produced both local changes and published software, materials, etc.

Institutional Development:

- *College Science Improvement Program (COSIP)*—Operated 1967-73, supported comprehensive plans of predominantly undergraduate colleges and con-

CHART 1

Enrollment Trends in Institutions of Higher Education, by Institutional Characteristics



Enrollment in 4-year institutions is projected to decrease significantly during the 1980's and into the 1990's, while enrollment in 2-year institutions is projected to decline slightly in the early 1990's. Enrollments in both public and private institutions are expected to fall over the next decade.

SOURCE: The Condition of Education: 1985 Edition, National Center for Education Statistics, U.S. Department of Education

sortia for development of their science instructional programs. One component was for consortia of 2-year colleges and universities, another was for minority institutions (later renamed and moved to Department of Education in 1980).

- *Comprehensive Assistance to Undergraduate Science Education (CAUSE)*—Operated from 1976-81, similar to COSIP, but open to all institutions.
- *Resource Centers for Science and Engineering*—Operated from 1978-81. Minority education was the focus of these four major ($2.8 million each) awards to four regionally dispersed sites. Programs brought together colleges, schools, and communities to improve performance and participation of minorities in science and engineering.

Faculty:

- *Science Faculty Fellowships*—Operated from 1957-1981 (except 1972 and 1973). Awards to individual faculty in partial support of sabbatical leave-type activity, for study and for research, to enhance their effectiveness as teachers.
- *College Teacher Workshops and Seminars*—Operated from 1956-1975. Awards to professional societies, educational institutions, industry and non-profit organizations for two to five week summer conferences for undergraduate faculty, dealing with recent advances in scientific research or newly emerging fields.
- *Research Participation for College Teachers*—Operated from 1959-1970, and intermittently in the 1970's. Awards to academic and other research organizations for support of faculty from small colleges to participate in scientific research in summers.
- *Chautauqua Short Courses*—Operated from 1970-1982. Regional field centers provided 2-3 day sessions for faculty on recent advances in science and technology by reseachers in the field. Program reached up to 5,000 faculty yearly.

At present, there are two NSF activities supporting undergraduate education in the Directorate for Science and Engineering Education: (l) The Office of College Science Instrumentation provides partial funding for efforts by four-year colleges to improve their laboratory instruction and to acquire modern instrumentation; the 1986 budget for this activity is $5.5 million. (2) A small program in the Division of Teacher Preparation and Enhancement funds model programs that exhibit potential to improve the preparation of undergraduates who plan to teach science and mathematics at the precollege level (ca. $6 million per year).

The Foundation supports research in non-doctoral institutions in several ways. The regular research support programs (RSP) placed $36.9 million there in 1985; Research in Undergraduate Institutions program (RUI), $8.8 million; and the program for Research Opportunity Awards (ROA), $1.4 million. However, it is important to note that these programs do not address directly many of the deficiencies identified in this study.

3. The Need for Change

> *"The strains of rapid expansion, followed by recent years of constricting resources and leveling enrollments, have taken their toll. The realities of student learning, curricular coherence, the quality of facilities, faculty morale, and academic standards no longer measure up to our expectations. These gaps between the ideal and the actual are serious warning signals. They point to both current and potential problems that must be recognized and addressed."*
> Involvement in Learning, *The Final Report of the Study Group on the Conditions of Excellence in American Higher Education (B11:8).*

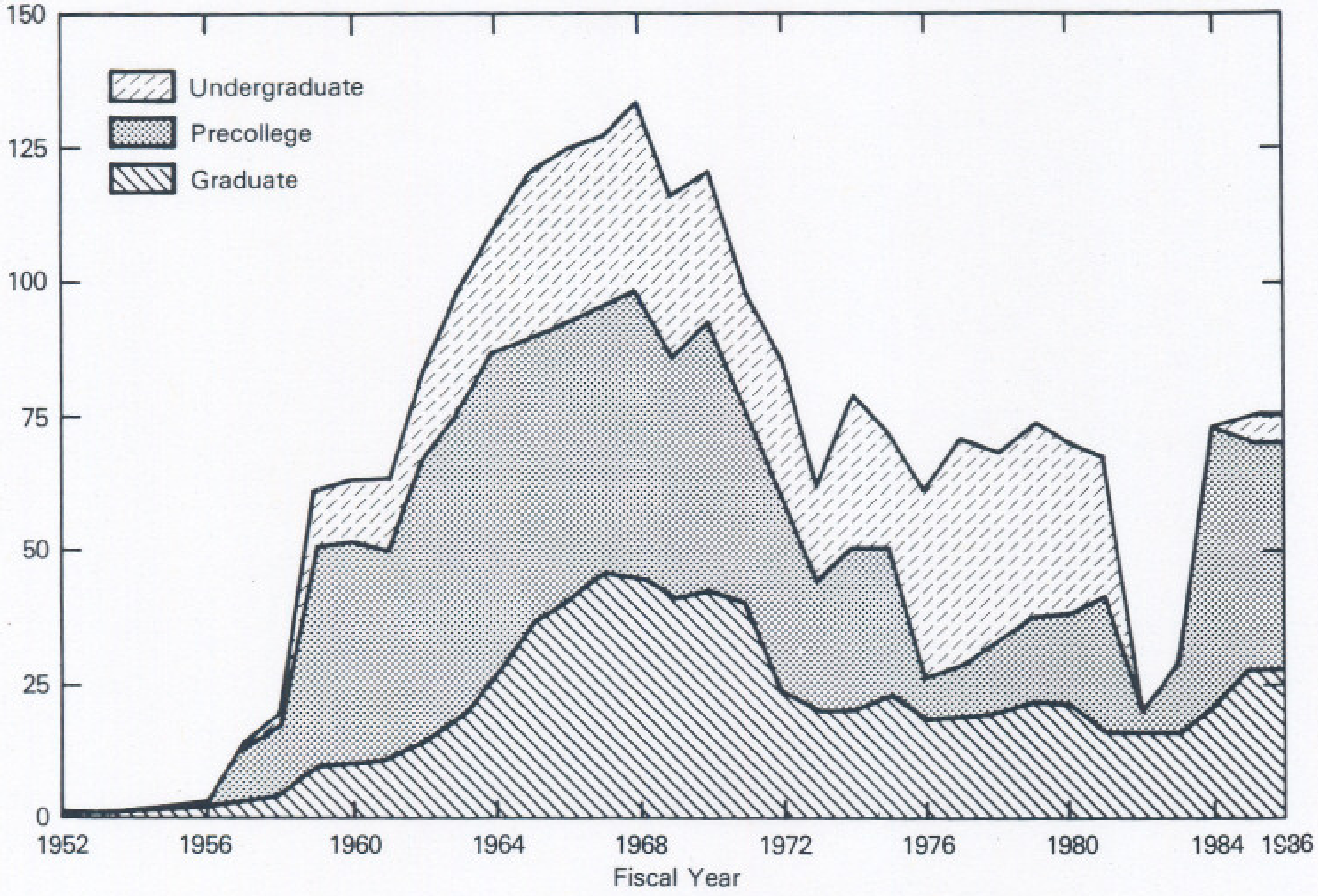


CHART 2

Science and Engineering Education Directorate Obligation Trends

(Millions of Dollars)

SOURCE: National Science Foundation: Science and Engineering Education Directorate (SEE).

Numerous national study groups (B9-B14), NSF advisors (B15), and leaders from government, industry, and the academic community (W1-W41) have identified deficiencies in the quality of undergraduate education in the United States, emphasizing the need for Federal leadership in this area. They assert that:

- The great majority of undergraduate students—who will become community leaders and decision makers—are not receiving the special kinds of scientific, technical and mathematical knowledge they need, which includes the principles, practices, and techniques of science and awareness of its limits.
- Texts and other instructional materials are kept in use even though they are seriously outdated, and the use of advanced information technologies is not being explored. This situation may reflect reduced faculty ability and incentive to learn about and integrate new developments into the curriculum. The "cottage industry" of random faculty textbook writing is no longer adequate to meet the need for high quality new materials and modes of college-level instruction.
- Students of science embark upon lifetimes of professional work of critical importance to the Nation from schools unable to offer even minimal practical experience of high quality. Laboratory programs and hands-on experience are so deficient that graduates enter upon their careers or begin advanced training in their fields without exposure or practice in the most central professional skills.
- The situation in engineering is especially distressing, for the baccalaureate degree is the main point of entry into practice. The engineering and technical professionals who enter the work force at the end of

TABLE C

National Science Foundation Education Obligations by Level of Education

(in millions of dollars)

Fiscal Year	Total NSF Dollars	Total SEE Dollars	Percent SEE of Total	LEVEL							
				Precollege		Undergraduate		Graduate		Informal	
				%	$	%	$	%	$	%	$
1952	3.47	1.54	44.4	0	0	0.3	.005	99.7	1.54	0	0
1953	4.42	1.41	31.9	0.7	0.01	2	.03	97	1.37	0	0
1954	7.96	1.89	23.7	2	0.04	5	.09	93	1.76	0	0
1955	12.49	2.10	16.8	6	0.13	9	.19	85	1.79	0	0
1956	15.99	3.52	22.0	24	0.85	16	.56	59	2.08	0	0
1957	38.63	14.30	37.0	71	10.15	8	1.14	21	3.00	0	0
1958	49.97	19.20	38.4	66	12.67	13	2.50	22	4.22	0	0
1959	132.94	61.29	46.1	67	41.06	17	10.42	16	9.81	0.03	0.02
1960	158.60	63.74	40.2	65	41.43	18	11.47	16	10.20	0.5	0.32
1961	174.99	63.44	36.3	61	38.70	22	13.96	17	10.78	0.5	0.32
1962	260.82	83.60	32.1	63	52.67	19	15.88	17	14.21	0.4	0.33
1963	320.75	98.72	30.8	57	56.27	23	22 71	19	18.76	0.4	0.39
1964	354.58	111.23	31.4	54	60.06	21	23.36	24	26.70	0.4	0.44
1965	415.97	120.41	28.9	44	52.98	26	31.31	30	36.12	0.3	0.36
1966	466.43	124.30	26.7	42	52.21	26	32.32	32	39.78	0.1	0.12
1967	465.10	125.82	27.1	40	50.33	24	30.20	36	45.30	0.3	0.38
1968	495.00	134.46	27.2	40	53.78	26	34.96	33	44.37	0.2	0.27
1969	400.00	115.30	28.8	39	44.97	26	29.98	35	40.36	0.2	0.23
1970	440.00	120.18	27.3	42	50.48	23	27.64	35	42.06	0.2	0.24
1971	513.00	98.81	19.3	37	36.56	22	21.74	40	39.52	0.4	0.39
1972	622.00	86.10	13.8	41	35.30	32	27.55	27	23.25	0.8	0.69
1973	645.74	62.23	9.6	39	24.29	28	17.42	31	19.29	1.0	0.62
1974	645.67	80.71	12.5	38	30.67	36	29.06	24	19.37	3	2.42
1975	693.20	74.03	10.7	38	28.13	29	21.47	30	22.21	2	1.48
1976	724.40	62.50	8.6	12	7.50	56	35.00	28	17.50	4	2.50
1977	791.77	74.30	9.4	13	9.69	58	43.10	24	17.83	5	3.72
1978	857.25	73.96	8.6	19	14.05	48	35.50	25	18.49	7	5.18
1979	926.93	80.00	8.6	20	16.00	46	36.80	26	20.80	8	6.40
1980	975.13	77.19	7.9	22	16.93	42	32.30	26	20.33	9	7.62
1981	1,041.78	70.66	6.8	37	26.08	37	26.00	21	14.83	5	3.75
1982	999.14	20.90	2.1	18	3.82	0	–	72	15.00	10	2.08
1983	1,085.79	30.00*	2.8	43	12.81	0	–	50	15.00	7	2.19
1984	1,306.91	75.00*	5.7	70	52.50	0	–	27	20.30	3	2.20
1985	1,502.89	81.96*	5.5	52	42.46	6	5.00	33	27.30	9	7.20
1986**	1,555.35	87.00*	5.6	53	46.00	6	5.50	31	27.30	9	8.20

SOURCE: National Science Foundation: Science and Engineering Education Directorate (SEE) (Detail data may not add to totals because of rounding)

*Includes prior year carry over funds.

**Does not include Gramm-Rudman-Hollings.

this period need to be familiar with the most current tools and knowledge; there is seldom a period of graduate study in which deficiencies or omissions can be repaired. Yet, the pace of change in engineering is perhaps even greater than in the natural sciences, since it is driven from both sides - by discovery in the world of science and by innovation and technological development in the world of industry.

- Insufficient attention is being given to the education of professional specialists - those who will become medical or engineering technologists and precollege teachers, and who are generally relegated to non-elective "service" courses that often do not meet their special and varied needs.

Paralleling all of these deficiencies and underlying some of them are serious difficulties with the currency and vitality of the faculty - the fundamental resource for high quality instruction.

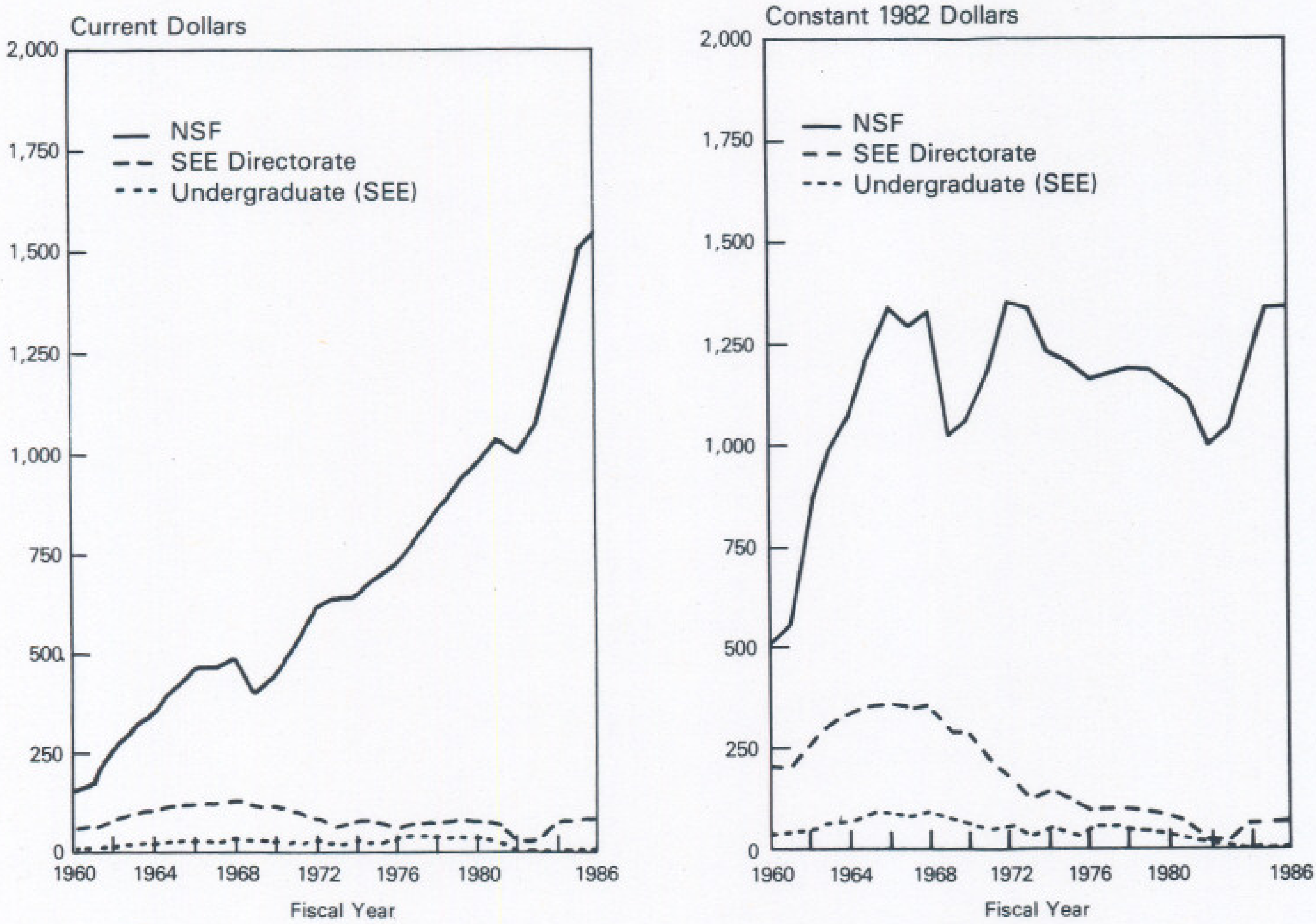
Recent analyses of U.S. undergraduate education (B12,B13, B16,B17) point repeatedly to problems of faculty obsolescence and "burnout" at every type of undergraduate institution, including the 2-year colleges - where it is estimated that half of all college students take their introductory college-level science and engineering courses (B18).

Students in professional science and engineering tracks may complete their undergraduate study with far from contemporary knowledge, gained from faculty who

CHART 3

NSF Obligations for Science and Engineering Education

(Millions of Dollars)



1. GNP implicit price deflators used to convert current dollars to constant 1982 dollars.

SOURCE: National Science Foundation: Science and Engineering Education Directorate (SEE).

are losing touch with their own disciplines and related fields. Students in non-professional tracks may finish their undergraduate study without any real sense of the scope of contemporary science or of its impact on every aspect of contemporary life.

National figures concerned with collegiate education in the technical fields suggested many ways of correcting these deficiencies (W1-W41). The most frequently recurring themes were:

- incentives to make the faculty and their implements current, vital, and dynamic;
- up-to-date instrumentation linked to related curriculum development;
- opportunities for faculty to pursue professional development that will help maintain contact with rapidly expanding knowledge in their fields;
- integral, "hands-on" research activities that provide needed experiences for students;
- improved curricula, materials and technologies for pre-professional and professional education that reflect the current states of knowledge and practice; and
- improved curricula and materials that introduce the general student to the language, knowledge, thought processes, and methods of science and technology in a manner that integrates directly with the other aspects of a liberal education (B13,B19).

4. The Charge to the Committee

In May of 1985, the Chairman of the National Science Board, Dr. Roland W. Schmitt, appointed the Task Committee on Undergraduate Science and Engineering Education. The Committee was charged to determine an appropriate NSF role in undergraduate science, mathematics, and engineering education. The Committee was also asked to identify possible mechanisms for carrying out that role. The text of Dr. Schmitt's May 16, 1985 Letter of Appointment and Charge to the Committee follows:

"Your charge is to consider the role of the National Science Foundation in undergraduate science and engineering education.

"NSF and other agencies have comprehensive programs at both graduate and precollege levels. However, currently no systematic federal leadership or support exists for science, engineering and mathematics education at the undergraduate level. Several recent major reports have expressed concerns about the health of undergraduate education, especially science, engineering, and mathematics. Some of the issues that merit consideration are the need for curriculum changes to provide students with broader-based, interdisciplinary backgrounds, and the need to reverse the decline in numbers of highly able students going on to graduate work in science and engineering.

"Within existing NSF resources*, what is an appropriate NSF role in undergraduate science and engineering education? What are possible mechanisms for carrying out that role? Should NSF move to establish undergraduate science, engineering and mathematics programs apart from support for undergraduates provided in some research grants? Should NSF have a role in shaping undergraduate curricula?

"Your work should begin at the June 1985 meeting of the National Science Board and a final report should be submitted to the Board at its March 1986 meeting. You should feel free to ask one or two outside consultants to help the committee with its work. You should also feel free to develop and modify this charge as necessary. Because of the close relationship between this specialized task and the general charge to the Education and Human Resources (EHR) Committee, you may find it useful to keep the EHR Committee informed of your progress."

During the course of its work, the Committee consulted with higher education organizations, conducted hearings, met with NSF program officials, and reviewed the literature. This report presents the Committee's Findings, Conclusions and Recommendations.

5. Demographic Changes

One of the most significant changes in the technical personnel supply that will be encountered over the next decade derives from a projected decline in the size of the 18-19 year-old age group from which come most of the college and university students in all fields (Chart 4) (B20). Unless patterns of field selection change, many fewer young people than at present will choose to pursue scientific and engineering careers (Chart 5) (B21).

The Nation is already seeing the first effects of this demographic decline. Over the period 1973-83, the number of undergraduate science majors fell by about 15%. The number of engineering majors rose by 92% during this period (in response to rapidly growing industrial demand) (B22). However, the proportion of entering students planning to pursue engineering careers dropped to 10.0% in 1985, down from 10.4% in 1984, and a peak of 12.0% in 1982.

During the period 1960-1980, the character of our society was becoming dramatically more technologically based. Yet the number of baccalaureate degrees in the

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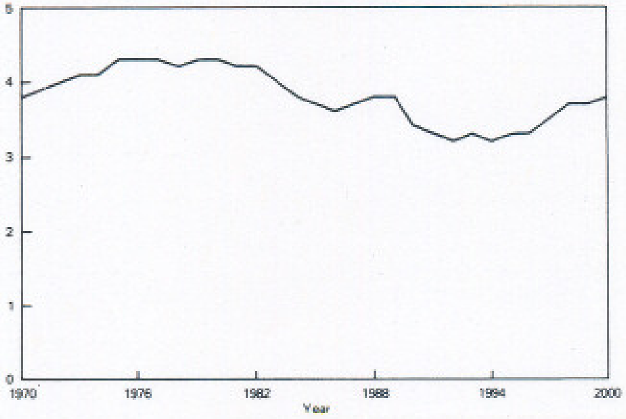
*Dr. Schmitt removed this restriction in a later communication.

CHART 4

Number of U.S. 18-Yr Olds

(Millions)

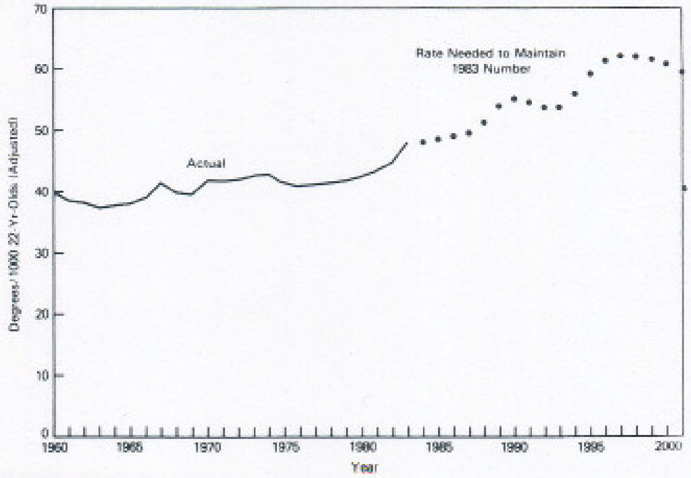


SOURCE: National Science Foundation: Division of Science Resources Studies (SRS).

CHART 5

BS Rate in Natural Science and Engineering

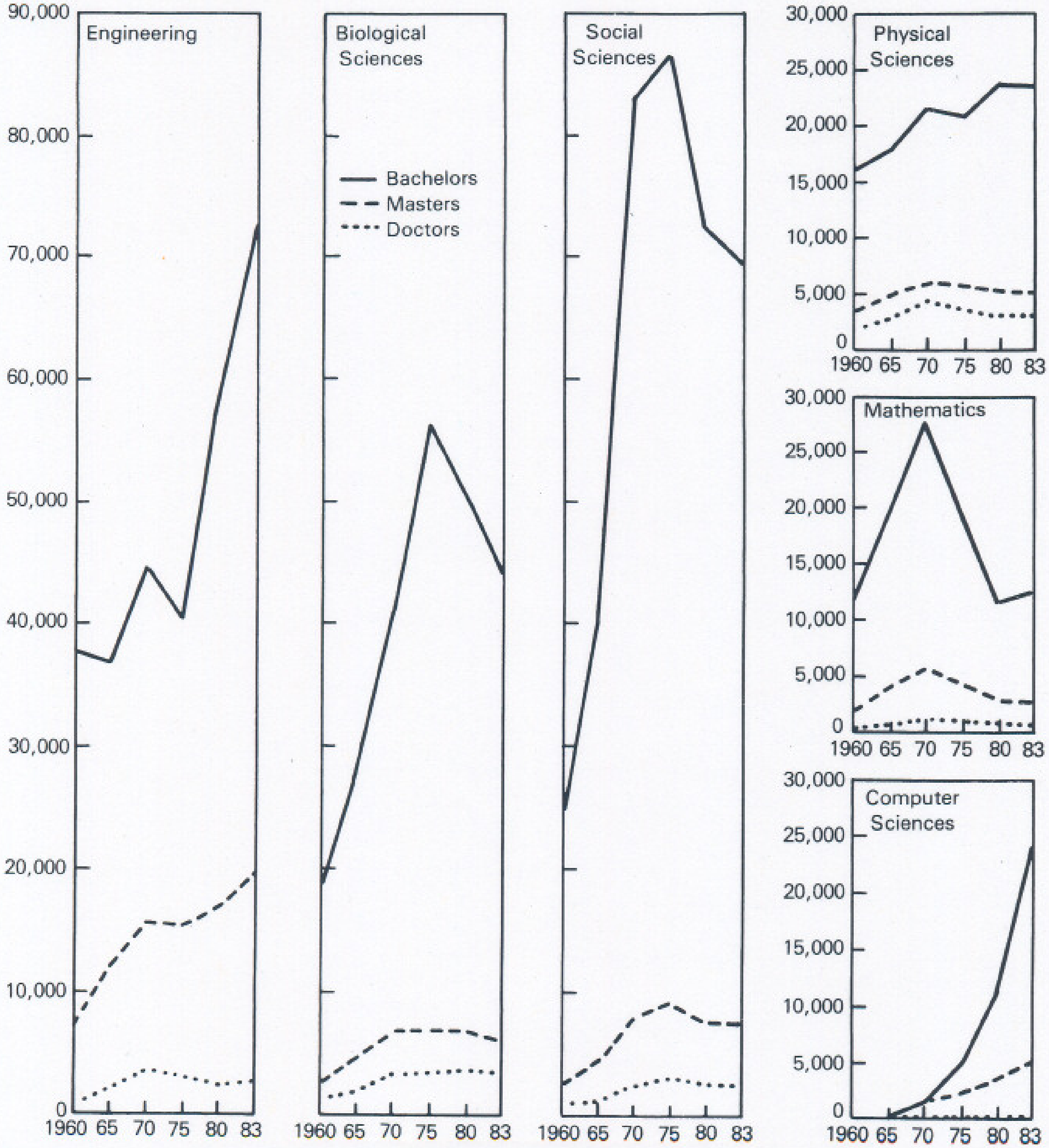
Degrees Per 1000 U.S. 22-Yr-Olds



SOURCE: National Science Foundation, Division of Policy Research and Analysis (PRA) natural sciences, engineering, and mathematics combined did no better than stay even with the pace of population increase of 22-year olds. While bachelor's degrees in computer science and engineering have risen since 1975, those in the biological sciences and in mathematics have declined. A decline in degrees in the physical sciences has been recorded since 1980. These trends, together with related changes in masters and doctoral degree production are illustrated in Chart 6 and Tables D, E, and F (B1:267)(B23:154-156).

CHART 6

Degrees by Major Field Group: 1960-1983



SOURCE: National Science Foundation: Division of Science Resources Studies (SRS).

Perhaps of greater concern is a comparison of the majors chosen by freshmen in recent years, Table G. Significant decreases were found in 1985 from previous years in all the technical disciplines, while business majors, the freshman's most popular choice, rose to 23.9% of all majors in 1985 (B24).

Among students who complete degree programs in science and engineering, about one-half of the B.S. recipients, two-thirds of the M.S. recipients, and three-fourths of the Ph.D. recipients actually enter the science and engineering workforce (B23:21). If present patterns of field selection continue and if employer demand does not abate, it is clear that the Nation will face manpower supply shortages in a significant number of technical fields over the next ten years, which is approximately the length of the high school to postdoctorate pipeline.

6. Resource Constraints

The U.S. educational enterprise is a major aspect of our economy, involving a total annual expenditure in 1985-86, estimated at $260 billion. Higher education accounts for $101 billion of this, and its undergraduate component amounts to $42 billion. The cost of the instructional portion of undergraduate education is estimated to be $20 billion. See Table H (B25).

An accurate estimate of the cost of undergraduate science and engineering education is not available. However, Chart 7 compares the number and percent of science and engineering baccalaureate degrees (31%) with the other baccalaureate degrees (69%) awarded in 1982-83 (B5). On this basis, we estimate that the instructional expenditures for undergraduate science and engineering education are at least $10 billion.

At many institutions, problems of excessive class size, heavy teaching loads and inadequate support for student research have contributed to a conviction that the overall quality of undergraduate science, mathematics and engineering education has declined. These burdens, usually related to resource constraints, reduce the time available for faculty in different kinds of institutions to pursue their personal scholarship and advance and deepen their disciplinary understanding.

Higher education is very labor intensive. Constraints on resources not only lead to over-utilization of faculty and support staff, but to deferral of expenditures on facilities, equipment and maintenance. In fields that are experimental or observational by nature (as are all that relate to the Foundation's mission, except mathematics), these deferrals leave faculty and students with deficient libraries, inadequate laboratories, and obsolete equipment.

Undergraduate programs have suffered also as a consequence of the elimination or minimization of science and mathematics requirements for non-science majors. There is a double effect of such a trend: first, the breadth of the undergraduate non-major curriculum is reduced undesirably; second, the enrollment-related resources flowing to science departments are decreased in consequence of lower student registrations overall.

TABLE D

Bachelors Degrees by Major Field Group: 1960-83

	Physical Sciences	Engineering	Mathematics	Computer Sciences	Biological Sciences	Social Sciences
1960	16,057	37,808	11,437	–	17,806	23,383
1965	17,916	36,795	19,581	87	28,072	40,994
1970	21,551	44,772	27,565	1,544	40,760	82,707
1975	20,896	40,065	18,346	5,039	56,179	86,428
1980	23,661	59,240	11,473	11,213	50,496	72,266
1983	23,497	72,954	12,557	24,678	44,067	69,477

SOURCE: National Science Foundation: Division of Science Resources Studies (SRS).

TABLE E

Masters Degrees by Major Field Group: 1960-83

	Physical Sciences	Engineering	Mathematics	Computer Sciences	Biological Sciences	Social Sciences
1960	3,387	7,159	1,765	–	2,548	2,544
1965	4,918	12,056	4,148	146	4,612	4,348
1970	5,948	15,597	5,648	1,459	6,783	7,956
1975	5,830	15,434	4,338	2,299	6,931	9,229
1980	5,233	16,846	2,868	3,647	6,854	7,658
1983	5,288	19,721	2,839	5,321	6,041	7,540

SOURCE: National Science Foundation: Division of Science Resources Studies (SRS).

TABLE F

Doctors Degrees by Major Field Group: 1960-83

	Physical Sciences	Engineering	Mathematics	Computer Sciences	Biological Sciences	Social Sciences
1960	1,838	786	303	–	1,207	841
1965	2,829	2,124	682	6	1,945	1,290
1970	4,313	3,681	1,236	107	3,308	2,503
1975	3,628	3,151	975	213	3,420	3,123
1980	3,095	2,519	724	240	3,668	2,635
1983	3,270	2,846	698	262	3,368	2,507

SOURCE: National Science Foundation: Division of Science Resources Studies (SRS).

One might argue that a smaller service course instruction load would relieve some of the pressures on science departments, but the exact opposite was reported to the Committee (B26,W20). Close coupling between enrollment and budgets at most institutions is perceived as leading to further program degradation as attempts are made to reduce expenditures - often for laboratory instruction and program enrichment, such as research participation for undergraduate students. It is apparent that

TABLE G

Trends in Majors Chosen by Freshmen During Fall of 1985*

Percentage of All Freshmen

	1977	1985	
Biological Sciences	4.7	3.4	
Physical Sciences	3.1	2.4	
	1983	1984	1985
Computer Sciences	8.8	6.1	4.4
	1982	1985	
Engineering	12.0	10.0	

*Reported in "The American Freshman: National Norms for Fall 1985—Conducted by the Cooperative Institutional Research Program of UCLA and The American Council on Education.

Cited in the "Chronical of Higher Education"; January 15, 1986

many institutions will choose to place highest priority on programs for majors; as a result, elective courses for nonmajors will suffer from lowered resources and attention.

State funding of higher education during the past ten years has increased substantially, but not in pace with enrollments, nor have the ravages of earlier "double digit" inflation been repaired (B27:84-85). More reasonable levels of support are being achieved in some states as they recognize the relationships between strong graduate research and their attractiveness to high technology industries, but the fact that high quality graduate education in engineering and the sciences must be based on strong undergraduate programs has not been recognized with proportionately increased funding.

Private support of higher education has increased, too, but there is a shortfall similar to that found in the public sector. Industrial gifts to education (all levels) have increased in the past fifteen years from 0.43% to 0.68% of pretax net income; they aggregated $1.6 billion in 1984 (B7). Although the higher education share of this total is substantial, as is that of technical fields such as engineering and the sciences, most industries have concentrated their support on graduate education and research linked closely to their interests, not upon the essential undergraduate base.

Broadly, then, the resources applied to undergraduate education in the last fifteen years have fallen steadily behind needs, and the situation is especially intense in the costly science and engineering fields upon whose quality the Nation now relies so heavily.

7. Participation of Underrepresented Groups

"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." Thomas W. Cole, Jr., President, West Virginia State University (W2).

The number of women and minorities entering upon the study of science and engineering has increased significantly during the past ten years, but their participation in these professions has not yet reached equitable levels (B28:21-38,167-177) (W2,W24,W36).

Unfortunately, a continuing increase in the representation of women and minorities in science and engineering fields is by no means assured. In fact, the proportion of women in the first year of engineering school dropped in 1984 after rising significantly each year since 1969 (B29,W12). Even if the numbers of female and minority entrants continue to rise, this increase will probably not offset the fall in the total number of persons entering the student stream that results from the demographic decline in the total number of available 18-19 year olds.

The Nation is not being adequately served by current efforts to increase the number of women and minorities in the science and engineering workforce. Unless these efforts are maintained where they are effective and intensified where they are not, the nation will continue to deprive itself of an important source of future scientists and engineers to offset the decline in total number of new entrants expected between now and 1995.

Concerns about underrepresented groups in science and engineering were the subject of several of those presenting testimony to the Committee (W2,W21,W24,W36).

The problems for minorities start in the early years of schooling. Minority students drop out of school in disproportionately high numbers compared to majority students at each potential entry point into the workforce along the education pipeline, as shown in Table I (W2).

TABLE H

Expenditures for Undergraduate Education in The U.S., 1985-86 (Estimated)

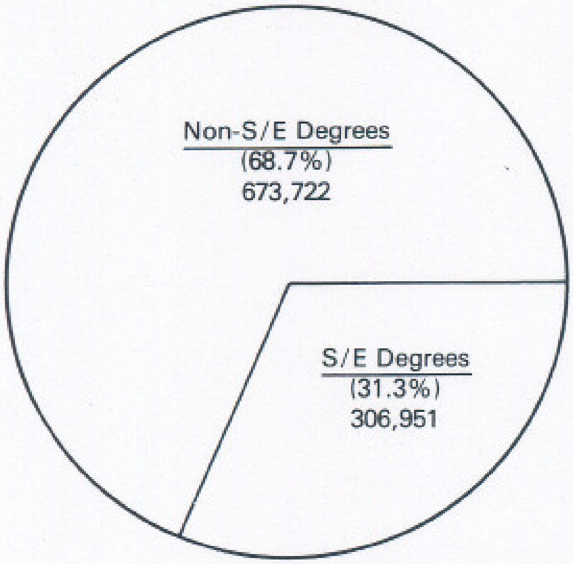
(Billions of Dollars)

	Total	Public Institutions	Private Institutions
Education and General:	$42.0	$29.5	$12.4
Instruction:	$20.3	$15.5	$4.8

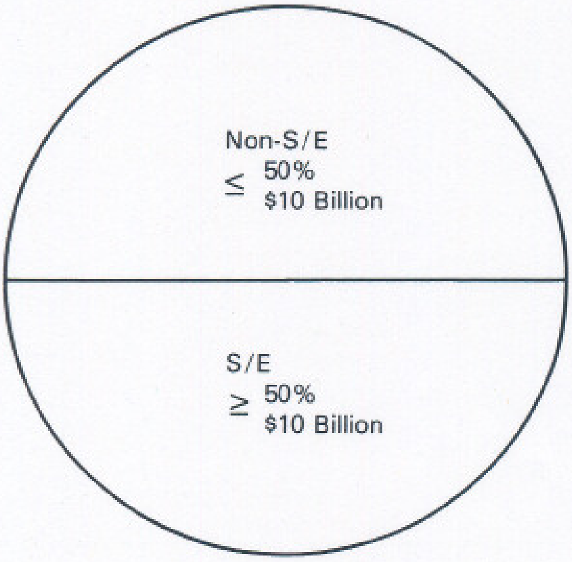
SOURCE: Estimate provided by the National Center for Higher Education Management Systems. (NCHEMS)

CHART 7

Bachelor's Degrees Awarded in the U.S., 1982-83
Total = 980,673



Estimated Instrumentation Cost
of S&E Component



SOURCE: National Science Foundation: Division of Science Resources Studies (SRS).

Most minorities are less likely than whites to be in an academic curriculum while in high school, and less likely to take advanced mathematics courses (Table J) (B28:29).

Among the minorities, blacks and hispanics seem to be the most seriously underrepresented in science and engineering, followed by American Indians. Although Asian-Americans are generally thought to be overrepresented, there is some indication that this is a result of recent immigration and less due to behavior of U.S. native Asian-Americans (W12).

Those women and minorities who earn degrees in science and engineering fields generally have higher rates of unemployment and earn lower salaries than their male and majority counterparts (Table K and Chart 8) (B28:5,12).

One witness (W21) noting that the physical sciences in particular had problems of underrepresentation of women and minorities said: "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."

Persons with physical handicaps also have had historically seriously low rates of participation in science and engineering. In 1984, 75,000 employed scientists and engineers reported having a physical handicap. However, recent data indicate that handicapped scientists and engineers are four times more likely than all scientists and engineers to be out of the labor force (B28).

All available information (B30) indicates that handicapped students enroll in secondary and postsecondary science and mathematics courses less frequently than do all students, that they pursue further training in science and engineering to a lesser extent, and that even today handicapped students are discouraged or prohibited by counselors and educators from enrolling in science and mathematics courses, due to a perception that science and engineering are "too difficult" and inappropriate fields for persons with handicaps (B31).

Maintaining the vitality of the nation's science and technology enterprise requires attracting the best talent from every available pool, including persons with handicaps.

8. The Changing Faculty

"We have given less attention than the situation deserves to enhancing and updating the capabilities of

TABLE I

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	14	8	4	4	4
Complete Grad/Prof	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 J

Mathematics and science coursetaking by race[1]

Coursework	White	Black	Asian	Native American
MATHEMATICS				
Algebra I	71%	64%	66%	57%
Geometry	60%	46%	68%	34%
Algebra II	38%	29%	39%	22%
Trigonometry	26%	16%	43%	14%
Calculus	8%	4%	19%	4%
SCIENCE				
Physical science	67%	71%	52%	67%
Biology	79%	80%	79%	71%
Adv. Biology	20%	16%	25%	14%
Chemistry	39%	30%	58%	24%
Chemistry II	5%	3%	9%	3%
Physics	20%	12%	36%	9%
Physics II	2%	1%	7%	0%

[1] Represents individuals in 1982 who were sophomores in high school in 1980 (High School and Beyond, First Follow-up).

SOURCE: "Women & Minorities in Science & Engineering" 1986, National Science Foundation.

> *current faculty." Fred W. Garry, Vice President-Corporate Engineering and Manufacturing, General Electric Co (W16).*

Net growth of college and university faculties in the disciplines related most closely to Foundation programming slowed over fifteen years ago, except in computer and life sciences (B32:7). In some places there have been no replacements of retiring faculty for years; in others there have been fewer candidates than needed to fill available positions.

Over a quarter of a million scientists and engineers were engaged in teaching and related activities in colleges and universities in 1984. Tables L and M provide information on their numbers according to field, status, and institutional type. These and similar data require presently-lacking information about the distribution of effort and the time commitments of part-time appointees before one can estimate the numbers of full-time equivalent faculty members at each kind of collegiate institution. (This is one of many examples pointed out to the Committee of incomplete coverage by present databases.)

In the natural sciences, student numbers were falling slowly to a new plateau; in mathematics, a steady rise in nonmajor student registrations coincided with a constant supply of new faculty. In engineering, fluctuating enrollments occurred while there was both relatively rapid fall in the fraction (B1:267,268,274)(B8:139-163)(B23:9) of native baccalaureate engineers who elected to enter upon graduate work (W12) (and thus enter the pool of potential future faculty members) and an increase in the rate at which young faculty members left engineering schools for industrial positions.

The result in almost all fields is an aging permanent faculty, and in many areas increasing reliance on graduate students, part-time, and less-than-optimally-qualified persons to carry the instructional load.

Aging of the faculty is commonly expected to result in a lowering of the vitality of undergraduate education as its members are perceived, with or without justification, as being less responsive to student needs and interests and less motivated to maintain their professional acuity. At many institutions, the increasing number of foreign nationals among the graduate assistants and faculty is believed to have lowered the quality of undergraduate education, primarily because these individuals have difficulty in making themselves clearly understood in instructional settings. It has been reported that some are perceived by female students to be biased against them as potential professionals (B33,W12)

These institutional concerns are important, but changing faculty perspectives may have serious ramifications for the ability of colleges and universities to recruit and retain qualified staff members. The 1984 Carnegie Foundation survey of 5,000 faculty members at a representative sample of 310 institutions revealed a pervasive uneasiness among professors over the state of their careers in both personal and professional terms. Nearly half of the faculty members polled would seriously consider a reasonable offer from outside the academic community (B34).

B. Students; Faculty and Their Implements

1. Students

> *"It is well known that undergraduate interest in basic science has recently plummeted. Within a decade the percentage of American undergraduates intending to major in science fell by 33 percent, with the absolute number of such intended majors dropping by almost 40 percent. 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." S. Frederick Starr, President, Oberlin College (W5).*

TABLE K

Selected characteristics of scientists and engineers by racial/ethnic group: 1984

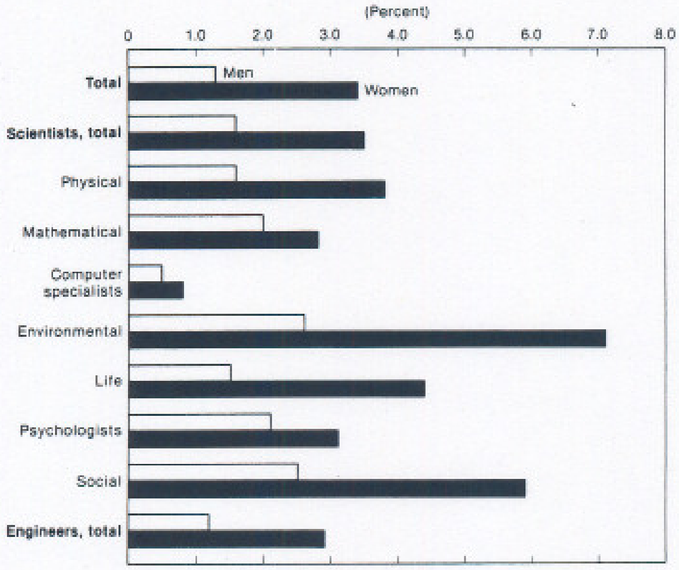
Characteristic	White	Black	Asian	Native American	Hispanic[1]
Unemployment rate	1.5%	2.7%	2.4%	3.4%	2.1%
S/E employment rate	86.8%	81.3%	90.8%	78.3%	80.3%
S/E underemployment rate	2.5%	6.6%	1.8%	2.9%	4.2%
Annual salary	$37,500	$32,500	$38,200	$40,500	$33,100

[1] Includes members of all racial groups.

SOURCE: "Women & Minorities in Science & Engineering" 1986, National Science Foundation.

CHART 8

Unemployment rates for scientists and engineers by field and sex: 1984



SOURCE: "Women & Minorities in Science & Engineering" 1986, National Science Foundation.

Education implies learning and may involve teaching. The Findings, Conclusions, and Recommendations of this report are more often set forth in terms of educators and their tools for teaching than in terms of the needs of those who are learning. But, in this review of the state of undergraduate education in mathematics, engineering, and the sciences, the Committee kept in sight the fact that the ultimate beneficiary of any improvement effort is the student.

The student body is diverse. Curricular separation of students with different kinds of interests in science and mathematics begins in the middle school and increases thereafter. As a result, undergraduate education in mathematics, science, and even in engineering, is offered to students having widely differing identifications with the subject matter - ranging from the intense concern of those few who consider themselves even as freshmen to be pre-doctoral students to the larger number who want a last look at one of these disciplines as a "cultural phenomenon."

The ranges of need and opportunity are wide. Students who approach technical subjects from a cultural perspective should be offered courses and other educational experiences that relate science and technology to the worlds they perceive as well as to the "real" world. Undergraduate scientists, engineers and mathematicians can exercise their creativity and accelerate their acquisition of professional skills by participating in active research programs of their faculty mentors.

All of these students, whether "general" and in the "main line" or pre-professional and in the "pipeline", or somewhere in between, deserve the highest quality educational experience that can be provided through the efforts of faculties, the use of facilities, and the application of the methods and materials of education.

2. The Faculty

Colleges and universities cover wide ranges of institutional size and complexity and, therefore, of the "at-

TABLE L

Scientists and engineers employed at universities and colleges by field and status: selected years

FIELD AND STATUS	1967	1969	1971	1973	1975	1977	1978	1980	1982	1983	1984
ALL FIELDS	212,855	231,756	257,904	264,887	278,919	297,856	307,757	324,249	349,090	358,929	370,450
FULL TIME	170,557	187,082	209,416	216,424	223,336	236,278	242,170	254,990	268,550	274,092	281,561
PART TIME	42,298	44,674	48,488	48,463	55,583	61,578	65,587	69,259	80,540	84,837	88,889
ENGINEERS	25,253	25,387	27,130	27,530	27,919	30,083	30,997	33,737	36,376	37,737	39,015
FULL TIME	20,983	21,431	23,039	23,485	22,580	24,105	24,666	26,472	27,986	28,844	29,435
PART TIME	4,270	3,956	4,091	4,045	5,339	5,978	6,331	7,265	8,390	8,893	9,580
PHYSICAL SCIENTISTS	26,243	28,149	29,443	30,210	30,836	32,120	32,839	33,554	34,500	34,778	35,521
FULL TIME	23,361	25,040	26,346	26,666	26,662	27,553	27,902	27,993	28,600	28,514	29,030
PART TIME	2,882	3,109	3,097	3,544	4,174	4,567	4,937	5,561	5,900	6,264	6,491
ENVIRONMENTAL SCIENTISTS	5,111	5,549	6,500	6,934	7,855	9,337	9,618	9,960	10,200	10,153	10,624
FULL TIME	4,294	4,935	5,752	6,091	6,787	8,075	8,285	8,453	8,672	8,691	8,933
PART TIME	817	614	748	843	1,068	1,262	1,333	1,507	1,528	1,462	1,691
MATHEMATICAL AND COMPUTER SCIENTISTS	17,776	22,495	24,548	24,770	28,475	31,996	33,034	35,957	42,234	45,666	49,282
FULL TIME	14,397	18,390	20,282	20,794	22,404	23,870	24,349	26,030	28,375	29,941	31,940
PART TIME	3,379	4,105	4,266	3,976	6,071	8,126	8,685	9,927	13,859	15,725	17,342
LIFE SCIENTISTS	87,347	97,206	110,274	112,352	113,466	117,441	122,956	133,702	146,264	151,440	156,279
FULL TIME	66,620	74,882	85,907	88,418	90,684	94,306	97,726	108,155	116,291	119,615	122,689
PART TIME	20,727	22,324	24,367	23,934	22,782	23,135	25,230	25,547	29,973	31,825	33,590
PSYCHOLOGISTS	11,358	14,780	16,806	18,876	21,649	23,699	23,752	23,257	23,711	23,772	23,967
FULL TIME	8,554	11,536	12,994	14,777	15,973	17,307	17,406	16,733	16,820	16,856	17,087
PART TIME	2,804	3,244	3,812	4,099	5,676	6,392	6,346	6,524	6,891	6,916	6,880
SOCIAL SCIENTISTS	39,767	38,190	43,203	44,215	48,719	53,180	54,561	54,082	55,805	55,383	55,762
FULL TIME	32,348	30,868	35,096	36,193	38,246	41,062	41,836	41,154	41,806	41,631	42,447
PART TIME	7,419	7,322	8,107	8,022	10,473	12,118	12,725	12,928	13,999	13,752	13,315

SOURCE: Academic Science/Engineering: Scientists and Engineers, January 1984, Surveys of Science Resources Series, National Science Foundation.

TABLE M

Scientists and engineers employed at universities and colleges by type of institution and status: selected years

TYPE OF INSTITUTION AND STATUS	1967	1969	1971	1973	1975	1977	1978	1980	1982	1983	1984
ALL INSTITUTIONS	212,855	231,756	257,904	264,887	278,919	297,856	307,757	324,249	349,090	358,929	370,450
FULL TIME	170,557	187,082	209,416	216,424	223,336	236,278	242,170	254,990	268,550	274,092	281,561
PART TIME	42,298	44,674	48,488	48,463	55,583	61,578	65,587	69,259	80,540	84,837	88,889
INSTITUTIONS GRANTING:											
DOCTORATE IN S&E	142,676	154,424	171,238	174,474	180,330	193,204	200,366	218,021	231,711	236,545	244,286
FULL TIME	114,446	124,604	140,339	143,393	148,096	159,848	164,732	179,775	189,420	192,756	197,508
PART TIME	28,230	29,820	30,899	31,081	32,234	33,356	35,634	38,246	42,291	43,789	46,778
MASTER'S IN S&E	24,729	29,441	30,080	28,703	34,075	34,790	38,628	37,362	39,030	40,665	44,743
FULL TIME	20,748	25,212	25,597	24,851	27,511	27,118	29,395	27,915	28,721	29,730	32,822
PART TIME	3,981	4,229	4,483	3,852	6,564	7,672	9,233	9,447	10,309	10,935	11,921
BACHELOR'S IN S&E	23,025	21,690	23,198	28,363	27,113	27,411	26,222	26,830	28,815	29,469	29,812
FULL TIME	19,328	17,927	19,623	23,620	22,406	22,437	21,165	20,784	21,646	22,219	21,813
PART TIME	3,697	3,763	3,575	4,743	4,707	4,974	5,057	6,046	7,169	7,250	7,999
OTHER DEGREES 1/	22,425	26,201	33,388	1,348	1,345	607	858	842	687	610	545
FULL TIME	16,035	19,339	23,857	812	828	467	705	680	579	489	476
PART TIME	6,390	6,862	9,531	536	517	140	153	162	108	121	69
2-YEAR INSTITUTIONS	-	-	-	31,999	36,056	41,844	41,683	41,194	48,847	51,640	51,064
FULL TIME	-	-	-	23,748	24,495	26,408	26,173	25,836	28,184	28,898	28,942
PART TIME	-	-	-	8,251	11,561	15,436	15,510	15,358	20,663	22,742	22,122

[1] Data for 1967 through 1971 includes 2-year institutions as well as institutions awarding degrees in non-science/engineering field.

SOURCE: Academic Science/Engineering: Scientists and Engineers, January 1984, Surveys of Science Resources Series, National Science Foundation.

mosphere" in which their faculty members work. Some have a few hundred students and correspondingly few faculty members; others have enrollments in the tens of thousands, and correspondingly large faculties. In some of these institutions, faculty members do little but teach; in others, they are expected to be productive scholars and researchers as well as teachers.

Whatever the atmosphere about them, many faculty members confronted with choices among careers in industry and in various kinds of educational settings, elected careers in education in an enviroment in which the highest priority was teaching. At non-doctoral institutions, the purpose of research is less the creation of a contribution to knowledge and more the involvement of the faculty member and the participation of students.

Colleges and universities without research.

Although in the majority of cases college faculty do find their jobs rewarding and their career decisions to have been sound, they soon learn that they face a number of obstacles.

Faculty at two- and four-year colleges teach more class hours and a broader range of subject matter than do their counterparts at universities. It is not uncommon for a college faculty member over the course of several years to teach as many as half of the courses offered by the department.

Because many college departments are small, their administrations often avoid hiring faculty members in the same subfield, attempting to cover as many of the subfields of a given discipline as possible. Given the degree of specialization that exists in science and engineering today, a faculty member at an undergraduate college may not have a colleague with whom to discuss research.

The disciplinary refreshment of faculty in such colleges must depend in large part on mechanisms that move the individual into a research-oriented environment. Attendance at professional meetings is especially important for faculty at smaller non-doctoral institutions because it places them in such an environment at modest cost. Where personal and institutional resources permit or can be augmented, a sabbatical leave in a research institution is preferred because of the immersion it represents. Unfortunately, the very institutions whose faculty need this refreshment the most are the ones least able to bear the full cost.

Colleges and universities with research.

Faculty members at institutions whose resources do permit modest support of their research activities are not necessarily better off, in part because of the greater expectations they face. Their teaching loads may be somewhat lighter and their research may be supported from budgets for supplies and instrumentation. But, since they have time allocated for research, it is expected that they will be productive - that their research will meet the tests of currency, quality, and novelty applied to all submissions to the professional journals, regardless of institutional origin. And, the number of their publications will be counted, too.

Factors such as these make it difficult for colleges to retain research-active faculty members. Both industries and larger educational institutions can lure them away with promises of greater support for research and, in the case of the latter, without completely eliminating the close student-teacher interactions that impelled the choice of a teaching career in the first place. The special needs of faculty in research-sponsoring colleges are those that expand research opportunities through the provision of more sophisticated apparatus and instrumentation, that permit uninterrupted involvement of both faculty member and advanced students for substantial periods in or between school years, and that in other ways support the college as a place where research can be done.

Since universities and colleges are diverse in many aspects, the models described above fall short of indicating the variety of solutions being tried for the problem of maintaining faculty sharpness. But, a common thread runs through the entire discussion of this issue - it is that the mechanisms for combatting faculty obsolescence must be capable of frequent application and must permit real flexibility in matching persons with opportunities.

Doctoral universities.

Faculty members in doctoral universities have special problems where undergraduate education is concerned. Their research activity simplifies somewhat the maintenance of high quality instruction of graduate students, but intensifies the difficulty of maintaining breadth in their work with undergraduate students - especially students with majors outside their own disciplines. Further, maintaining breadth must be done while specialist activities are carried out under high pressure. The result is that doctoral-university faculty are like all others in having to grapple with professional obsolescence and insufficient time to attend to maintenance of pedagogical skills.

Disciplinary explosions.

> *"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 areas of modern society, such as medicine, law and business . . . This is not an isolated instance." David T. McLaughlin, President, Dartmouth College (W18).*

Modern biology is an example of a field in which an explosion in knowledge has resulted in a revolution in the way the subject is - or ought to be - taught. Faculty members in all kinds of colleges mentioned above are hard-pressed to keep up with even the most significant developments in the field. New teaching strategies must be developed, as well as new instructional instrumentation and materials. Testimony to the Committee urged the Foundation to establish programs that would provide the *time* to faculty members for pursuit of these objectives (W13).

Recognition.

There is much fine teaching being done in mathematics, science, and engineering. National recognition of such excellence could serve to stimulate the entire profession. A program of Presidential Awards for Excellence in Undergraduate Teaching would certainly call attention to the best teaching of undergraduates as well as to the individuals who carry it out. Properly structured, an awards program could also serve as a mechanism to tap the experience and creative energies of the best teachers *and* make the results of their efforts widely available to the teaching profession.

3. Courses and Materials

The content of instruction - the curriculum - is at the core of the teaching and learning process at any level. At the undergraduate level it is especially important that the curriculum be dynamic, reflecting the rapid increases in knowledge and changes in theory that are taking place in consequence of scientific and technological progress.

Students majoring in technical areas.

Advances of recent years - biotechnology, genetic engineering, chemical processes, the computer and all of its ramifications, robotics, lasers - all bring pressures for change throughout the disciplines. As systems become more complex and interactive they also bring greater imperatives for inter- and multi-disciplinary approaches to problems and consequently for restructuring curricula.

Shortly after the start of their undergraduate years, students are gaining rapidly in intellectual development and are undertaking studies in depth. For most students, whether science/engineering majors or not, this is the time for the first and last formal instruction in the basic sciences that support their majors - i.e., the physics underlying chemistry, the chemistry supporting biology.

The diversity of needs and requirements is so great among students at this level that it is no longer reasonable to expect that a single curriculum in a discipline will suffice for all students. **Students preparing to enter the health fields or to become high school teachers do not need and should not be expected to take the same basic science courses as those who plan to be practicing engineers or research scientists.** Yet these "other" students who constitute the majority of students enrolled in freshman and sophomore mathematics and science courses are often relegated to a single set of "service" courses whose content and challenge is insensitive to the diversity of their needs and often of distinctly lower quality than those offered to science majors.

Changing patterns of employment are also affecting student needs for organized curricula. The technology degree programs, e.g. chemical technology, health technology, etc., are becoming increasingly important as demands for these types of workers increase (W4). Yet these curricula are often static and stale from neglect in the shadow of professional engineering and science programs.

The pre-professional curricula, however, are not without problems in many institutions. At best, they are beset by unsettled, often long-standing contention over length, emphasis, and specific content (W7,W17,W18). At worst, they are dull, unimaginative, and as obsolete as many curricula offered to non-majors.

The general student.

> *"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. . . . 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." Bernard J. Luskin, Executive Vice President, American Association of Community and Junior Colleges (W4).*

Several who brought statements to the Committee were concerned primarily with the needs of students majoring in nontechnical areas - those who constitute the vast majority of American undergraduates today.

Too many college graduates are ill-prepared for the world that actually exists about them, a world that increasingly reflects and depends upon scientific and technical endeavor (W4,W10,W19,W23). Many college graduates lack the background to deal with the technical aspects of some of the complex and critical issues that confront contemporary society - disposal of toxic wastes, environmental quality, occupational safety, nuclear power, and manipulation of genetic material - issues that involve decisions by governments at several levels. Ultimately, the government is the people and they and their leadership should be both aware and well informed. It is especially important that the people understand what science is and what it is not; it is not sufficient that they know "a little of this and a little of that."

The general college student is not well served, the Committee learned (B13,B19,W35), by the introductory courses in individual sciences intended for non-major science students (they assume more background and more interest than the general student should be expected to bring to them) or even by the special courses devised for their benefit. Too often, it seems, these special courses are watered-down non-mathematical versions of the standard introductory courses for science students; some have a strong "applied" or "environmental" orientation; and some focus narrowly on selected topics such as kitchen chemistry, physics for airline passengers, or biology for the home gardener. All of these attempts, in the views of their critics, fail what ought to be their central objective, to illustrate the nature of science and scientific thought; they overemphasize facts, underemphasize process and methods, and avoid abstraction.

Modes and materials.

The mechanisms and modes of delivery of instruction have taken on significance nearly as great as the content, with the advent of the new technologies, especially the computer. Ways must be sought to exploit the power of these technologies in the learning process, in the interests of increased efficiency and effectiveness of learning and lower overall costs. The lure of the computer may also prove important in making science learning more palatable to the non-scientist.

There is strong evidence that in recent years the most talented scientists and engineers have not been working on novel new textbooks, educational software, and technologies as they did a decade or two ago. This has been observed by members of the Committee at their own institutions.

A federal role.

Clearly, a strong need (as well as opportunities) exists for an NSF role in the support of the creation of advanced course and curriculum materials, technologies, software, and other novel ways of advancing excellence in instruction in undergraduate science, mathematics, and engineering. The nationally competitive and merit-based nature of NSF support would serve to provide incentives and to motivate the best faculty throughout the Nation and would encourage academic adminstrators to provide local support for this needed activity. In addition, where major new approaches may be indicated (e.g., the creation and testing of a complete new course in engineering design or a novel computer-based instructional delivery system), it would be neither reasonable nor cost-effective to have universities across the country duplicating each other's work. Some of the problems will be addressed most effectively through individual projects, others by team or consortial efforts.

4. Laboratories

> *"We have to introduce people to the idea that science is something that is practiced, not something that exists in books. . . . We have to make certain that students experience the experimental side of science at the undergraduate level, regardless of major or specialty. . . . 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." William G. Simeral, Executive Vice President, E.I Dupont de Nemours and Company (W19).*

Science and engineering are strongly observational and experimental in nature. The laboratory experience is a central and essential element in the undergraduate training of students in these areas. Through the experiences of collecting data and organizing and interpreting them, students can come to understand the underlying principles of the disciplines and how science and engineering are really done. Thus, the quality and effectiveness of the curriculum overall is strongly dependent on the strength and currency of the laboratory component.

There are strong indications that the quality of undergraduate science and engineering laboratory instruction has deteriorated significantly in recent years. Reports and testimony to the Committee indicated that much instrumentation in undergraduate laboratories throughout the U.S. is either worn out or obsolete in the face of rapid advances in science and technology (B35,B36,W15,W21).

Institutions of all kinds are finding it difficult to acquire needed new equipment. Major research universities in some cases have had to focus on their research needs to the detriment of undergraduate laboratory programs. Insufficiencies and inadequacies of laboratory equipment appear to extend across the scientific and engineering disciplines.

A report in 1982 of the National Society of Professional Engineers (B35) concluded that the cost of modernizing U.S. academic engineering laboratories would be $2 billion. This and other studies find that the lack of modern engineering instructional instrumentation causes new graduates in many areas of engineering to be inadequately prepared.

A 1984 American Chemical Society study (B36) obtained a profile of the current inventory of laboratory equipment in college and university chemistry departments. The total needs for chemistry instrumentation were found to be nearly $150 million, not including maintenance, a major portion of which would be used in whole or in part for undergraduate instructional purposes. The report called for increased support by funding agencies of both research and instructional instrumentation.

The American Physical Society in 1985 conducted a survey of the chairpersons of U.S. physics departments and received an unusually heavy response (70%; 553 out of 791 departments) (W15,W21). The survey concludes:

> *"The overwhelming consensus is that physics departments badly need new modern laboratory equipment for advanced or upper division courses, the present equipment being judged as obsolete in many respects, and that physics departments badly need replacement equipment for classical physics experiments and for the introductory laboratories as well."*

Because biology is the "exploding science" at the present time, its needs for new instructional equipment are especially intense, but more difficult to specify than those of physics and chemistry. The methods employed to investigate biological systems have changed dramatically. There are few research universities able to reflect these changes in undergraduate laboratory instruction, and the situation in other kinds of institutions is even less favorable (W13,W18). At the same time, industrial demands for qualified, well-educated, laboratory-experienced personnel are expanding, fueled in part by the need to maintain national competitiveness in related fields such as biotechnology.

Witnesses before the Committee suggested a number of ways the Foundation could act to alleviate these situations:

- enlarge and extend the present College Science Instrumentation Program;
- establish a program to stimulate new approaches to the instructional laboratory's content and methods;
- support a program to develop computer simulations of some kinds of laboratory experiments (to augment the experience gained in traditional laboratory exercises);
- initiate an effort to design and develop simplified instrumentation *specifically for instruction* (so that research-like, "cutting-edge" experiments could be done in the mass-enrollment introductory laboratory courses, but at less than research-like cost); and
- reestablish an undergraduate research participation program (with emphasis on placing undergraduates in university and industrial research laboratories during the summer months).

One very great need in the instructional materials area is for new experiments that will permit good science to be done and learned in the mass-enrollment introductory laboratory courses at modest cost. Colleges and universities are beginning to cut back on the amount of laboratory work required in such courses because of escalating costs of apparatus and materials (B37:30,51). Solution to this problem might well involve collaboration among the industrial manufacturers of laboratory equipment, top research scientists, and the best teachers of science (B37:31).

The Committee finds these reports and testimony to be deeply disturbing. Instructional equipment problems are closely interwoven with curriculum difficulties since many technical subjects cannot be effectively included in the curriculum without supporting laboratory instrumentation.

C. Disciplinary Perspectives

1. The Sciences

> *"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." Jean E. Brenchley (Pennsylvania State University), President-Elect, American Society for Microbiology (W13).

Survey data and testimony presented to the Committee indicate that the situation in undergraduate instruction in the basic sciences is far from satisfactory. As detailed above, physics department chairmen have cited pressing needs for the procurement of modern laboratory equipment for advanced undergraduate courses and replacement equipment for introductory courses (B14). The American Chemical Society reports that chemistry department chairs regard their instrumentation as largely obsolete (B36). The head of a biotechnology group at a large state university testified that problems in curriculum development, teacher effectiveness, and scarce instructional resources threaten the maintenance of adequate undergraduate programs in the biological sciences (W13).

Large classes in many departments lower the quality of instruction; this situation is especially severe in the important introductory courses taken by non-majors. Few departments use new educational technologies effectively to individualize instruction (W33). As it becomes more difficult to recruit U.S. graduate students in many fields, institutions are being forced to appoint teaching assistants whose English language ability is not adequate for instruction (B12:58;W12). As teaching quality declines, negative feedback from disillusioned students lowers the morale of faculty and makes study opportunities in the sciences less attractive to potential majors who are then lured by other professional programs that offer greater prospects for career rewards.

The contents of science curricula are discovery-driven. This guarantees continuing pressure on faculty members to update their courses and to develop more efficient and more stimulating ways of teaching their subjects. Unfortunately, a good deal of time is required if this course and curriculum tuning is to be done well. There is real concern in the several disciplinary communities that not enough of this kind of time is being spent.

The situation in biology is an extreme example. There has been an explosion of knowledge in the past decade; new applied fields (e.g. bioengineering, biotechnology) have arisen and new industries have been born during this explosion, such has been its character and momentum (W18).

The result in colleges and universities has been disarray. Faculty members in research universities have concentrated on keeping up with the explosion of knowledge rather than working on incorporating its content into new courses, especially courses that could be taught in non-research institutions. The methods for study of biological systems have changed so rapidly that even research universities are hard pressed to keep advanced laboratory courses equipped with state-of-the-art apparatus, and few if any institutions have been able to revise the mass-enrollment introductory-level laboratory courses to reflect the new knowledge and techniques. The faculty themselves are often unable to keep abreast of - much less master - the new science.

The emphasis on disciplinary research that has changed the nature of doctoral university faculties in the past 35 years has had a marked effect on non-doctoral institutions, which produce many of the Nation's new baccalaureate engineers and scientists. These institutions face all of the difficulties noted above with only a small fraction of the human and financial resources available to programs embedded in doctoral universities. And, their faculties, quite understandably, are beginning to moderate their commitment to improve teaching in order to spend time - and an increasing part of the resources of their colleges - on basic research.

Few doubt the importance to students of the intellectual stimulation gained by their teachers from their research activities, and neither do many doubt the harm of increasing the fraction of faculty members whose allocation of research time is first to the discipline and second to the improvement of teaching.

Interestingly, some of the solutions to these difficulties suggested by witnesses before the Committee amount to more - not less - support of research in collegiate institutions (W11,W25).

Opportunities for undergraduate research are frequently identified in reports (B38) and testimony (W21,W25,W27) as being of significant importance for undergraduate instruction in the basic sciences. Such research opportunities enable good departments to recruit outstanding science students for graduate work later.

In non-doctoral institutions, the support of student involvement in the research activities of the faculty is of benefit to all parties; the enthusiasm and ingenuousness of the undergraduate are just as stimulating to an investigation as the determination and dedication of the doctoral student, and both learn important things about themselves as well as about the discipline in being part of a vigorous research program.

In the doctoral universities, few faculty members who are leaders in disciplinary research devote significant amounts of time to the curriculum research and course development activities necessary to build new knowledge into the educational experiences of students. As faculties in all kinds of institutions have become more discipline-centered and less institution-centered, this concentration of leadership effort has begun to have a negative impact on the quality of instruction (W26).

Witnesses before the Committee urged that ways be found to involve active research scientists in course and curriculum development activities that result in transferrable products - new courses and new curricula that can be adapted to needs of other kinds of colleges and universities. They emphasized the need to replace obsolete instructional and research equipment; argued that ways must be found to reverse the falling-off of laboratory course requirements (because of rapidly escalating costs of laboratory instruction); pointed to the necessity of developing new programs to help faculty members stay abreast of their fields; and urged that the very best of the teachers and researchers in each of the sciences join in efforts to improve the courses and instruction in science that are designed to meet the needs of the general student - tomorrow's non-scientist citizen.

2. Mathematics

> *"Mathematics is both an enabling force and a critical filter for careers in science and engineering. . . . Mathematics is not just one of the sciences, but is* the *foundation for science and engineering. . . . The reality (however) . . . is both simple and awesome: undergraduate mathematics is a totally different subject than it was twenty years ago." Lynn A. Steen, President, Mathematical Association of America (W20).*

Mathematics underlies all of the sciences and engineering. In the first two years of college, a typical undergraduate science or engineering student takes as many courses in mathematics as in the chosen major. For students preparing for a research career in science or engineering, the total number of courses in mathematics taken over the four undergraduate years may exceed the number of courses in the major. Successful efforts to improve the undergraduate curriculum in mathematics will have immediate impact not only on mathematics but also on instruction in all the sciences and engineering.

The "general" or "non-technical" undergraduate is not untouched by mathematics, for one or more courses in mathematics are required for, or elected by, nearly every college student. The importance of mathematics in nearly every field of study is becoming widely acknowledged. Colleges across the country are instituting mathematics proficiency requirements and many also have distribution requirements in the subject. Thus, successful efforts to improve the undergraduate curriculum in mathematics can have a significant impact on the level of scientific literacy in the nation. These efforts will not be successful unless solutions are found to serious problems in the areas of faculty and curriculum (B26).

Faculty Shortage and Faculty Development.

The spectre of a major shortage of qualified college mathematics faculty looms on the horizon. A major decrease in the rate of production of Ph.Ds in mathematics is occurring simultaneously with an increase in the number of non-academic jobs that are available for mathematicians and an almost explosive rise in registrations in relatively elementary mathematics courses in colleges and universities (W17).

The enrollment increase derives from larger enrollments in engineering and some science curricula, and the steady rise over the past twenty years in the amount of instruction that must be done to remedy deficiencies in the mathematical preparation of students in the secondary schools. When coupled with falling Ph.D. production in the field, these factors combine to worsen the conditions of faculty employment.

As in science and especially in engineering, instruction at the elementary and remedial level in mathematics is done increasingly by graduate teaching assistants or adjunct faculty, many of whom do not communicate well in English (B39). The senior faculty must teach the more advanced courses and their reluctance to "teach more and more junior high school mathematics to college age students" is understandable. Several persons testified that a substantial research effort in the "teaching and learning" areas should be directed at secondary school mathematics in hope of improving that instruction so that remediation would not be required in the colleges.

The decrease in faculty supply and increase in student enrollments have resulted in steadily rising teaching loads for mathematics faculty. Time for the individual research that characterizes the field, and for other kinds of faculty refreshment and development is decreasing perhaps even more in the college than in the university. Witnesses stated that, for these and other reasons, it would be timely and beneficial for institutions, governments and their agencies, including the National Science Foundation, and private sources of funding, to invest seriously in programs of faculty development in mathematics (W17,W20).

Curriculum Change.

The mathematics curriculum is ripe for change. Research activity in mathematics has never been more intense. New applications of mathematics are continually being discovered, and these new applications in turn are stimulating new research. The impact of computing technology on mathematics is dramatic. For all of these reasons, mathematics is changing. And if mathematics is changing, then so must instruction in mathematics.

These changes are already beginning. Many college mathematics departments are installing instructional computer facilities, and their availability is altering the way such subjects as differential equations and numerical analysis are being taught. The increasing graphics capability of computers that can be afforded for classroom use is modifying rapidly the approach to a subject like differential geometry - as not long ago research in that area was revolutionized. On a more elementary level, instruction in calculus is changing, and some schools are introducing courses on the mathematics of computation at both the lower and upper division undergraduate levels.

The pace of necessary changes in the undergraduate mathematics curriculum will be too slow unless substantial support comes from sources external to the colleges and universities. Too few of them can afford the costs of research and development for the new courses they need - ones that embody recent advances in mathematics research and in computing technology. The sensible way to accomplish these changes is for a few colleges and universities to develop prototypical courses and instructional materials with support from a foundation such as NSF. These materials can then be tested, refined, disseminated for the benefit of all, and serve as templates for later commercial publishing (W20).

Leadership funding of this kind should not be expected from the publishers themselves, though they will follow successful pioneer efforts. This is the lesson of the CHEM study and PSSC Physics courses developed for high school instruction by the 1960's projects sponsored by NSF - today, most high school chemistry and physics texts are based on them.

First steps of this kind are already being taken. An example is provided by the Sloan Foundation's recent support for the introduction of discrete mathematics into the freshman curriculum. Sloan sponsored a conference on this topic, from which came a proceedings volume that described a variety of options. Next, Sloan provided support for six institutions to develop model courses, some were independent courses in discrete mathematics while others combined discrete mathematics and the calculus. Steps such as these are needed in many other subject matter areas, and witnesses appearing before the Committee urged that the National Science Foundation assume a leadership role in their initiation.

Undergraduate Research.

Resource requirements in mathematics are generally different from those in science and engineering. At the graduate level, the need is for the support of human resources rather than laboratory facilities and equipment. Even the human resource needs in mathematics are different from those in the sciences. The primary need is for support of the professional researcher - for secretarial assistance and perhaps for computing. Need for support of laboratory technicians and maintenance staff is limited to computer-related activities.

This pattern of support requirements extends naturally to the undergraduate level, where, for example, student-faculty apprentice-mentor relationships are different from those found in the laboratory sciences and engineering. Mathematicians generally work alone, but even when mathematicians do work with others, these groups tend to be rather small and to consist either of researchers of comparable experience and talent or of a senior researcher working with one or two talented postdoctoral research associates. Undergraduates usually do not have the requisite knowledge or experience to make direct contributions to research projects in mathematics (W20).

Nevertheless, the health of the mathematics research enterprise may well depend on the availability of opportunities for mathematics majors to have meaningful summer experience in their field. This is especially true for the many future mathematicians who are studying at relatively small undergraduate colleges where there may be only one or two mathematics majors with an interest in a research career. The interaction with one's peers that is so important in the process of solidifying one's career goals is often absent in such settings. A stimulating summer experience can do much to make up for that.

3. Engineering

> *"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." National Research Council, Committee on the Education and Utilization of the Engineer (B12:62).*

As our society becomes ever more dependent upon science and technology, so too does it become dependent on the availability of talented, broadly educated engineers. Indeed, the health of this nation's engineering schools is a critical factor in determining the economic and military security of this Nation and the quality of American life. Undergraduate engineering education is at a crossroads, not because it hasn't served the Nation's needs and met its expectations, but because it has. High demand for engineering graduates coupled with greater interest in engineering careers on the part of the Nation's best high school seniors has resulted in dramatic enrollment increases nationwide. This trend has persisted for nearly a decade, during which period most academic institutions were experiencing increasing fiscal constraints (B51).

The engineering profession has attracted many highly-qualified students. The resulting overload of facilities and faculties during a period of austerity has generated substantial downward pressures on the quality of engineering education. Several witnesses testified that a decade of such pressures had already caused significant deterioration in the vitality and quality of the engineering programs at many if not most of the Nation's engineering schools.

Characteristics.

In contrast to most other professions, engineering education is focused at the undergraduate level; the four-year baccalaureate program represents the terminal degree for most practicing engineers (B12:3).

There are many kinds of engineering: civil, computer, mechanical, electrical, aerospace, manufacturing, chemical, and others. An undergraduate engineering curriculum is not, however, limited and monolithic in its structure. About half of the content is common to all the specialty tracks, a factor which permits students to move from one field or subdiscipline to another without adding substantially to their times in course. Because 128-140 semester hours of course work may be required, (compared with the "standard" 120 semester hours), about 4.5 years, on the average, are taken to complete the "four-year" engineering curriculum. In some areas, recent development has been so rapid that the normal processes of curricular compression have not had time to act; in those areas there is often serious interest in adding a fifth year to the baccalaureate curriculum or making the M.S. the entry level degree (B12:4).

Production of Graduates.

(a) *Quantity*. While it is true that the United States lags far behind other industrialized nations in per capita production of engineering graduates, the sense of crisis among engineering educators and employers has less to do with the quantity than the quality of undergraduate engineering education. At the present time, the nation is producing roughly 70,000 B.S. engineering graduates each year (along with 15,000 M.S. and 3,000 Ph.D. graduates) (B1:267). For the long term, anticipated retirements and limited technical mobility of the engineering workforce (50% of whom are within 10 years of retirement), coupled with the demographic decline in the number of high school graduates (roughly 25% to 30% in the East and Midwest), raise serious concerns about the Nation's supply of engineers. However, in the short term, aside from periodic shortfalls in critical areas such as electrical, computer, manufacturing, and aerospace engineering, there appears to be an adequate supply of baccalaureate engineering graduates (B40:108;W14).

There is *right now* a serious shortage of faculty in most branches of engineering, one that is expected to worsen in the next few years. This situation arises in part from the attractiveness of entry-level positions in industry. Engineers nearing the end of B.S. degree studies receive several interesting offers and see no need to continue their education to the master's level or beyond (W14). The result is a dearth of advanced degree candidates who might be recruited to academic careers.

Undergraduate enrollments in engineering have nearly doubled in the last decade, but the number of doctoral candidates is about the same as it was ten years ago (B41:63-65,73). Thus, the production of potential faculty members is presently *only half* the national need; this factor is limiting the growth of baccalaureate engineer education and jeopardizing its quality.

(b) *Quality*. Of more serious concern is the quality of undergraduate engineering education. While undergraduate engineering enrollments have more than doubled over the past decade, and the attractiveness of engineering careers is drawing the most talented of our Nation's high school graduates into engineering programs, limits on available financial resources and insufficient engineering doctorate production have held the amount of institutional space and the number of engineering faculty positions roughly constant (B32:9) and led to serious overloads of both staff and facilities. This situation has been compounded by the serious obsolescence of the laboratory and instructional facilities, which have fallen far behind modern technology and engineering practice.

The engineering curriculum, in the view of some who met with the Committee, has not kept pace with the demands placed on professional engineers. Further, it is said to be deficient in one element that is important to the maintenance of balance between "producer" and "consumer" views of the proper preparation for engineering practice (W14).

Upon graduation most engineers go into industry and business in the private sector. The preparation for work in the private sector can only be touched upon in the undergraduate years, unlike the situation in other areas where several years of graduate study and postdoctoral work immerse a person in the type of work they may later do in a university, government, or industry laboratory. There are no "teaching hospitals" or similar arrangements to help prepare engineering graduates for work in the professional real world. A research experience for undergraduates would be another way of preparing for practice, but more than one-half of the B.S. engineering students graduate from non-Ph.D. engineering institutions where research opportunities are limited. The universities that receive 50 percent of the federal funding for research graduate only 26 percent of the B.S. engineers (B49).

Large companies have training programs to help new engineers become productive in the industrial environment, and large companies are generally quite complimentary about the high quality of graduates. However, small companies have not thought that they have the resources to provide extensive training programs. They are critical of these same graduates because of their inexperience and lack of specific knowledge (which, in combination, retard the arrival of new engineers at the point where they can apply the knowledge they *do* have in innovative and creative ways). As the country is highly dependent on small companies and industries for innovation and creative products and processes, and for providing new job opportunities, it is important that more attention be given to the preparation of graduates to meet their needs.

Other Problem Areas.

(a) *Faculty shortage*. Despite concerted efforts by institutions, industry, and federal agencies, roughly 1,500 (8.5%) of our nation's budgeted engineering faculty positions remain vacant. If resources were available to cope with enrollment growth during the past decade, 6,700 faculty positions would have to be filled (B41). Of particular concern are the critical shortages in high demand areas such as electrical engineering, computer science and engineering, and manufacturing engineering.

Key factors in constraining the supply of engineering faculty are the limited production of engineering doctorates (particularly U.S. nationals), inadequate salaries, obsolete facilities, instructional overloads, and inadequate opportunities for professional development. The inability of engineering schools to attract younger faculty has led to an aging faculty cohort with limited ability to respond to technological change. Anticipated retirements over the next decade will almost certainly intensify the shortage of engineering faculty.

It is imperative that faculty devoted to teaching be provided opportunities to maintain competence, and to develop new areas of knowledge and methods for maintaining a vital, inspiring, creative, and exciting link with the students. The teacher must have time for reflection as well as experience if he is to consider and adjust the balances of science and technology, theory and practice, depth and breadth, and ethics and economics as various technical topics are presented to the students. Teaching loads have nearly doubled over the past 10 years and time for pursuit of scholarly activities and practice-related activities has become practically nonexistent in many institutions.

(b) *Instrumentation, equipment, and facilities.* An especially serious aspect of today's engineering education is the difference between the amount and condition of instructional laboratory instrumentation and equipment and that appropriate to the dimensions of the teaching task. Laboratories in the schools "producing most of our engineers (are) a national disgrace," according to one distinguished educator (B52).

Recent NSF surveys have estimated that only 18% of the equipment used in engineering instructional laboratories is state-of-the art (B53). It is estimated that the deficiency in needed laboratory equipment now exceeds $2 billion. To maintain the quality of instructional equipment at adequate levels, institutions should be investing roughly $1,500 to $2,000 per graduate per year (B35).

Of comparable concern are the costs associated with servicing and maintaining the modern laboratory - amounting typically to 10% to 15% of equipment purchase costs per year. All too frequently corporate gifts of badly needed equipment lie unused because of inadequate resources to maintain the items.

Investments of similar magnitude must be made to achieve the computing environment characterizing contemporary engineering practice. Keeping pace with modern tools of engineering such as computer-aided design, supercomputers, and computer networks presents academic institutions with staggering challenges. Yet failure to expose students to such technology will guarantee the rapid technological obsolescence of newly graduated engineers.

Few engineering schools have managed to maintain the quality of facilities necessary to respond to surging enrollments and sophisticated new technology. The absence of federal programs to assist in the construction or renovation of instructional space has been particularly damaging, since it was this support during the 1960s that enabled many institutions to get substantial matching funding from public and private sources. According to several of our witnesses, most engineering instruction now occurs in facilities inadequate for the installation and maintenance of modern instrumentation and information technology.

(c) *The Curriculum.* Numerous studies have asserted that the undergraduate engineering curriculum has not been kept abreast of technological change and professional practice. There are growing concerns about the limitations inherent to the traditional four-year program (W7,W41). Issues of concern include: the growing vocational focus of the curriculum; over-specialization; inadequate exposure to engineering practice - particularly engineering synthesis and design; and the inability of the traditional discipline approach to keep pace with the intellectual evolution of engineering practice, which tends to be cross-disciplinary in nature. Furthermore, there continues to be general concern that for some fields, such as electrical and computer engineering, the entry degree into the profession should be extended to the M.S. level (B12:51-84).

There seems to be widespread agreement that inadequate attention has been paid to curriculum development in engineering education. This has been due in part to an overloaded and aging faculty, as well as to the absence of external programs aimed at stimulating curriculum innovation and implementation.

A number of problem areas were identified by the witnesses but none so serious as the lack of emphasis on a systems approach. For example, *design* is an important element in almost every aspect of engineering practice. While the teaching of the design of *components* is reasonably well done, there is so little instruction about design of *systems* in most institutions that good teaching materials are rare - especially in the sub-area of manufacturing design, where the need nation-wide is especially great.

Summing Up.

The consensus of the testimony presented to the Committee is that there are grave problems in engineering education. **The serious shortage in the availability of engineering faculty, the poor quality of physical facilities and deficiencies in instructional laboratory equipment, and the failure to keep the undergraduate engineering curriculum abreast of technological change have all been documented extensively in numerous studies and reports.** The success rate of institutions seeking approval of their programs by the Accreditation Board for Engineering and Technology has fallen-off sharply (B43).

The testimony identified a number of causative factors:

First, the attractiveness of engineering careers coupled with no growth in the student capacity of good educational programs has limited freshman enrollment to an increasingly higher "cut" from the applicant spectrum. More able entrants mean higher quality graduates; the ability of students has risen faster than the quality of their education has declined, until recently. The result has been to mask the lowered quality of education.

Second, few academic institutions have taken steps to re-establish a balance between engineering enrollments and resources through major internal reallocation or by limits on engineering enrollments.

Third, American industry has been a driving factor in the intense demand for engineering graduates, but it has been slow to develop a corresponding interest in supporting engineering education at a level adequate to meet this demand or to modify its recruiting practices so as to better balance the demand with the supply. Also, faculty members leave academe for industry, but very few experienced engineers have been attracted from industry into faculty positions.

Finally, some of the blame must be shared by those responsible for the character of federal programs to aid education. In the various changes that occurred in the last decade: research and graduate education have enjoyed support closer to their needs; K-12 programs have received attention at last, though not nearly enough funding; but undergraduate education - which is the level critical for the *quality* of engineering in the future - has been largely ignored.

D. Institutional Perspectives

1. Doctoral Universities

> *"Since the phase-out of the NSF programs (for course and curriculum development) we have seen a decrease in the flow of new instructional materials from the research universities. . . . Some of the burden for curriculum improvement has been assumed by (private) foundations and by corporate initiatives. . . . 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." J. M. Ballantyne, Vice President for Research and Advanced Studies, Cornell University (W1).*

Education in science, mathematics, and engineering at the doctoral universities presents special problems in addition to sharing many of the concerns of non-doctoral institutions.

The presence of research scientists who are at the cutting edge of their fields is a resource for undergraduate science and engineering instruction that is unique to doctoral universities. The effective utilization of this resource for undergraduate education while maintaining a high level of research productivity should be a central concern of doctoral universities, both public and private.

The strong focus on graduate-level research at these universities creates a dichotomy of interest for some faculty members. There is institutional pressure to obtain grant support for research; promotions, tenure, salaries, and peer group recognition are more strongly linked to research productivity than to teaching. The resulting "publish or perish" syndrome often detracts from efforts to improve undergraduate education. Those faculty members who act on serious interests in undergraduate instruction take some risks and may make considerable sacrifices in order to persist in such activity while facing pressures to maintain strong research programs and to obtain funding for them.

Needs.

(a) *Facilities*. Well-equipped, modern laboratories are especially important to educational programming in the doctoral universities. Witnesses described to the Committee serious deficiencies in the character and condition of teaching space, instructional laboratories, and equipment for demonstration and instruction; the scarcity of computers devoted to instructional tasks; and the simple lack of enough equipment to serve the students enrolled. One of those testifying stated:

> *"The teaching labs in electrical engineering still make regular use of instruments manufactured in 1920, oscillators manufactured in 1940, microwave equipment manufactured in 1962, and computers manufactured in 1970." (W1)*

The situation becomes even more critical when we consider the widely acknowledged need for high-quality, "hands-on" laboratory experiences for undergraduates, the increasing use of sophisticated equipment in modern science, and the rapid emergence of new technologies and their use in new scientific disciplines such as biotechnology and others springing from modern biological science. Several individuals testified to the Committee that donations from industry are not likely to solve the equipment problem that now confronts the science and engineering disciplines (W8,W16).

(b) *Curriculum improvement*. The sudden phase-out in the late 70's of Foundation programs to stimulate innovation in college-level science and engineering courses resulted not only in the elimination of this flow of often-creative projects, but indirectly in a further reduction of effort on the part of research faculty members to prepare new instructional materials. **Because they work at the frontiers and borderlines of knowledge, the involvement of research scientists in course and materials development is necessary in order to assure that such work products are up-to-date and that they reflect both the directions and excitement of the most active lines of research.**

The problem is one of making such participation by research scientists not just possible but attractive. Further, it is desirable that such faculty members be exposed to fields close to but apart from their own specialties and to recent advances in the sciences of teaching and learning - so that the effectiveness of their work on new materials will be enhanced.

(c) *Faculty shortages*. Current information predicts that a serious shortage of science and mathematics faculty will develop in the near future. This situation already exists in engineering. Many students have shifted from other fields into engineering, and shifts have occurred from one engineering field to another. Between 1976 and 1982, the number of undergraduate students in engineering increased by almost 60%; during the same period, the engineering faculty increased less than a third. Currently popular fields such as Electrical Engineering and Computer Science are experiencing serious faculty shortages. There is inadequate production of engineering doctorates to meet the demand (B42).

Related to faculty shortages are the problems of larger class size and increased teaching load. Maintaining a reasonable faculty/student ratio is important for effective undergraduate instruction in mathematics, the sciences, and engineering. More staff support (e.g., secretarial help, lab technicians, lab assistants) is also needed to provide high-quality undergraduate instruction. When faculty members are overloaded and lack staff support, they do not have time or incentive for new curriculum or materials development.

(d) *Intellectual breadth of science and engineering education*. Testimony to the Committee recommended that federal programs aimed at strengthening science and engineering education give prominence to its intellectual breadth (W7). The basic premise is that the best professional education in science and engineering education is one that is broadly based. The humanities and social sciences contribute to the breadth and intellectual skills needed for engineers and scientists to be effective professional leaders.

(e) *Science literacy*. One of the missions of science education in the schools is to produce a citizenry for the future that has at least minimal acquaintance with the methods, content, and significance to society of contemporary science. Colleges and universities expect their students to further advance the reading and writing skills they bring with them from high school; similar expectations are becoming manifest in mathematics and the sciences.

The introductory science course, whether designed for majors or non-majors, is often the only exposure that non-science students will have to the subject at a collegiate level of sophistication. It is important that this course be well-designed and well-taught, so that students who complete it have a good foundation in science to take with them into their lives as citizens and as the potential leaders in many different communities.

The introductory course may serve as a gateway to science and engineering careers; one would hope that able students who have not made a career choice at that time might be attracted to science or engineering because of a motivating experience there. It is also an important course for students who have already decided to become scientists or engineers; potential science majors need a good start in their freshman year to reinforce their interest in science and to set the stage for advanced studies.

Despite their importance, introductory science courses generally do not receive sufficient support. The typically large number of students enrolling in introductory courses places a strain on facilities and equipment; replacements, maintenance and repairs are serious problems with large associated costs.

Teaching the introductory courses requires special skills and attributes. In some doctoral universities, distinguished faculty scholars have elected to teach these large courses. Because of the heavy demands of such teaching assignments and the lack of recognition and reward that often accompany them, non-tenured faculty at those universities may take considerable risks in choosing to teach introductory courses.

Competitive national funding programs aimed at providing modern equipment and facilities for introductory science courses and attracting outstanding faculty members to teach them and work on their improvement would be highly desirable. Such programs would establish incentive, recognition, and rewards for faculty, and would reinforce the importance of the introductory courses in the curriculum.

(f) *Improved Articulation Between Colleges and Universities and the Secondary Schools*. Science literacy at the undergraduate level is built on good teaching in the secondary schools. There is need for greater exchange and cooperation among secondary school science teachers and the faculties of all kinds of colleges and universities. Such cooperation could involve not just refresher courses for school teachers, but joint efforts in revising textbooks, increasing available literature, making films, and/or organizing workshops. Greater continuity in the science curriculum between high school and undergraduate education would permit offering more advanced material and increase teaching effectiveness at the undergraduate level. Because of their quality and prestige, and because of their obvious stake in the outcome, doctoral universities and their faculties should play leadership roles in this area.

2. Community and Junior Colleges

Two-year colleges serve a large fraction of the Nation's college population. In 1985, 41% of full-time freshmen and sophomores attended community, junior, or technical colleges. This number includes 42% of the Black college students, 54% of the Hispanic students, and 43% of the Asian student population (W4).

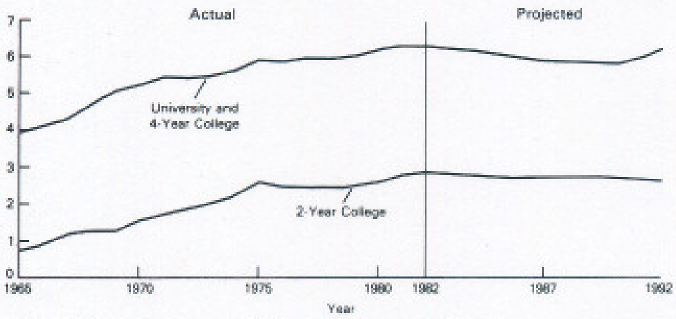
The growth of the two-year colleges in the past two decades has been extraordinary. In 1964 there were 637 two-year colleges; by 1984 the number had doubled to 1,272 (Table A). Student enrollments (FTE) grew from approximately 600,000 to 3,000,000 during this period (Chart 9).

Although many of its students are enrolled in college transfer programs, the two-year college provides the ma-

CHART 9

Full-Time Equivalent Enrollment in Higher Education Institutions

(Millions)



SOURCE: U.S. Department of Education Center for Statistics

jority with their last opportunity to study science in a formal educational setting. A typical community college student is more likely to pursue an occupational or technical curriculum than a liberal arts program. Many move directly from the two-year college to employment. Those that do transfer to four-year institutions often have satisfied any science requirements before transfer and do not elect additional science.

The quality of the engineering, science, and mathematics taught at two-year colleges is thus of prime importance. It provides the underpinning on which the technical skills of occupational students are built, and is the culminating science education experience for a substantial portion of citizens.

Needs.

The major identified needs for science education in the two-year colleges are in the areas of: (a) faculty development, (b) courses and curricula, and (c) facilities and equipment.

(a) *Faculty development*. Earlier Foundation programs for college faculty are viewed almost universally as having had significant positive impact on the quality of science, mathematics and engineering instruction in the United States (B37:12;W6, W8,W10,W21,W26). One witness estimated that 50% of science faculty who are entering the last third of their careers received their initial training with both the encouragement and financial assistance of the National Science Foundation (W4). For some, this came in the form of NSF programs for secondary school teachers. Some of the teachers who earned advanced degrees through NSF institutes became two-year college faculty; the new generation of teachers does not have this opportunity. Furthermore, many two-year college faculty are prevented by geographical considerations from any significant interaction with faculty at research institutions. Relatively modest partnership support from NSF for faculty development could lead to genuine improvements in science and mathematics instruction.

(b) *Courses and curricula*. The potential applications of technology to education are of great interest to two-year colleges. Computers and computer networks, television, videotape and videodisc technology are seen as bringing new dimensions to teaching and learning. Investments by NSF in this area can lead to great advances in the capability of two-year colleges to deliver high quality instruction.

Because of the concentration of their faculties on instruction, community colleges lend themselves well to research and development projects on teaching and learning, especially those that are facilitated by the presence of large and heterogeneous student bodies.

The two-year colleges are a part of *higher education*. Their transfer programs provide large numbers of upper division students to four-year institutions. Articulation at this transfer point is difficult and requires serious and permanent collaborative efforts between the source and acceptor colleges. NSF-sponsored demonstration programs might be especially helpful to the development of consortial interactions that could make the transfer process smoother administratively and less risky for the student.

(c) *Facilities and equipment*. As is the case with many four-year colleges, the two-year institutions (community, junior, and technical colleges) are beset by outdated laboratory facilities and serious deficiencies in both the amount and condition of apparatus and equipment.

Unusual pressures are placed on two-year institutions because of the diversity of their curricula. The costs of instruction in most liberal arts subjects are much lower than in the laboratory courses that are part of every technical, scientific, and pre-engineering curriculum. Were two-year colleges' programming limited to the college transfer area, their concerns would be identical with those of four-year institutions. The extra pressure on them arises from the substantial science instruction included in many of the technical/certificate curricula they offer. The importance of Foundation leadership and intervention is intensified by the programmatic diversity of these institutions.

3. Non-Doctoral Colleges and Universities

The non-doctoral colleges and universities in the United States play a significant and critical role in educating professional scientists and engineers as well as in providing a background in science to students majoring in non-science fields. These are institutions, both public and private, that award bachelors or masters degrees but do not have large doctorate programs. They include liberal arts colleges, some private universities, and state colleges and universities that do not have graduate training and research as a major responsibility.

The liberal arts colleges have a long tradition of excellence in undergraduate education. The most selective of them graduate significant numbers of science and engineering baccalaureates, and they are a major source of students for graduate programs (W5). The state colleges and universities educate large numbers of students of science and engineering; like the liberal arts colleges, they also provide the only college-level science education for the majority of their students who do not become professional scientists or engineers.

Student tuition is the major source of operating funds for all private colleges and universities; only a few of the better-endowed institutions receive significant income from investments. State funds are usually appropriated to public institutions on the basis of student enrollment. Teaching and doing science is expensive, but it is a necessary part of the undergraduate education these institutions provide. Even so, resource constraints result in unintended bias toward support of less costly programs and sometimes force adoption of techniques for science and engineering instruction that are detrimental to its quality, e.g., de-emphasis of laboratory work, over-reliance on demonstrations, etc.

Predominantly Minority Institutions.

Some 130 colleges and universities have mostly undergraduate programs and enroll primarily minority students. These constitute a special and unique subset of the group comprising the nondoctoral colleges. "Minority" is not a uniform label. These institutions differ among themselves in ethnicity, programmatic emphases, and geographic distribution.

Minority institutions are usually smaller and less well-financed than their non-minority counterparts. Further, they are all in transition between narrow service to a special population and more comprehensive attention to the educational requirements of diverse student groups. As a result, all of the concerns expressed here apply to them - but the problems are intensified, even exacerbated, by virtue of their continued fiscal poverty and long-standing exclusion from equitable access to resources of all kinds (W2,W24).

Five institutions in the Southwest, fourteen in Puerto Rico, and one in Florida enroll mainly Hispanic students. In Alaska, the students at one college are almost all Native Alaskans. There are ten institutions in cities with large and diverse minority populations (New York, Chicago, Santa Fe, San Antonio, and Los Angeles) that serve several major minority student cadres.

In nearly a hundred of these predominantly minority institutions, the student body is mostly Black - these are the "historically Black" colleges. Small for the most part, their number includes, however, several comprehensive institutions and more than one research university. The historically Black institutions (HBI's) are concentrated in 20 states, mostly in the Southeast, and in those states they graduate over half of the Black bachelor's degree recipients. The HBI's make a special contribution in science and engineering, since they produce more than 40% of all Black undergraduate degrees in the technical fields (W24). The HBI's together with the two-year colleges enroll approximately 60% of the Black students in U.S. higher education.

Thus, Black students are still highly concentrated in the HBI's. There is strong feeling in the Black community that majority institutions, while effective for some minority students, are not appropriate for others. Many minority students are uncomfortable and hesitant in a department or school where they may be the only students of their race or ethnicity, and where majority faculty may not be conscious or thoughtful of their unique situation.

Minority institutions and the HBI's often serve as links to the minority communities in ways that their majority counterparts cannot. They can help to strengthen the educational pipeline from the very earliest years of schooling, producing impacts well beyond undergraduate education. In the words of one witness: ". . . 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." (W2)

Needs.

Non-doctoral institutions share many of the concerns of the doctoral universities; need for course and curriculum improvement; actual and impending faculty shortages; difficulty of staving-off faculty obsolescence; the need for more facile transitions between schools and colleges and between undergraduate and graduate institutions, etc.

Testimony before the Committee (W3, W5, W8, W11, W25) and position papers submitted to it (B38, W29, W31, W32, W37, W38) identified the priority needs of undergraduate institutions, included suggestions for how the Federal Government might respond appropriately to those needs, and commented on the adequacy and appropriateness of present support. Some of the deficiencies can be met without new programs; others will require initiatives from NSF.

The needs these institutions identify fall into two broad categories: tools (equipment, instructional materials, facilities) and people (support for faculty and students). The most widespread need, identified by many who appeared before the Committee or wrote to it, is for scientific equipment for instruction and research. Present holdings are inadequate and obsolete, and they are getting worse rather than better. Some instructional laboratories cannot be operated because of lack of equipment, and in others the equipment used is out-of-date or rundown. Modern instructional equipment in adequate quantity is vital. Research equipment is also necessary to help faculty keep up to date in their fields and to provide to students the research opportunities that are a highly desirable part of excellent undergraduate education in science and engineering.

Submissions to the committee pointed also to serious deficiencies in the quality of instructional materials. Texts, laboratory manuals, and methods of teaching have not kept up with progress in science and engineering. Certainly, materials for teaching must reflect the current state of a discipline if undergraduates are to be well educated.

The eminent need identified in the "people" category is for support of faculty research and other skill-enhancing activities. Active participation in research is the preferred way for faculty to keep up-to-date. Without qualified faculty whose knowledge is current, the education enterprise cannot succeed. Institutions find that faculty recruiting and retention are more successful if they facilitate faculty research and other activities that help faculty keep abreast of progress in their disciplines.

4. Some Common Concerns

The Federal Role.

Non-doctoral institutions traditionally have relied on tuition and on private or state funding for their operations; all agree that these will continue to be their principal sources of funds. However, it is a national and, therefore, federal concern that those students who may become some of the Nation's leading scientists and engineers be encouraged and taught well as undergraduates. Federal encouragement and support of excellence in undergraduate education are both necessary and proper.

There are activities, particularly curriculum development, where the individual institution does not have the organizational structure or resources to make a national impact. There are others, particularly updating of instrumentation and supporting undergraduate research, where federal funding in augmentation of local resources encourages excellence. Further, there is the question of equity: predominantly undergraduate institutions feel unfairly excluded from current NSF activities even though the Foundation is mandated to support their important national role in undergraduate science and engineering education (W5,W31).

Women, minorities, and the handicapped in the United States are underrepresented in every kind of place in higher education (students, faculty, administration) and in every field for which college and university work is preparation (including science, mathematics, engineering, and all the specialized professions). There is strong support for special efforts to achieve equitable representation in all of these areas.

Why should NSF provide the support rather than some other federal agency? While others certainly have appropriate roles to play, NSF is in an unusually strong position. Throughout the scientific community NSF is viewed as an agency dedicated to excellence, one that will support high quality activities to address the problems of undergraduate education. Other agencies are seen as having narrow missions that do not include sensitive support for undergraduate education, or there is doubt in the community about their ability to concentrate resources to advance its quality.

Many of the more serious and longer-range problems of undergraduate education require for their solution the cooperation and involvement of scientists and engineers who are experienced in both research and education. The Foundation has an enviable record of achievement in getting research scientists to work on educational development.

Continuity of Funding.

> *"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. . . . 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 the NSF's 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 which are set up only to be knocked down. Although NSF funding for teaching will probably never exceed twenty-five percent of the amount the Foundation invests in research, teaching must have the same long-term continuity of effort and support which is provided for research." John S. Toll, President, University of Maryland (W10).*

The federal response to most of the needs identified by institutional sectors should not be based on the assumption that after a few years the needs will disappear and programs again can be dismantled. Support must be steady; what is excellent now soon becomes outdated and renewal must be stimulated: curricula age, equipment becomes obsolete, and faculty must work continuously to maintain their disciplinary and pedagogical skills.

Certainly, the priorities for federal contributions to the health of undergraduate technical education will change over time, but neither the provider nor the beneficiaries of such support are well served if such change is catastrophic, wholly unpredictable, or unrelated to major national needs and priorities. The great need at the present time is for the United States Government to catalyze and stimulate desirable change in undergraduate technical education by establishing and stabilizing diverse programs targeted on excellence and renewal. The poor results of short-term, uncoordinated responses are all too apparent.

Teaching and Research - and the Long Term.

Finally, both testimony (W3,W4,W10,W15,W22) and written submissions (W30) pointed to the need to provide some long-term financing for the continuing evolution of undergraduate science and engineering education. In these domains, re-interpretation of fact does occur, but the pressure to accommodate *new* fact is much greater. The Federal Government and other supporters of research have caused university-based disciplinary research to acquire impressive momentum. Several of those who brought testimony to the Committee stated that such funding of basic research at substantial levels over the long period since World War II was responsible more than any other factor for the present tension in the academy between teaching and research (W1,W26).

It is important, therefore, that there be continuous funding of the efforts of college and university faculties to generate equally impressive momentum in efforts that would bring integration and transmission of new knowledge into balance with the creation of new knowledge. No national interest would be served by increasing the teaching loads of doctoral university faculty members. Many national interests would be served if they increased their leadership of efforts to improve instruction.

III. CONCLUSIONS AND RECOMMENDATIONS

A. The State of Undergraduate Science and Engineering Education in the U.S.

> *"If the 'research plant' of higher education has been deteriorating, the 'instruction plant' of undergraduate science and engineering has been collapsing." Jon C. Strauss, President, Worcester Polytechnic Institute (W6).*

Mention was made earlier of the many studies and surveys that have been published about various aspects of the condition of undergraduate science, mathematics, and engineering education in the United States. These reports and the observations of members of the National Science Board led to the formation of this Committee. (A number of these reports are referenced in the Bibliography.) Later in this section the conclusions of the Committee will be presented; but, we begin with a sharp and succinct expression by the Editors of NATURE (B44).

1. As Described by the Editors of NATURE

"There is mounting and disturbing evidence that the quality of teaching in both public and private universities is declining. Faculty are aging and are not being replaced at sufficient rate, especially in engineering. Laboratory instrumentation is, despite corporate munificence, seriously out of date, particularly in institutions not famed as research establishments. And increasing teaching loads all too often force universities and colleges to rely on the teaching of undergraduates on new graduates, for many of whom English is not a first language.

"Quantity is another and a daunting aspect of the problem. The proportion of young people in the United States going on to higher education in science and engineering is only a half of what it is in Japan, while there is mounting evidence that demand is being constrained both by the high cost of higher education and the continuing poverty of high-school education at all but the excellent institutions. Can the United States continue to be astonished at the imbalance of its trade with Japan?. . .

"The result of this neglect is that university teaching has come to seem a chore to faculty members at many institutions, not an activity vital to the function of an institution. (There are some honourable exceptions, chiefly among the private universities.) Research, by contrast, brings its own rewards, both intellectual and (mainly in the United States) financial. . .

"A credible programme for science and engineering education at the undergraduate level would provide what is at present lacking, a subset of university teachers whose primary commitment would be to excellence in education. . .

"By any analysis, the strength of the United States rests on its scientific and technical workforce, as do all of its hopes for the future. There is no known alternative to diligent study and excellent teachers. Americans should not need to be told that."

2. As Found by this Committee

Any complex undertaking is in trouble when the gap between actual and tolerable imperfection grows so large as to hazard its proper functioning. This Committee finds that the gap *is* that large today for undergraduate education in mathematics, the sciences, and engineering and technology. The principal deficiencies are in some areas of *effort* and some areas of *supply*.

Insufficient efforts are being made to:

- inform all students of the nature of science and of technological endeavor and of their relationships to the functioning of contemporary society;
- attract to professional careers interested and talented members of groups presently underrepresented among scientists and engineers;
- maintain overall academic quality in different kinds of educational institutions;
- involve industry, professional societies, and other parts of the private sector in sharing responsibility for the health and quality of the educational enterprise;
- provide education with the tools and develop the human resources it needs to do its job;
- explore the potential of advanced technologies to improve the effectiveness and efficiency of teaching and learning;
- maintain without tension a balance between undergraduate teaching and graduate research; and

- sustain steady interest in - and financing of - necessary educational improvements.

As a result of these and other factors, there are deficiencies in the supplies of:

- properly qualified faculty in some areas;
- instrumentation and other materials for instruction that reflect the states of current knowledge and practice;
- mechanisms for maintaining the acuity of faculty members in their disciplines; and
- information about undergraduate education and its changing aspects over time.

3. The Special Situation of Engineering

The reader will have noted that the highest priorities for action urged upon the Committee at this time are:

- strengthening the laboratory experience, in part through increased support for acquisition and maintenance of instructional instrumentation and equipment;
- changing courses and curricula better to reflect the state of knowledge and the needs of both pre-professional and non-professional students; and
- attraction, retention, and disciplinary resharpening of well-qualified faculty members.

The concerns that led to these priorities are similar in all the disciplines with which the Foundation is concerned and in all kinds of institutions that have direct roles in undergraduate education. But, there is little doubt that at this time *the problems of engineering are especially intense* because of both the intellectual character of engineering education and the national need for engineering graduates.

There are two main reasons for the present situation in engineering education, one permanent, the other changing slowly: First, progress in engineering is driven by *both* the results of scientific research *and* the continuing revolutions in professional practice - it is both knowledge-driven and technology-driven. Second, the principal level of entry into practice of engineering is at completion of the baccalaureate degree, in contrast to mathematics and the sciences, for which the usual preparation of professionals is the doctorate.

The sub-disciplines of engineering differ among themselves less than those of science. A revolution in one is transmitted more quickly to another in engineering than in science. When a period of rapid change begins (electrification, electronics, automation, microelectronics, computerization, etc.), the whole of engineering is caught by the wave; in contrast, progress in one field of science usually affects other fields much more slowly - in many areas of science there is time for accommodation.

The whole of engineering is now engulfed in yet another revolution resulting from the convergence of several technologies - microelectronics, computer and communications technology, and materials science. The demand for the very best engineers has expanded steadily for over twenty years, particularly in advanced technologies such as electrical and computer engineering. One of the dilemmas faced by engineering education today has been caused by the degree to which industry diverts the most talented baccalaureate engineers from further graduate education and preparation for teaching careers. This has been a key factor in causing the serious faculty shortages faced by engineering schools. A member of the Committee put the matter very bluntly during discussion at one of the public hearings - "Industry is eating the seed corn . . ." (B47:125).

4. Supply-Demand Cycles

Generally, the recommendations to be found later in this section do not focus on the *quantitative* aspects of professional manpower supply and demand, primarily because the time constants or "characteristic times" for the two are quite different. The rate of change in industrial employment needs is typically an order of magnitude faster than that of academic preparation of scientists or engineers. Further, economic driving of industrial demand causes fluctuation in both its scale *and* its composition; there are no quick-acting analogues for the latter in the educational stream. Students tend to "vote with their feet" in making career choices. The result is a cycle of shortage and glut whose dampening would seem to involve restrictions on individual choice that are foreign to American traditions.

5. Research and Teaching

> *"The language of the academy is revealing: professors speak of teaching* loads *and research* opportunities, *never the reverse. . .*
>
> *"The enemy of good teaching is not research, but rather the spirit that says that this is the only worthy or legitimate task for faculty members." Association of American Colleges,* Integrity in the College Curriculum *(B10).*

In several instances, the recommendations of the Committee will reflect an important *qualitative* aspect of the manpower situation - the very real tension in higher education between the research and teaching roles of the faculty. A number of those who testified before the Committee remarked on this tension, and a few identified a specific cause for this undesired effect - the steadily increasing and substantial support by federal agencies, the National Science Foundation included, of research in universities in the sciences and in technical fields over an extended period - now approaching forty years.

According to the generally accepted taxonomy of institutions of higher education, doctoral universities offer the highest academic degrees in a broad spectrum of professions and disciplines. The Ph.D. has always been a research degree - awarded to one who has made a contribution to the knowledge in his field (and who thereby has learned how to go about making such contributions). In support of such activities - the learning and pursuit of research - universities long ago accelerated their development of great libraries and museums, constructed fine laboratories, and found ways to send parties into the field.

As recently as fifty years ago, the continuity of academic research depended on financial support from a wide variety of sources: individual and corporate philanthropy, non-federal taxation, and gifts and grants from interested parties of many descriptions. The federal role was limited largely to the support of "agriculture and the mechanical arts", as it was in the post-Civil War l860s, when the Land Grant Colleges were established. At that time there was less difference between an "Oberlin" and a "Harvard" than there is today.

Between 1935 and 1945, the federal role in support of research in the natural sciences expanded greatly for reasons of national defense. The people who did that kind of fundamental research, found to be the wellspring from which flowed needed technological progress, were in universities. Many of them were supported there; many were gathered together in special project areas to pursue specifically oriented and directed ends - most of which were successful by very pragmatic standards. By 1950, a decision had been made - fundamental research was worth supporting for its own sake in the national interest, and the Federal Government continued the leadership role it had assumed out of wartime necessity.

The results could have been predicted easily. In universities, faculty members in those areas to which research money was easily available became, in time, less citizens of their academic campuses and more citizens of their disciplinary communities. Their *priorities* shifted from the task of imparting their knowledge to the young to the creation of new knowledge - not simply to maintain their skills as professionals by exercise of that important faculty, but as an end in itself. A revision of the professorial value system followed inevitably.

Since the prestigious have always been objects of emulation, it is not surprising that faculties in kinds of institutions different from what became the doctoral universities should adapt *their* value systems accordingly, first in the natural sciences, but increasingly in all areas. Today, "research" is expected for advancement even in the faculties of some two-year colleges.

If substantial improvements are to be made in undergraduate education in mathematics, the sciences, and engineering, *some* of the attention of the Nation's best research scientists will have to shift from the acquisition of new knowledge in the disciplines to the development of more effective ways of transmitting the knowledge of the disciplines.

B. Support for Needed Change

1. State and Local Governments

The responsibility for the financial health of public colleges and universities lies primarily with states and municipalities. Governments at all levels are among the supporters of private higher education through taxation and other policies that recognize the importance to the public welfare of all colleges, universities, and their graduates.

Insofar as public institutions are concerned, most of the direct effort to reverse the downtrends of quality in undergraduate education in engineering, mathematics, and the sciences must be made at the state and local levels of government. It is there that educational policy is made and the basic financial support for public colleges and universities is marshalled.

The 1983 report of the National Science Board Commission on Precollege Education in Mathematics, Science and Technology endorsed the establishment of Governor's councils in each state:

> *". . .with representation from key sectors with interests in elementary and secondary education (for example, government officials, educators, school board members, professional scientists and engineers, business, labor and industry leaders and parents). These Governor's Councils should develop educational goals for their States, monitor progress toward those goals, and make recommendations for the improvement of education - particularly in mathematics, science and technology. They should help generate public support for necessary improvements. They should encourage local boards of education to set higher standards and evaluate progress, and they should facilitate the exchange of information among school districts, ..., and with .... other States." (B3:10)*

Every State in the Union has a state-level board of education. Had they been able to carry out the functions just described, that recommendation would not have been necessary.

Nearly every State has a state-level body of some kind charged with a variety of responsibilities in relation to its public colleges and universities; in some cases (usually authority to approve new degree programs), they relate to private institutions also. Some of these bodies do continuously and effectively carry out planning, evaluation, and coordination of educational programs, in addition to their usual role in budget approval and recommendation. But very few of these bodies can assume the positions of advocacy and exhortation envisioned in the excerpt from the report of the Commission.

The Committee is persuaded that state councils or commissions *for higher education* - analogous to the Governor's councils proposed for elementary and secondary education - could be very effective in developing goals and winning support for improvements that must be made in higher education, particularly in undergraduate education in mathematics, engineering and the sciences.

Legislatures across the nation have already shown themselves willing to provide authority and funding for new research centers in their states to create a climate more attractive to high technology industrial enterprises. One hopes that legislatures would attend with similar enthusiasm to strengthening the undergraduate educational base for such research activities.

2. Academic Institutions

Clearly, the primary responsibility for assuring quality lies within academic institutions themselves. Colleges and universities, public and private, and their governing bodies must make the commitments necessary to:

- provide instructional offerings that are of high quality and appropriate to their missions;
- provide a support base adequate to assure a competent and vigorous faculty;
- plan for the renewal of facilities and other resources; and
- work to form lasting partnerships with industry in support of the broad educational mission, not just of focused research.

Public institutions, of necessity, must be responsive to the people who, through state and municipal governments, tax themselves in order to support higher education. It is difficult to hold the concerned attention of the public for extended periods, much less indefinitely. But an *informed* public can appreciate the long-term, continuous effort necessary to achieve and maintain excellence in undergraduate education, and can make the sophisticated judgment that it is not just the disciplinary research fast-track that is worthy of support in the interest of the future. Higher education must tell its story better than it has if the decimating swings of public funding during the last decade are not to recur.

The universities, public and private, have a special responsibility. They should be models for the behavior of the rest of higher education. If any sector of education can guide the substantial curricular reform necessary to bring undergraduate education closer to the mark, if any sector can provide leadership by reallocating internal resources to restore instructional research and good teaching to their proper and honored places in the professorial hierarchy of priorities, if any sector can do what must be done to bring its teaching laboratories as close to the state-of-the-art as its research laboratories, the sector comprising the universities can - and must. It is no mean task to change value systems; but the doctoral universities let happen the ascendancy of disciplinary research over teaching, and they should lead the move to redress the balance.

3. Professional Societies

The professional societies in mathematics, engineering, and the several sciences support many outstanding programs of continuing professional education, of accreditation or approval of professional education, and of educational activities directed toward the general public. Some of these organizations have spoken early, often, and eloquently as the downward drift of quality in undergraduate education became apparent. The Committee believes that the professional societies have much to offer as serious efforts are made to improve undergraduate education, including the education of the future citizenry-at-large - which citizenry will determine the conditions under which professionals are allowed to do their work (B37:7-10).

The professional societies are in a unique position to serve as brokers and bridges between the academic and industrial worlds, whose close partnership is an important key to the success of broadly-based efforts to improve undergraduate education. Part of that bridging is accomplished through the accreditation process. In view of widespread concern with the narrowness of professional education, it is important that the professional societies and other accrediting bodies assure breadth and avoid early over-specialization in the curricula they design and monitor (B37:44-45).

4. Industry and Other Private Sector Groups

A variety of interactions between industrial and educational institutions have contributed to the growth and eminence of the Nation in science and engineering - an eminence that now is threatened. Many of these interactions withered or disappeared altogether as federal funding of basic research and in certain areas of development put money into academic institutions on a grand scale.

Recently, it has become a national policy to urge and to facilitate the formation of industrial/academic partnerships to the mutual benefit of both parties. Private industry will never match, much less supplant, the scale or variety of federal involvement in academic research, but the growth of partnership and collaborative activities in pursuit of common interests cannot help but benefit industry, education, *and* government.

There is a long history of industrial provision of research support to academic laboratories. It is time for industry to consider similar programs to support the instructional activities of colleges and universities. Industry thrives on incentives and cost-cutting - to neither of which higher education paid much attention until recently. One of the serious consequences of academic cost-cutting is the ill-advised de-emphasis on laboratory instruction, particularly in large enrollment introductory courses. Industrial interest could be very effective in the development of lower-cost experiments and apparatus so that laboratory instruction would be available to more students rather than fewer.

The exchange of professionals between industrial and academic institutions is a practice of long standing. There has never been greater need for expansion of such partnership activities. Especially in engineering, opportunities for young faculty members to maintain real contact with the world of professional practice will be important as undergraduate engineering education is modified to meet the changing needs of industry and society.

Industry and business can participate usefully in many of the formal processes of science and engineering education. Professionals employed by industry can serve as adjunct faculty on a continuing basis as well as on exchanges. There is great need for industrial participation in efforts to improve the science literacy of the people, for industry is a direct victim of science illiteracy. As to the future, tomorrow's citizens are today's students, and industry should consider the benefits of diverting significant portions of its *present* resources to the education of future generations of both citizens and technical professionals. Undergraduate research and faculty research leaves or sabbatical year appointments are other areas in which the opening of industry's doors can assist education and improve its quality and relevance.

5. The Government of the United States

A role must be defined for the National Science Foundation in a national effort to improve undergraduate education in mathematics, science, and engineering. An important part in that effort should be played by other agencies and departments of the United States Government.

Information was sought (W42) and received (W43-W47) from the larger federal agencies and departments concerning their activities and programs that relate to undergraduate education in mathematics, engineering and the sciences. In the main, these activities involve the participation of faculty members in research related to the agency mission. The Committee urges the continuation and expansion of these programs, and notes that it would be especially helpful if some preference could be shown in the proposal evaluation process to projects that involve undergraduate students in the research to be performed.

The Department of Education administers a variety of programs that allocate funds on a national scale for the benefit of individuals and institutions. The major thrust of its programs is toward the schools. One of its most important activities is data collection. It would be very helpful if that activity were enlarged to include undergraduate as well as precollege education and expanded to provide special information about science and mathematics education to assist the improvement of school-college articulation in all its aspects.

A number of federal agencies (e.g., Defense, Energy, Aeronautics and Space, Health and Human Services) have missions that depend strongly on the scope, scale, and quality of undergraduate education in the disciplines of primary interest to the National Science Foundation. At any given time, at least one of them is affected by the cyclically recurring shortages of qualified professionals in various fields. As part of their efforts to improve the quality of education afforded the young scientists and engineers they must attract, these agencies should seek ways to assist undergraduate education. Direct fiscal grants to colleges and universities should be considered. They all operate extensive research or development laboratories; advanced students and faculty members on leave could be given appointments in them to pursue research projects in collaboration with government scientists and engineers.

Apart from direct participation by the Foundation and other agencies in programs to improve undergraduate education in technical fields, the Federal Government can assist such efforts in many indirect ways. For example, strong tax incentives could stimulate corporate support of science and engineering education; special funding could be provided to stimulate the renovation of instructional facilities and the replacement of out-dated apparatus and instrumentation; more realistic indirect cost rate regulations could be developed for depreciation and replacement of research facilities and equipment used by undergraduates; etc.

In many ways, federal programs and policies could be adjusted to initiate and catalyze a wide variety of improvements related to undergraduate technical education - for a modest cost in direct or tax expenditures, and with strong leverage.

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

"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... and, most of all, from the colleges and universities themselves." Robert R. Wilson, President, American Physical Society (W21).

The facts before it lead 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.

1. States

The Committee's primary recommendation to the States is that they reestablish undergraduate science, mathematics, and engineering education as a high priority of essential importance to the economic, social, and cultural well-being of their citizens.

It urges that legislatures give timely and responsive consideration to recommendations for improvement of such undergraduate education. For example, the National Society for Professional Engineers has recommended special legislation in each state that would aim at achieving national norms for a minimum level of support for laboratory instrumentation amounting to $2,000 per engineering (or science) graduate per year.

The Committee recommends that appropriate state-level bodies encourage, coordinate, and support institutional long-range planning for the renewal of facilities, equipment, and other physical resources that are necessary to improve and maintain the quality of undergraduate education in mathematics, engineering, and the sciences.

The Committee also recommends that each state that has not done so create a special education commission or review body to determine conditions and needs in undergraduate education in science, mathematics and engineering in their state; to help set educational goals and objectives for their state; monitor progress; and to make recommendations for improvement. Such a body should also recommend ways and means to help generate public support for needed change.

2. Academic Institutions

Faculties and governing bodies have the primary responsibility for the academic health of colleges and universities, whatever the resource picture. There is little doubt that the laboratory-centered character of good instruction in engineering and the sciences ties their quality with unusual firmness to the provision of adequate funding for capital expenditures on facilities, instrumentation and equipment. But course and curriculum improvement are vital activities that are less dependent on massive funding than they are on the initiative, creativity, and expertise of faculty members and the good sense of academic administrations to provide the necessary time.

To Academic Institutions, the Committee recommends:

- 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;
- careful long-range planning for the renewal of facilities, equipment, and faculties;
- development of both short-range and long-range plans for modernization of undergraduate instructional and research equipment;
- strong faculty efforts (and strong administrative support of them) to update and upgrade courses and curricula designed to meet the needs of both majors and non-majors;
- increased participation by *all* faculty members in the instruction of undergraduates and in other efforts to raise the quality of their educational experience;
- joint efforts with other institutions to improve the school-to-college, two-year to four-year college, and undergraduate-to-graduate transitions; and
- expansion of partnerships in education with industries and other organizations in the private sector.

3. The Private Sector

Private support of higher education has decreased in constant dollars during the past fifteen years. A few private colleges and universities have disappeared in the maelstrom of rising costs powered by double-digit inflation. Fortunately, state scholarship programs, federal and state student loan programs, and other forms of public support of students attending private institutions have kept public and private expenditures on student support and institutional operations approximately in balance.

Witnesses from several private colleges and universities informed the Committee that the problem of facilities obsolescence in private institutions was especially severe because of the termination of earlier programs of federal support, most of which were leveraged through substantial requirements of matching. The Committee decided to make no recommendation to the Foundation about capital facilities.

Industrial and other corporate support of higher education has kept pace with inflation, but, in spite of the recent upturn of industrial funding of graduate research activities, is still less than 1% of pretax net income (B7). A doubling of this level of giving to education would be sound business policy, and trebling of the amounts earmarked for undergraduate mathematics, engineering, and science would represent enlightened self-interest, especially on the part of technology-oriented industries.

To the Private Sector, the Committee recommends:

- greater and more stable support for education at all levels;
- within higher education, more generous gifts for undergraduate education in mathematics, engineering, and the sciences;
- within those fields, special emphasis on the funding of construction and renovation of laboratories and other special instructional facilities;

- expanded partnerships with colleges and universities in efforts to improve pre-professional education; and
- increased corporate efforts to improve the public understanding of science and technology.

4. Mission-Oriented Federal Agencies

To Mission-Oriented Federal Agencies, the Committee recommends that:

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

D. Recommendations Concerning the Role of the National Science Foundation in Undergraduate Science, Mathematics, and Engineering Education

> *"Our recommendation is simply that the 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 come from products which didn't 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." Terry L. Gildea (Hewlett-Packard Co.) for Technology Education Consortium (16 major high technology corporations) (W22).*

1. Role

The Chairman of the National Science Board remarked in his charge to this Committee that "currently no systematic federal leadership or support exists for science, engineering, and mathematics education at the undergraduate level." The Committee has confirmed this observation.

Many institutions and organizations are concerned with undergraduate education. These include the colleges and universities themselves, learned and professional societies, education associations, private philanthropic foundations, industrial firms and their associations, and various state and federal agencies. However, none of these has *comprehensive and national responsibility* for the undergradute science, mathematics, and engineering educational enterprise in the United States.

It is the determination of this Committee that the National Science Foundation is the body that can take such responsibility and that it is the proper leader of efforts to advance and maintain the quality of undergraduate instruction in mathematics, engineering, and the sciences in the United States. The enabling legislation for the National Science Foundation obligates it to assume such a leadership role.

The Foundation must serve not only as a point of leadership for educational excellence across the Nation, but should actively draw together and coordinate the efforts toward that goal of educational institutions and the other interested parties.

The declining state of undergraduate science and engineering instruction is one of the most serious problems facing higher education. Because of the massive resources required for full remediation (currently estimated at several billion dollars), recommendations for Foundation efforts in this area must focus on catalytic, highly leveraged programs that provide leadership, models, and incentives, in contrast to those that require a major expansion in the support base.

2. Leadership

> *". . .when it comes to (a research-oriented issue) there are one or two people that just care desperately about this as their number one priority. . . . Nobody else much cares . . . it's number one on somebody's, two people's, priority list and maybe nine or ten on everybody else's.*
>
> *"Education may be third on everybody's priority list. It's not that it's not there. It's not that it's not important. It's just not the number one; it may be number two or three.*
>
> *"Under those circumstances . . . you tend to get an oversupply of the things that are number one on a few people's priority list and an undersupply of things that everybody thinks are important, but not quite too important.*
>
> *"And, traditionally, the way those number three items on everybody's list get solved is a crisis gets created."*

John P. Crecine, Senior Vice President, Academic Affairs, Carnegie-Mellon University (B46:124-125).

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:

- 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;
- implement new programs and expand existing ones for the ultimate benefit of students in two-year and four-year colleges and in universities;
- actuate cooperative projects among two-year and four-year colleges and universities to improve their educational efficiency and effectiveness;
- stimulate and support a variety of efforts to improve public understanding of science and technology;
- 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;
- bring its programming in the undergraduate education area into balance with its activities in the pre-college and graduate areas as quickly as possible;
- expand its efforts to increase the participation of women, minorities, and the physically handicapped in professional science, mathematics, and engineering;
- design and implement an appropriate data base 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;
- develop quickly within the Directorate for Science and Engineering Education an appropriate administrative structure and mechanisms for the implementation of these recommendations and others that follow; and
- the Directorate for Science and Engineering Education should foster collaboration among all parts of the Foundation to achieve excellence in science, mathematics, and engineering education.

3. General Recommendations

In developing and exercising its leadership of national efforts to revitalize and improve undergraduate education in science, mathematics, and engineering, the National Science Foundation should:

- concentrate on key programs that emphasize motivation and initiative for needed change, and leverage its resources;
- make use of its historic relationships with the science and engineering research communities;
- build upon its present activities to improve pre-college science and mathematics education;
- move flexibly between full funding and catalytic funding in specific program areas as changing conditions warrant, arranging program and project support in ways that leverage or magnify its financial allocations; and
- support continuing review, study, and analysis of "undergraduate education indicators" to guide, through related research, its decisions concerning major shifts in programmatic emphasis and direction, and to provide to colleges, universities, and other constituencies of undergraduate education, the information they need to plan for change in their continuing pursuit of excellence.

4. Identification of Areas of Current Highest Priority

The deliberations of this Committee and the hearings before it during 1985 constitute a timely review, study, and analysis of many different "undergraduate education indicators" - for mathematics, engineering, and the sciences - in the spirit of the last General Recommendation above. On this basis, the Committee recommends that the Foundation give highest priority attention *at this time* to:

- Laboratory Development and Instrumentation (supporting development projects and efforts to remedy deficiencies in instrumentation, so as to improve laboratory instruction);
- Faculty Professional Development (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);
- Course and Curriculum Improvement (encouraging and supporting efforts to improve the ways in which knowledge is selected, organized, and presented);
- Comprehensive Improvement Projects (which might address several of the above priorities simultaneously in a given institution, or one across a given discipline, or a combination of these through consortial efforts, etc.); and

- Undergraduate Research Participation (stimulating and supporting the involvement of advanced undergraduate students in research in their colleges and in other places with programs of technical investigation).

In addressing these priorities, special attention should be given to:

- increasing the participation of underrepresented groups; and
- the collection, study, and analysis of information and data on undergraduate education in science, engineering, and mathematics.

E. Programs and Projects

Every person who made a statement to the Committee or participated in the general discussion which followed each presentation had ideas for programmatic emphases, specific programs, and individual projects that the Foundation might sponsor and/or support. Often these ideas were the subjects of specific and direct recommendations.

The development of a mix of programs and projects that is responsive to the single prioritizing recommendation above and to the goals statements and general recommendations that preceded it must involve substantial efforts over time by the professional staff and advisory bodies of the Foundation, officers of the Congress and other Government agencies, and peer reviewers from the several disciplinary communities. Further, that mix will change as conditions change.

The following section describes the program elements which, in the judgment of the Committee, represent balanced responses to the deficiencies it has identified. (Appendix A contains a more detailed description of these and other selected Programs and Projects.)

F. A Balanced Undergraduate Program for the National Science Foundation

1. Program Perspective

> *"I would encourage the National Science Foundation to get involved specifically in support of undergraduate science and engineering education. . . . 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." David P. Sheetz, Vice President, Director of Research and Development, The Dow Chemical Company (W9).*

The National Science Foundation can establish and maintain a strong position of leadership in efforts to improve undergraduate education in mathematics, engineering, and the sciences at a relatively modest cost. The National Science Board Commission on Precollege Education in Mathematics, Science and Technology, in its report, *Educating Americans for the 21st Century*, defined a role for the Foundation in precollege education that entailed an annual expenditure of approximately $175 million.

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 by the NSB Commission, and with the level of present Foundation support of research ($1,300 million).

At this time, the recommended distribution of this increased annual expenditure is:

• Laboratory Development	$20 million
• Instructional Instrumentation & Equipment	30 million
• Faculty Professional Enhancement	13 million
• Course and Curriculum Development	13 million
• Comprehensive Improvement Projects	10 million
• Undergraduate Research Participation	8 million
• Minority Institutions Program	5 million
• Information for Long-Range Planning	1 million

It is anticipated that adjustments will be made from time to time in the distribution of available funding over these areas of high priority. These major program elements are described individually in the remainder of this section.

2. Major Program Elements

- Laboratory Development .... $20 million
  (supporting development projects to
  improve the laboratory component of
  science and engineering instruction)

The goal of this program is to modernize the character and improve the effectiveness of laboratory instruction in science and engineering in undergraduate institutions. The program should be made attractive to the best and most creative faculty at the host universities and colleges. The scope of individual projects might range from development of a small number of new experiments for a single kind of course to an effort to re-think and then fully detail the laboratory component of an entire undergraduate curriculum.

Among the kinds of proposals that might be invited under this merit-based program are those for projects that would:

- create more open-ended laboratory exercises;
- integrate the laboratory and expository elements of the curriculum in more effective ways;
- develop more effective and efficient ways of teaching or structuring the laboratory experience; and
- re-think the laboratory component of mass-enrollment introductory courses and design and develop experiments that would require simple, inexpensive apparatus and instrumentation - and design, pilot-produce and test such apparatus and instrumentation.

Where practicable, collaboration with the instrument manufacturing industry should be encouraged.

- Instructional Instrumentation and Equipment .... $30 million
  (encouraging and supporting joint efforts to remedy the serious deficiencies of instructional instrumentation and equipment)

The goal of this program is to strengthen and support models of excellence in undergraduate science and engineering laboratory instruction at the nation's colleges and universities. At this time, the competition for merit-based support under this program should emphasize improvement of instruction through the utilization of modern instrumentation.

Among the kinds of proposals that might be invited under this program are those for projects that would:

- introduce modern instrumentation to improve the experiences of undergraduate students;
- interface computers with laboratory instruments, or make other instructional applications of current technologies; and
- establish partnership or consortial arrangements for sharing costly instructional apparatus and instrumentation.

The instrument purchase aspects of the program should require (as does the present College Science Instrumentation Program) the one-for-one matching of Foundation allocations with contributions from local resources, including donations by industries.

- 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)

The goals of this program are to raise the status and improve the quality of teaching at the undergraduate level, to induce scientists and engineers to use some of their creative energies in such efforts, and to encourage colleges and universities to take a more systematic interest in keeping their teaching corps abreast of their disciplines and current in the best education arts. The Committee recommends two different broad types of activities, here termed *Cooperative Development Projects* and *Faculty Development Networks*.

Among the kinds of proposals that might be invited to the competition for merit-based Cooperative Development Projects are those that would support:

- sabbatical leaves (supplementing a home institution contribution) to engage in curriculum design;
- research-oriented appointments at a different academic institution or in a national or industrial laboratory; and
- teaching-related appointments in another institution providing an opportunity for course or curriculum development work.

Projects could be located at colleges, universities, national laboratories, industrial research centers, science museums, and other sites or combinations of them. Co-sponsorship by both home and host institutions would be expected, and continuing collaborations encouraged. Projects should be designed to improve the disciplinary and teaching skills of the individual faculty member while resulting in the preparation of an evaluative "product" - which might be a new course, a revised curriculum, a set of ingenious laboratory experiments, etc. These activities should be substantially cost-shared with the participating institutions.

Faculty Development Networks, organized on a regional basis, would utilize the best traditional techniques and test and evaluate new low-cost methods for keeping large numbers of faculty members abreast of recent advances in their fields. Lecture series at a single site and electronic teleconferencing of topical seminars represent the ends of the spectrum of approaches that might be tried. The subject matter might be community-identified or Foundation-determined. In all cases, top mathematicians, engineers and scientists would be engaged to present the material.

Participant costs in these network programs should be the responsibility of the home institution. Initially, the Foundation might supply part or all of the organizational and instructional costs; but, in time, those should be borne by the home institutions through modest fees remitted to the hub university and/or through other local co-sponsorship.

- Course and Curriculum Development . $13 million
  (encouraging and supporting efforts to improve the ways in which technical

knowledge is selected, organized, and presented)

The goals of this program are to assure a continuing flow of new knowledge into undergraduate courses and curricula, to stimulate design of more efficient and more effective ways of presenting knowledge to students, and to encourage experimentation and innovation in the organization of information for teaching and learning.

Among the kinds of proposals that might be invited to the merit-based competition for awards under this program are those that seek support for:

- design of a new curriculum in a science or engineering field or in mathematics that would result in more effective preparation of baccalaureate level professionals;
- development of new courses in major, minor, and general student curricula;
- application of new technologies to instruction, including, for example, development of new software and other teaching/learning aids;
- preparation of new instructional materials; and
- research on improved methods of college-level teaching and learning.

Proposals should be invited from the Nation's best talent in all kinds of institutions. Where whole professional curricula are involved, several universities might collaborate, possibly under the sponsorship of the professional society of the discipline. Activities proposed under this program might be carried out by individuals, by small or large groups, at single or several educational institutions, or by consortia among educational and industrial collaborators.

Projects meeting high standards of technical content should be judged on the degree of their creative content or originality and on the likelihood that they will yield results or products capable of widespread adoption, adaptation, and use.

• Comprehensive Improvement Projects (addressing several of the above priorities simultaneously in a single institution, or across a given discipline, or in a combination of these through consortial effort)	$10 million

The goal of this program is to provide a flexible mechanism for the support of large and/or complex projects designed to improve undergraduate instruction across a whole discipline, in several areas within an institution simultaneously, or in a cluster of institutions - projects that are characterized by breadth, large scale, or multiple foci.

Among the kinds of projects that might be invited to the merit-based competition for awards under this program are those that would:

- engage a scientific society and representatives of many kinds of institutions in the development of a new professional curriculum in a particular discipline;
- permit a single institution to design and partially to implement a thorough restructuring of its curricula in all areas of, say, physical and biological science;
- bring together faculty members of several doctoral universities to create an up-to-date curriculum in a discipline in which there has been a recent explosion of knowledge or revolution in understanding; and
- support the efforts of several engineering colleges and a number of industrial research centers in a compact geographical region to design and implement an effective "teaching hospital" experience for advanced engineering undergraduates.

Selection of projects for support should be based on the quality and soundness of the planning done, the potential for exportation and adoption of the outcomes (where this is possible), and the excellence of the results likely to be achieved. There should be substantial cost-sharing in these projects, most of which would lend themselves to the "challenge grant" approach, which would result in high leverage of Foundation funding.

• Undergraduate Research Participation . (stimulating and supporting the involvement of advanced undergraduate students in research in their colleges and in other places with programs of technical investigation; projects based on this funding could involve 2500 students)	$8 million

The goal of this program is to support a variety of efforts that will increase the fraction of advanced students in engineering and the sciences who top off their undergraduate careers with significant participation in an active research program. This program will complement the support now available through the Research in Undergraduate Institutions program, Engineering Research Centers, etc.

Among the kinds of proposals that might be invited under this program are those for projects that would:

- encourage and support participation of undergraduates in research activities of science and engineering faculty members; and
- encourage and support the provision of research opportunities to undergraduate students by national laboratories, industrial research centers, and other kinds of institutions that have ongoing programs of technical investigation.

Evaluation of proposals submitted to the program should place comparable weights on the appropriateness and value of the educational experience and on the quality of the research to be undertaken.

- Minority Institutions Program .... $5 million (strengthening the capability of minority institutions to increase the participation of minorities in professional science, mathematics, and engineering)

The goals of this program are to increase the number of minorities entering professional careers in engineering, mathematics, and the sciences, and to strengthen the capability of minority institutions to recruit and prepare individuals for such careers.

Among the kinds of projects that might be invited to the competition for awards under this merit-based and highly flexible program are those that seek support for:

- the kinds of endeavors described under other subsections of these programmatic recommendations;
- outreach activities in the precollege community designed to acquaint young minority students with opportunities that merit continuing their education through college, and to attract them to careers in mathematics, engineering, and the sciences;
- teacher-training and enrichment projects to strengthen the precollege education of minorities; and
- educational partnerships between and among minority and majority institutions that would increase the availability of high-quality educational resources to minority students in all parts of the country and in all types of institutions.

As with other kinds of host institutions, cost-sharing would be expected for many kinds of projects hosted by minority institutions. In arranging the phasing or matching of Foundation support, careful attention should be paid to the maturity and strength of the institution's ties to its local and constituent communities and their record of contributions.

- Information for Long-Range Planning . $1 million (collecting, studying, and analyzing information and data on undergraduate education in science, engineering, and mathematics, in support of long-range Foundation planning; this funding would support an appropriate level of collaborative work with the U.S. Department of Education and other major data sources)

The goals of this program are the acquisition and maintenance of a database on the qualitative and quantitative aspects of undergraduate education in mathematics, engineering, and the sciences, and the support of review, analysis, and research of such information to facilitate and improve the Foundation's long-range planning in these areas of education.

Proposals should be invited from the most highly qualified individuals and institutions for merit-based, competitive awards for specific projects. Much of the data collection activity is likely to involve collaboration with other Government agencies, particularly the U.S. Department of Education. Further, the program should be coordinated with parallel efforts underway in other Directorates of the Foundation. The research and analysis activities may be done partly within the Foundation, partly through awards to individuals and institutions outside it.

The kind of database envisioned by the Committee would be a valuable resource for entities other than the Foundation, so care should be taken in its design to assure flexibility as well as an agreed level of comprehensiveness. Information should be collected on students, faculty, and facilities; on inputs and outputs as well as contents; and on qualities as well as quantities.

This increase of $100 million, although by itself 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 those 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, and other agencies of the United States 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 FY 1988;* attainment of *a total of $100 million in new funds by FY 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.

NSF Budget Estimate		*Recommended Funding Above FY 1987 Budget Estimate*	
FY 1987 $13	Program (short title)	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

Examination of this table in the light of the Findings and Conclusions detailed in earlier sections 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.

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 education goals must be made by state and local governments and by the components of the private sector.

3. Procedural Recommendations

In arriving at these program and funding recommendations, the Committee considered carefully groups and institutions with special needs. 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 (B50). With these considerations in view, we add the following three recommendations that cut across the areas just described:

a. *Increased Participation of Women, Minorities, and Physically Handicapped*. The NSF should actively seek this goal in implementing the above recommendations, including program management and proposal review, and the projects that are supported.

b. *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.

c. *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 primary continuing concerns of the National Science Foundation and 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 act to implement the program and action recommendations contained herein. A detailed plan for both the leadership and 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.

4. 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.

Although the individual Committee recommendations have different specific objectives, taken together they constitute a strategy to:

- exert high leverage to improve undergraduate instruction, serving national as well as local interests;
- stimulate and invigorate faculty with creative potential at all types of institutions, thus raising the overall quality of teaching;
- yield products such as teaching aids, laboratory manuals, scholarly publications with extensive impact; and
- assure that the nation's brightest young people are given high quality, rewarding experiences in science in time to affect their career choices.

In addition to the strengthening and development of regular science, engineering, and mathematics courses and laboratories, the recommendations speak to the need for greater science literacy on the part of the general student, the education of future teachers of precollege science and mathematics, and efforts to reduce the barriers to careers in science and engineering for women, minorities, and the handicapped.

The Committee anticipates that by no later than 1990 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.

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 well-being of all U.S. citizens.

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IV. APPENDICES

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A. Programs and Projects

Every person who made a statement to the Committee or participated in the general discussions which followed each presentation had ideas for programmatic emphases, specific programs, and individual projects that the Foundation might sponsor and/or support. Often these ideas were the subjects of specific and direct recommendations.

The development of a mix of programs and projects that is responsive to the single prioritizing recommendation above and to the goals statements and general recommendations that preceded it must involve substantial efforts over time by the professional staff and advisory bodies of the Foundation, officers of the Congress and other government agencies, and peer reviewers from the several disciplinary communities. Accordingly, this Appendix to the report presents a selection of the ideas presented in testimony and submissions to the Committee as *examples* of general elements of future Foundation programming in the undergraduate area.

1. Faculty Professional Development

Some New Modes

The Committee believes that the intellectual health and vitality of the faculty is the most important consideration at the undergraduate level, as it is at the precollege and graduate levels of education. All of the broad recommendations and suggested programs presented in this report have as ancillary direct objectives and desired benefits the stimulation and motivation of the best faculty for excellence in teaching.

There is a great need to raise the status of teaching at the college level, to induce scientists and engineers to use some of their creative energies to improve teaching, and to encourage colleges and universities to take a more systematic interest in keeping their teaching corps abreast of their disciplines and current in the best education arts. Several submissions to the Committee and a number of persons who testified before it described new and interesting ways the Foundation might assist continuing attention to these objectives.

Cooperative Development Projects could advance the art and cause of teaching in the same way that research-oriented leaves contribute the energies of faculty members to advancement of their disciplines and themselves. Most colleges and universities give at least partial salary support to sabbatical or other kinds of faculty leaves, in the realization that continuous renewal of one's disciplinary knowledge and professional skills and enthusiasm is necessary for vital, effective teaching. There is a lot of supplementary support available to make possible research-oriented leaves of reasonable length (NSF's earlier Senior Postdoctoral Program had that purpose), but very little where the meat or matter of the leave activity relates directly to the teaching process.

Cooperative faculty development projects are envisioned as taking a variety of forms: supplemental sabbatical leave support; research-oriented appointments at a different academic institution or in a national or industrial laboratory; or teaching-related appointments in other institutions that afford opportunities for course or curriculum development activities that would improve the teaching skills of the appointees while transportable or disseminable products were created.

Such a program would be structured very flexibly to encourage a wide variety of activities that *simultaneously* honed the skills of the faculty member while yielding an improvement useful to other institutions.

The *cooperative* nature of a project, involving cosponsorship by the home and host institutions, would seem to assure address of such multiple objectives. The success of the appointees might lead to longer-term mutually beneficial interactions between the two organizations. (For example, such pairs might involve a two-year college and a major university, a four-year college and an industrial research institution, etc.)

Faculty Development Networks were proposed to the Committee as a mechanism for involving large numbers of faculty members for short terms. The networks would be planned on a regional basis and experimentation with advanced communications techniques (electronic mail, electronic blackboard, teleconferencing, etc.) would be encouraged to keep costs low.

Perhaps as many as fifteen regional hubs, probably universities, would contract to hold short course or workshop sessions of two-to-four days length, periodically. The centers would be sited so that almost all faculty in all types of institutions offering instruction to undergraduates would be less than a day's drive from one of them. The country's top mathematicians, engineers and scientists would be engaged to present the material.

Some disciplinary organizations already have substantial programs of this type devoted to continuing professional education, and each of them has discovered the mix of topics that permits all costs to be covered by "student" fees. The proposed networks program should be expected to do the same, in due course.

Other Modes

Many other ways of assisting faculty development were presented or described to the Committee, including:

- exchanges of faculty between educational institutions,
- participation in professional meetings,
- leaves to work in industry or government,
- workshops of extended length,
- visiting professorships of various durations,
- academic-industrial exchanges,
- summer seminars, and
- participation in research projects on teaching and learning.

2. Course and Curriculum Improvement

Fortunately, college-level instruction in science and engineering are discovery-driven to a substantial degree. Continuous evolution of content is inherent to instruction in the technical disciplines. Even freshman courses can, in principle, reflect quickly the results of significant research. (One of the most interesting topics under discussion by teachers of mathematics is the possibility of building this kind of flexibility into the mathematics courses taught to large numbers of undergraduates, so that such courses will have a similar timeliness and freshness about them.)

The pace of such course development through substitution of new knowledge for old depends in large part on the time and incentives faculty members have for the task. In smaller institutions, the pace is slowed because of the diversity and weight of the instructional burdens borne by the faculty. In major universities the pace is slowed (and natural leadership sidestepped) because of emphasis on disciplinary research.

Earlier in this report there was mention of the responsibility of the National Science Foundation and other supporters of academic research for the present primacy of disciplinary research in the professorial value system. There was also mention of their responsibility to assist the correction of that situation by provision of similar incentives to bring the very best scientists and engineers back into active work on the improvement of undergraduate education. That work could be: research on teaching and learning, preparation of new instructional materials, development of new curricular approaches (especially for non-scientist students), writing up-to-date texts and monographs that embody not just recent science but the best educational practices and the results of research in the cognitive sciences, the introduction of new technologies into the classroom and laboratory, etc.

NSF's Engineering Directorate is currently planning an activity that constitutes a limited implementation of this approach. It expects to support a small number of experimental projects in undergraduate engineering that will focus on team teaching via telecommunications by university and industry scientists.

Most of the programming of the National Science Foundation is organized to utilize the independent project mode. But it was proposed to the Committee that the Foundation should expand this traditional approach to permit more complex project management strategies: networking among the faculties of several institutions, involvement of persons who teach at different levels in the system, and other kinds of people and institutional clustering. The goal of these strategies is that projects supported by the Foundation should both impact students *and* involve faculty members from all types of institutions having undergraduate enrollment.

3. Laboratory Development and Instrumentation

The financial pressures of recent years have caused institutions to defer maintenance and replacement of much of the equipment that is used for the laboratory instruction of undergraduate students and for the joint faculty-student research activities that are such important elements in the preparation of future science and engineering professionals. A related and especially pernicious consequence of the same pressures has been the reduction - in some cases the elimination - of the laboratory component in large-enrollment introductory courses, courses that serve to introduce non-science students to the world of scientific observation and experiment.

The problem of obsolete undergraduate instructional equipment and laboratories extends across all disciplines, but seems especially severe in engineering and biotechnology programs. The introduction of radically new technology is changing the way engineers and biologists work as well as some of the traditional areas in which they have worked.

The professors and academic administrators who addressed this problem were unanimous in their support of one part of its solution - expansion of the Foundation's present College Science Instrumentation Program. They recommended strongly that the program not only be enlarged in terms of dollars allocated to it (a factor of ten was mentioned often), but be expanded at the same time to include all types of institutions with undergraduate programs - two-year colleges and doctoral universities as well as predominantly undergraduate four-year institutions. The students, after all, move in large numbers between institutions of different types as their education advances.

In addition, witnesses before the Committee presented strong arguments for an initial heavier-than-average-share dedication of the expansion part of the Program to schools of engineering and technology, in recognition of the intensity of their equipment problem at this time. Some witnesses argued that such a concentration of new resources for a few years would serve to accelerate the equipment donation activities through which industries have long lent their support to undergraduate engineering education.

Several persons who appeared before the Committee remarked on the desirability of expanding the mission of the present Instrumentation Program to include laboratory development activities. New emphasis might be placed on: improvement of laboratory instruction through utilization of new kinds of instrumentation, design of more effective and efficient modes of teaching or structuring the laboratory experience, creation of more open-ended laboratory exercises, or studies of new ways of integrating laboratory and expository elements in the curriculum. The hope was expressed that faculty members in doctoral universities would take special interest in such programs.

A strong laboratory development component in the College Science Instrumentation Program would go beyond the present commendable goal of assisting colleges and universities to use instrumentation to improve the educational experiences of students in science and engineering courses - majors, non-majors, and non-scientists alike. It would accelerate the application to laboratory instruction of computerization and other advanced technologies and could provide alternatives to the present cost squeeze on the introductory laboratory course.

An idea worth considering with respect to the mass-enrollment introductory laboratory courses is a program in support of academic and industrial team activity to devise experiments suitable for these courses but which require only simple, inexpensive apparatus and instrumentation. The strong arguments for the introduction of students to research quality instrumentation in advanced courses are simply beside the point when applied to introductory laboratories. These same study teams should be expected to design and at least pilot-produce and test the items of new apparatus and instrumentation that may be required for the experiments they devise, possibly in collaboration with manufacturers of instructional laboratory equipment.

4. Undergraduate Research Participation

The Committee was informed from many quarters that one of the most significant ways to enrich undergraduate education is to involve students directly in the research programs of faculty members. Participation in research as undergraduates provides students with good basic skills opportunities to apply these skills to investigation and experimentation at the frontiers of knowledge, to improve those skills and acquire others, to see how questions about nature are formulated and investigated, and, one hopes, to participate in the discovery of new knowledge.

Undergraduate research is unlikely to be elected by a science student unless his career planning includes at least the possibility of graduate work. Since the actual entry level for professional careers in the sciences is increasingly at that of the doctorate, the most able students should be encouraged to undertake graduate study. It is now well known that the undergraduate educational experience most effective in stimulating able students to pursue graduate study is participation in faculty research. In engineering, an undergraduate research experience is often the closest a student can have to the kind he will find upon entering industry.

Expansion of Foundation support of joint faculty-student research, especially in non-doctoral institutions, would be a triply-effective investment in the future. It would increase faculty activities at the most advanced levels of their disciplinary skills. It would provide simultaneously to the participating undergraduate scientists and engineers an experience highly beneficial to them in the long term. *And*, it would be powerfully and appropriately engaging to those students most diffident about technical careers - women, minorities, and the handicapped.

Faculty research is totally absent from some colleges. Their faculties must utilize external opportunities if conduct of research is an important mode for them to maintain and advance their professional knowledge. A variety of such opportunities has been described above. Similar external programming should be made available to provide a research experience to qualified students in engineering and the sciences.

5. Comprehensive Improvement Projects

The various programs and projects described above are characterized by relatively concentrated focus. In some cases, however, a multiple focus approach could have different but equally significant and desirable results for undergraduate education. Projects of this type could involve a single institution (the multiplicity arising from the collaboration of a number of different departments), a group or consortium of institutions, or a discipline-oriented society (bringing together representatives of many institutions to address a common problem).

An example of a multiple focus or "comprehensive" project is one comprising activities designed to improve undergraduate instruction in *all* areas of science, mathematics, and engineering offered by a single institution. Such projects would have to begin with or build upon careful long-range planning by an institution to strengthen its capability to offer high quality programs in technical areas. The execution phase might involve simultaneously a number of different activities of the types described earlier in this section. Foundation support, which might be substantial at the start, would have to be augmented and then replaced in accordance with a well-designed, realistic schedule; or, substantial and phased matching of Foundation support might be required from the beginning.

Another kind of comprehensive project was proposed in one of the position papers submitted to the Committee:

Advanced laboratory instruction ought to relate closely to actual engineering practice in the most favorable kinds of professional environments. No small school and only a few of the engineering colleges in research universities can afford to mount such programs.

The NSF-supported Engineering Research Centers initiated recently (and other research organizations such as national laboratories, major corporate research stations, etc.) could offer to advanced undergraduate students in engineering the kind of experience in relation to professional practice that medical students on rotating clerkships and internships receive in teaching hospitals.

At such an installation, advanced engineering students would receive hands-on experience with the latest research equipment; develop an appreciation for professional ethics and the concerns of the lay society that is the consumer of the products of engineering practice; learn at first hand the importance of economics in design, communications skills, good working relationships with associates and with management; and be introduced to the cross-disciplinary and multi-disciplinary aspects of contemporary engineering practice.

The application of this idea to science students in small colleges is equally attractive and apt. In such a project, the support of the Foundation would be more for the administrative structure to develop and sustain the necessary cooperation than for the conduct of the manifold elements of the project; the latter should draw their major support from the sponsoring and host institutions.

It was pointed out to the Committee that one Foundation program now ended had many of the hallmarks of the Comprehensive Improvement activity just described; that program supported the Resource Centers for Minority Education. These Centers did not operate at just the undergraduate level, but had elements ranging from middle school through graduate school. The Committee believes that those aspects of the Minority Centers that are found to be successful and transferrable ought to be combined in a new support program of the same kind, and that those successes can be exemplary to the planning by other kinds of institutions of their participation in the several thrusts identified in this report.

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W2. Cole, Thomas W., Jr., President, West Virginia State University

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W4. Luskin, Bernard J., Executive Vice President, American Association of Community and Junior Colleges

W5. Starr, S. Frederick, President, Oberlin College

W6. Strauss, Jon C., President, Worcester Polytechnic Institute

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W30. Council of Scientific Society Presidents (CSSP); Eric Leber, Administrative Officer

W31. Council on Undergraduate Research (CUR); Jerry R. Mohrig, (Carleton College) Chairman

W32. East Central College Consortium (Bethany College, WV; Heidelberg College, Hiram College, Marietta College, Mt. Union College, Muskingum College, and Otterbein College, OH; and Westminster College, PA; Sherrill Cleland, President, Marietta College

W33. John G. Kemeny, Professor of Mathematics and Computer Science and President Emeritus, Dartmouth College

W34. Student Pugwash; David Hart, Conference Director

W35. Task Force on the American Chemical Society's Involvement in the Two-Year Colleges; William T. Mooney (El Camino College), Chairman

W36. Texas Woman's University; Carolyn K. Rozier, Acting Vice President for Academic Affairs

W37. Union College, Schenectady, New York; John S. Morris, President

W38. Chancellors of University of Wisconsin Campuses (River Falls, Eau Claire, Green Bay, La Crosse, Oshkosh, Parkside, Platteville, Stevens Point, Stout, Superior and Whitewater); Gary A. Thibodeau, Chancellor, University of Wisconsin - River Falls

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W40. American Society for Engineering Education; W. Edward Lear, Executive Director

W41. Jerrier A. Haddad (retired), IBM Corporation

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