Chapter 4

Policy Issues and Options

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Chapter 4

Policy Issues and Options

INTRODUCTION

American schools, colleges, and universities have the capacity to provide enough scientists and engineers to meet the Nation's needs. Students and institutions can meet changing market needs, as evidenced by the response of engineering enrollments to the semiconductor industry boom in the late 1970s. However, many researchers, employers, and policy makers are concerned that future supply will be inadequate. In the early 1990s, the Nation will experience a decline in the number of college-age students (although some increase can be expected before the turn of the century). More important, fewer students, particularly those white males who have been the mainstay of science and engineering, seem to be interested in science and engineering careers. Women's interest in science and engineering, after rising for a long time, seems to have plateaued. Non-Asian minorities, traditionally poorly represented in science and engineering, will form a steadily increasing proportion of America's schoolchildren.

Two major trends are challenging the traditional educational route to a science or engineering career. First, the rising importance of minorities in the population will lead educators and employers to reach out to more diverse populations. Second, the end of expansion and the subsequent transition to a steady state of enrollments and research finding will require universities, employers, and the Federal Government to adjust their models and mechanisms of science and engineering recruitment.

Despite these trends, shortages of scientists and engineers are not inevitable. Generally, the labor market adjusts, albeit with transitory and sometimes costly shortages and surpluses. Rather than trying to direct market responses, policymakers should seek to prepare a cadre of versatile scientists and engineers for research and teaching careers, invest in an educational system that creates a reservoir of flexible talent for the work force, and ensure opportunities for the participation of all groups in science and engineering.

The Policy Setting: Federal Roles

The Federal Government has historically had both direct and indirect effects on the education of scientists and engineers (see table 4-1), but it is only one of many actors in the system. The Federal role in science and engineering education is most significant at the graduate level, more diffuse at the undergraduate level, and small in elementary and secondary education.

Federal investment in science education and training is undertaken for many reasons; there is no single objective or mission. One class of investments is in direct support of graduate students and production capacity at blue-chip universities. Other investments are made in newer, developing colleges and universities with growth potential, and in undergraduate and precollege education. Due to the uncertainty of payoffs from investing in creativity and reasons of efficiency and equality of access and geographical balance, Federal support is spread across different types of institutions and students.[1] Both short- and long-term investments are necessary in a marketplace-where demographics, economics, and technology constantly change the criteria for success in education for the work force.

The educational process from grade school to graduate school is 20 years long. T-his means there **are** many possible Federal options for renewing the future supply of scientists and engineers. It is difficult, however, to distinguish which option would have the greatest impact. At each level of the educational system, there are many choices for action. Few measures guarantee predictable effects in the relatively short term; most are more speculative and longer term possibilities. just as there are no immi-

[1]The *Federal Government can provide money, leverage power, and assist information and technology transfer. As a major investor in science and engineering education at all levels, it has more than local interests at heart and can be a catalyst.*

Table 4-1.—Landmark Federal Legislation Affecting Science and Engineering Education

1862	**Merrill Act. Established land grant colleges, and the precedent for Federal support of institutions of higher education.**
1890	**Second Merrill Act. Required States with dual systems of higher education to provide land grant institutions for Blacks as well as whites. Sixteen Black institutions were established as 1890 Land Grant colleges.**
1937	**National Cancer institute Act. One of the first in a long line of health manpower/National Institutes of Health acts.**
1944	**Serviceman's Readjustment Act (G.I. Bill). Provided extensive Federal support for large numbers of new undergraduate and graduate students. Not targeted to science and engineering, but by increasing the number of college students increased the output of scientists and engineers.** Nearly 8 million World War II veterans enrolled; many chose science and engineering majors.
1950	**National Science Foundation Act.** Established the National Science Foundation and included support of science education in the National Science Foundation's mission of supporting basic science. Set the tone for graduate science and engineering education: merit and geographical balance are the primary award criteria, with oversight of professional replenishment vested in the scientific community.
1951	**Selective Service Amendments of 1951.** Created draft deferrals for college students and for scientists. Following 1987, Act made students more vulnerable to the draft, and full-time graduate enrollment dropped as male students took deferrable full-time jobs.
1958	**National Defense Education Act.** Science and mathematics were major areas targeted for improvement through generous funding for equipment, guidance, testing, teacher training, and educational research. Increased the role of the Office of Education in science and engineering education. Authorized many graduate fellowships and undergraduate loans. The National Defense Education Act was expanded to most fields in 1964.
1964	**Civil Rights Act. Title IV set up technical advice structure for elementary and secondary** schools to desegregate on the basis of sex, race, color, religion, or national origin. Title Vll prohibited sex discrimination in employment (hiring, firing, pay, and working conditions).
1965	**Elementary and Secondary Education Act.** Established massive Federal support for schools and materials, particularly for schools with nontraditional and disadvantaged students. No focus on particular curricular area. Directed Federal education policy and money to special underserved populations (low-income, handicapped).
1965	**Higher Education Act. First major Federal legislation for higher education not linked to a specific goal (e.g., national** defense), but rather to promote-equality of access, student freedom of choice, quality of education, and' efficient use of human resources. Brought Federal money into higher education and expanded college enrollments. Supported continuing and cooperative education, libraries, teacher training, facilities, and student financial aid. Title II included a provision to support minority institutions.
1967-8	**Elementary and Secondary Education Amendments.** Authorized support of regional centers for education of handicapped, particuiarly deaf and blind. Supported bilingual education programs,
1972	**Education Amendments.** Consolidated higher education legislation prohibited sex discrimination in federally assisted education programs. Title IX prohibited sex bias in admission to vocational, professional, graduate, and public undergraduate institutions.
1974	**National Research Service Awards Act (National Institutes of Health).** Shifted emphasis of the National Institutes of Health training from growth to renewal and quality in a constrained budget. Set out the principle of requiring students to return services in exchange for support (not enforced). Instituted manpower planning. Fellowships by law must constitute 15 percent of the research training budget.
1980	**Science and Technology Equal Opportunities Act.** Promoted the full development and use of the scientific talent and technical skills of men and women of all ethnic, racial, and economic backgrounds. Directed a biennial report *to* assess opportunities and participation rates.
1984	**Education for Economic Security Act.** Targeted mathematics, science, computer learning, and foreign languages. Under this Act, the Department of Education provides modest funding, mostly on a formula basis, for: teacher training, magnet schools (designed for desegregation, but some with science and mathematics emphasis), and for improving mathematics and science education.
1986	**National Science, Engineering, and Mathematics Authorization Act of 1986.** Established a Task Force on Women, Minorities, and the Handicapped in Science and Technology in the Federal Government and in federally assisted research programs.

SOURCE: Office of Technology Assessment, 19SS.

nent crises in replenishing the science and engineering work force, there are no quick fixes.

The following discussion sets out policy areas for possible congressional action, presented under two strategies labeled "retention" and "recruitment," along with two Federal management issues (see table 4-2). Within each policy area, options are listed and described. The overarching policy issue is whether the Federal Government allows the market for scientists and engineers to take its course or intervenes more boldly.

Two Strategies

The two broad strategies of retention and recruitment complement each other, and would operate best in tandem. The retention strategy is designed

Table 4.2.—Federal Policy Options To Improve Science and Engineering Education

The following list summarizes the policy options discussed in this chapter, along with *rough estimates* of the current level of Federal spending in that area, as well as the number of students, teachers, or educational institutions affected. The estimates have been compiled from the reported budgets of major, separately budgeted Federal programs, as well as estimates of discretionary spending (usually small amounts in the mission agencies) based on contacts with agencies. Many departments and agency laboratories also run small outreach programs using employee volunteers and donating equipment; there is no way to estimate the value or impact of these programs. In most areas a great deal of money is also spent by private organizations and individuals.

Policy Option and Number of Students Affected	Estimated 1988 Federal Spending
Retention	
1. Support graduate training[a]	unknown 52,000 students (20°/0 of all graduate students)
fellowships and traineeships	$250 million 13,400 students (5°/0 of all graduate students)
postdoctorates	$300 million to $400 million 17,000 students (70°/0 of all postdoctorates)
2. Academic R&D spending/mission agencies	$5.5 billion
graduate research assistantships[a]	$500 million 33,000 students (12°/0 of all graduate students)
3. Flow and retention of foreign students	—
4. Institutional support[b]	unknown
research colleges	unknown
historically Black colleges and universities	$630 million to $750 million
research universities	unknown
5. Hands-on research experience	
research apprenticeships	$10 million to $12 million 5,000-7,000 undergraduates
cooperative education	$15 million 175,000-200,000 students (2%)
6. Targeted support for undergraduate science and engineering students (Pen grants, etc.)	$4 billion to $5 billion 4 million college students
Recruitment	
1. Intervention programs	
science/engineering (all agencies)	**8,000-25,000 students**
4H (U.S. Department of Agriculture)	**5 million students**
2. Elementary and secondary teaching	**$120 million to $180 million**
preservice and inservice training	$110 million to $150 million 10,000-250,000 teachers[d]
encourage and reward teachers	$1.2 million 106 teachers
3. Informal education	$13 million to $20 million
TV, fairs, camps, demonstrations	unknown
S&T centers	$10 million, 150 science centers
4. Improve opportunities for women	unknown
enforce Title IX	unknown
special support and intervention	unknown
5. Improve opportunities for minorities	unknown
enforce civil rights legislation	unknown
special support and intervention	unknown
6. Elementary and secondary education	
reproduce magnet schools	$75 million[e]
science-intensive schools and experiments	–[f]
adjust course-taking	
review tracking	—
revise testing	—

table continues

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Management of Federal Science and Engineering Education	
1. National Science Foundation as lead agency in science education	
SEE Directorate	$140 million
Research and related directorates	$217 million
2. Federal coordination and data collection	$40 to $80 million[g]

NOTES:
[a]National Science Foundation 1986 data. Includes fellowships, traineeships, research and teaching assistantships, and loans for full-time graduate students in doctorate-granting institutions. The number of students includes only those graduate students whose major source of support is the Federal Government; thus, the number here underestimates the total number of graduate students receiving Federal support, though it reflects the allotment for institutional allowances as well as student stipends. The vast majority of Federal support goes to full-time students.
[b]Only those funds directly related t. science and engineering instruction, facilities, and capability. Includes general development funds and capital funds for major science and engineering-related equipment, facilities, and libraries. Includes general support for historically Black colleges and universities (H BCUs) and Black land grant institutions. Does not include R&D, student support, or support for Federally-Funded R&D Centers.
[c]Only about 20 percent of this is directly related to science and engineering, and most of that is current R & about S35 million goes to science and engineering-related institutional support (facilities, institutional and departmental development, and general support). The rest is legislatively mandated general Federal support, mostly out of the Department of Education but also the National Institutes of Health and the Department of Agriculture, for the approximately 100 historically Black institutions. One institution, Howard University, receives nearly one-third of Federal support for HBCUs.
[d]Teacher training and enrichment programs are diverse. Some, like the National Science Foundation and mission-agency sponsored workshops, training institutes, and summer research experiences, invest significant time and money in each teacher, but reach only a few hundred teachers a year. Under Title II of the Education for Economic Security Act, the Department of Education distributes money by formula for teacher training, and thus in principle reaches nearly all of the 1.5 million public school teachers (and some private school teachers), but is so diluted by formula distribution that only a few dollars reach each school and teacher.
[e]Under current criteria, Federal funding for magnet schools is given to those school districts under court orders to desegregate. While it reaches only a small number of school districts (45-50), it reaches some very large ones (and thus a greater proportion of students) and many of those districts with continuing and significant racial imbalances in the delivery of education.
[f]Non-Federal spending is about $1 million to $8 million, 500-2,000 students.
[g]Includes National Science Foundation spending on data collection (Science Resources Studies, $5 million) parl of policy analysis (Policy Research and Analysis), and spending on education research ($10 million). The Department of Education's Office of Educational Research and Improvement has a total budget of about $67 million, which includes among other things funding for libraries, the ERIC database, major surveys, and the National Center for Statistics. Although only a miniscule portion of this is targeted to science and mathematics education, overall data collection includes science and mathematics education. In addition, other mission agencies keep administrative records of their R&D and education programs and spend small amounts on special research and data projects. Of special note are National Institutes of Health studies, including the Institute of Medicine's biennial personnel needs analysis, and the Department of Energy's annual manpower analysis,

SOURCE: Office of Technology Assessment, 1988.

to invigorate the current science and engineering work force by reducing attrition of undergraduate and graduate students. Such short-term retention programs could increase output of scientists and engineers within a few years. In contrast, recruitment is a long-term strategy to enlarge the base of potential scientists and engineers by recruiting more and different students into science and engineering. Such a strategy entails working with schools and colleges, and with children, teachers, and staff to renovate elementary and secondary mathematics and science education.

RETENTION POLICY OPTIONS

If the Nation wants more scientists and engineers relatively quickly, then retaining undergraduate and graduate students in science and engineering is the most useful policy strategy. Many able students leave science and engineering during college, after earning baccalaureate degrees, and during graduate school. Only about 30 percent of B.S. science and engineering graduates enter full-time graduate study, and nearly half of science and engineering doctoral candidates never earn Ph.D.s. Some loss is inevitable (and, indeed, beneficial to other fields), but those who leave unwillingly and prematurely are a rich resource that could be tapped. Because attrition rates are so high and the population of research scientists and engineers is relatively small, slight improvements in retention could increase significantly the number of scientists and engineers in the work force. Federal policies could work at all levels to retain more of these able, interested students in the pool.[2]

[2]Although *"scientists and engineers" are addressed categorically throughout most of this chapter, there are differences between them that demand separate policy consideration. Potential scientists aim for doctoral degrees, but most engineers enter the work force with a baccalaureate degree. Some engineers either continue immediately, or* re-

Many factors affect students' career choice and persistence in science and engineering: interest and aptitude; perceptions about careers gleaned from university faculty, peers, and summer jobs; and anticipated earnings and nonmonetary rewards. Students considering academic careers must also weigh the burden of undertaking and financing graduate training. The Federal Government affects these career decisions through targeted support of students, universities, and research, and through its pervasive influence on the American economy and research agenda. The extent and form of Federal support for students, particularly graduate students, affects the attractiveness of further study. Federal R&D support and national research missions (e.g., in health, space, defense) shape students' perceptions of the job market for scientists and engineers, as well as the environments in which students are educated.

Many of the policies discussed below involve established mechanisms that could be expanded effectively. There is an adequate reserve of prepared college graduates and graduate students who, with the proven incentives of fellowships and potential R&D-supported jobs, would be able to shift their career choices.

1. Support Graduate Training

The Federal Government is the most important source of direct support for graduate training, primarily through fellowships and traineeships, and of indirect support through universities (which pass on money to students through research assistantships). This support is intended to meet national research and education needs by making graduate study attractive to baccalaureate recipients, and sustaining those who enter graduate school through completion of their Ph.D.s. To achieve these goals, the Federal Government can adjust the overall level of support, distribute money among different forms of support, and vary the relative amounts of support given different categories of research, such as basic research and mission R&D, and different categories of students and institutions.

- Expand graduate fellowships and traineeships.
- Shift distribution of student support among the major forms of support: fellowships, traineeships, research assistantships (RAs), teaching assistantships (TAs), and loans. (Currently the bulk is in RAs.)
- Shift distribution of graduate student support between the National Science Foundation (NSF), the Department of Education, and the mission agencies. Authorize mission agency support for graduate training in those agencies not currently authorized.
- Expand special support programs for minorities and women.
- Expand postdoctoral fellowships and traineeships.
- Clarify tax status of graduate student stipends and support.

Federal support of graduate training is a proven, highly effective means of producing scientists and engineers. Federal influence at the graduate level is relatively straightforward: the support (Federal and otherwise) available for graduate students influences the number of students pursuing and earning Ph.D.s and directs them toward funded research areas. Different support mechanisms—RAs, TAs, fellowships, and loans—support students in different stages and aspects of their graduate study. This diversity of support mechanisms has served U.S. universities, students, and research well. The Federal Government has directed its support to an array of RAs and fellowships, and to training grants that benefit both universities and students.

The allocation of Federal support among these different mechanisms depends on the purposes sought. For example, if the Federal Government wanted to encourage teaching as a career, it might support more TAs. Currently there is little Federal funding of TAs, which total only about $3 million annually. Fewer than 400 full-time graduate students, or 0.1 percent, receive their primary support from Federal TAs. If increasing the research experience of women and minority students is a goal, then they could be targeted for RAs funded by Federal research grants to faculty (see below). Few arguments are mounted against Federal support of graduate students, particularly in areas where there is clear na-

turn after gaining *work experience, for a master's degree.* Traditionally *only a small number have sought Ph.* D.s *and* these *engineers have most often taken an academic position. Scientists are more likely to enter academia and other nonprofit environments. This chapter concentrates on the research work force, the subset of scientists and* engineers *most likely to have Ph.* D.s. *Unless otherwise specified, reference* here *to scientists and engineers means* research *scientists and engineers.*

tional interest, such as biomedicine, space sciences, environmental science, and basic academic research. The most controversial issues are the overall level of support and the allocation of training support among different types of students and institutions.

Fellowships and Traineeships.–FeIlowships and traineeships are the cream of Federal support. Fellowships provide flexible, generous support directly to a few of the very best graduate students, and promote successful, rapid completion of Ph.D.s. Multiyear training grants are awarded to institutions, which in turn distribute traineeships to graduate students. Traineeships provide valuable support for the university's education and research infrastructure. Training grants are a proven means of nurturing students who will become successful researchers. Together, fellowships and traineeships are effective, long-term, and low-risk investments in a core of creative graduate students and future researchers.[3] Expansion is possible; field-specific fellowships and traineeships offered in the 1960s, under the National Defense Education Act, helped spur unprecedented increases in science and engineering graduate enrollments and Ph.D. awards.

Current Federal fellowships and traineeships total about $250 million per year and provide primary support for about 13,300 (or 5 percent) of full-time graduate students. Training grants form the bulk of this support ($170 million annually, which supports about 9,000 or 3.7 percent of full-time graduate students). The single most important source is the National Institutes of Health (NIH) National Research Service Award traineeship. Fellowships alone total $80 million annually, which support just 1.6 percent of full-time graduate students.

Fellowships and traineeships maybe field-specific. One risk of increasing field-specific predoctoral and postdoctoral support is the national waste and personal cost of training students in fields with changing research priorities that undermine the job market (as in environmental sciences or renewable energy in the mid-to-late 1970s). However, such changes are difficult to predict. The best alternative is to encourage close monitoring of the labor market by Federal funding agencies, universities, and industry employers; to encourage universities and students to shift fields of study where the job outlook is bleak; and to help graduate students, new Ph.D.s, and young researchers move to neighboring specialties as necessary.

"Portable" fellowships (awarded to individual students who carry them to the institutions of their choice) tend to reinforce concentration of Federal R&D support in the best, well-established university departments. The advantage of fellowships is great for students and institutions, since they are flexible and generous, and produce both good research and Ph.D. researchers.

Traineeships and grant-linked research assistantships direct Federal support to a broader range of institutions. Because of the many years needed for graduate training and the resulting delay between fellowship awards and completion of Ph.D.s, no form of graduate support can address short-term personnel shortages or urgent research problems. Graduate students, however, seem to respond more quickly to increases in support than to decreases.

Fellowships and traineeships are particularly effective for attracting and nurturing minorities and women. Expansion of fellowship support is limited by the relatively small numbers of minorities who pursue graduate study; many more qualified women B.S. graduates, however, could be attracted. Currently, there are few such special programs in place; an exception is the widely-acclaimed Minority Access to Research Careers program of NIH. NSF awards about 50-75 graduate fellowships annually to minorities; the Department of Education offers minority fellowships which, although not targeted to science and engineering, are used by graduate students in these fields. Several other mission agencies have small programs that typically provide fellowships for 5 to 30 minority graduate students. In all, special Federal fellowship/traineeship programs for minorities total about $8 million to $10 million annually and fund about 100 to 150 graduate students (only a few percent of minority graduate students). Doubling special fellowship programs for minorities and establishing similar programs for women at the same level would require about $30 million dollars

[3] Because *fellowships and* traineeships *are usually awarded to the best students, it is difficult to say to what extent the form of support enhances graduate education and to what extent the better student would excel anyway. Undoubtedly, both the high quality raw material and the generous support are important. The complete fellowship and traineeship system, including promotion, selection, and the support itself, is effective.*

annually. Such funds could be set aside from existing fellowship programs, or additional funds could be appropriated.

Postdoctoral fellowships, generally 2 years in duration, augment the specialized knowledge and skills acquired during graduate study. Postdoctorates are particularly productive, creative researchers, because they can devote themselves to research full time. They are a reservoir of talent that fellowships can rapidly and efficiently guide toward current research priorities. Postdoctoral appointments also help retain Ph.D.s in the research work force, especially in slack job markets, and help shift researchers toward current priorities. Current Federal support is approximately $150 million per year, mainly in the life sciences, supporting about 5,000 postdoctorates (23 percent of all postdoctorates). Another $250 million or so per year supports about 11,000 postdoctoral students through research grants.

Taxation of Graduate Student Aid.–The tax status of graduate student aid has changed in the past few years with changes in tax law.[4] The guiding principle of the 1986 tax reform was to minimize special exemptions (e. g., student aid), while minimizing the burden by reducing the overall tax rate.[5] The general trend has been to reduce tax exemptions on student aid, both stipends for living expenses and aid to cover tuition fees. Currently, all forms of student aid—TAs, RAs, fellowships, and traineeships—are considered taxable income. Recent tax reform affirmed in legislation the taxable status of student aid, but both the tax code and its enforcement remain murky. There are varying interpretations of whether all forms of aid—from TAs, which are given for providing teaching services, to fellowships that have no formal work requirement–are covered by the same laws and taxed similarly, and whether aid that goes to tuition should be taxed in addition to stipend aid.

Most agree that tuition aid should not be taxable. However, there are concerns about scope and implementation. The financial attractiveness of graduate study is tenuous, given the low earnings of most graduate students; increasing withholding and students' eventual tax burden without a compensating increase in stipend could deter or lengthen graduate study.[6] To sustain the current level of support, Federal and other contributions for student aid would need to be increased. To compensate for the added tax burden on the recipients of their awards, NSF and other agencies are seeking to increase their allocations. This step would simply maintain the current levels of student and institutional support. States and universities would need to boost institutional support to maintain TAs and other forms of aid.

Confusion and some unanticipated problems have arisen from lack of coordination between tax legislation, the Employer Assistance Act, Internal Revenue Service regulations, and student aid legislation and regulations. Congress could clarify the tax status of tuitions and stipends, and set out in a separate section of the tax code the tax liability of each form of student aid.

2. Sustain Academic R&D Funding

The Federal Government is the Nation's R&D pacesetter. Its $60 billion annual R&D budget is about half of U.S. R&D, and influences the rest substantially. Federal R&D funds are even more visible on campus, where they support nearly two-thirds of all R&D.

R&D spending not only helps develop scientific and technological knowledge that is useful to national needs, but also has important and often underappreciated effects on the education of scientists and engineers (see table 4-3). First, the overall level of R&D spending, as well as its distribution among

[4] This section is based on personal communications with Bob Lyke, Congressional Research Service, February 1988, and Tom Linney, Council of Graduate Schools, February 1988. Also see Stacy E. Palmer, "Measures To Tax Scholarships Pose Dilemma for Graduate Schools," *The Chronicle of Higher Education*, Apr. 16, 1986, p. Al; and Arthur M. Hauptman, *Students in Graduate and Professional Education: What We Know and Need to Know* (Washington, DC: American Association of Universities, 1986), pp. 62-64.

[5] The main goal of the original post-World War 11 tax exemptions for student aid was to encourage college attendance. This goal has clearly been achieved for undergraduates where the financial burden rests with students and their families. Given the weak market incentives for graduate study, there still seems to be a need and national justification for special financial buttressing of graduate study (for which educational institutions and Federal and State Governments have traditionally paid).

[6] A related consideration is unanticipated or inequitable impacts of the tax law on certain groups, particularly foreign students and married students. Foreign student aid is withheld automatically at the highest rate, and they receive no deductions for children. This may discourage foreign graduate students and does nothing to increase the numbers of American students.

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Table 4-3.—Annual Federal Support of Graduate Education and Research
($ = approximately $75 million)

Most **Federal research-related funds that go to universities support current R&D, rather than the education of future researchers. Research support also is the largest source of Federal sup-** port for graduate education; research assistantships from university research grants and contracts support over three times as many graduate students as do direct Federal fellowships and traineeships.

Primary purpose:	Education	Research
Category of support:		
Individual student support (fellowship)	**$**	
Training support	**$$**	
Institutional development	**$$**	**$$$$**
R&D support	**$$$$$$ (RAs)**	**$$$$$$$$$$$$$ $$$$$$$$$$$$$ $$$$$$$$$$$$$$ $$$$$$$$$$$$$$ $$$$$$$$$$$$$$**

KEY: RAs = research assistantships.

SOURCE: Office of Technology Assessment, 1988.

fields and missions, both directly shapes the job market for scientists and engineers and is the single most important predictor of their future supply.[7] Second, the portion of Federal R&D spending that goes to fund science and engineering research on campus helps support large numbers of RAs, which are the most common form of Federal graduate student support.

Changes in national R&D policies affect both the attractiveness of the science and engineering career as well as the ease with which students can prepare for one. Currently, over one-quarter of Ph.D. recipients have federally-funded research assistantships during their graduate study, a mechanism that provides about $500 million in annual student support. The vast majority of this spending comes from the mission research agencies, which provide about $5.5 billion in academic research support annually. About 30,000, or 12 percent, of graduate students receive their primary support from RAs annually. Overall, about 5 to 15 percent of research funds awarded to university investigators is spent on RAs, with this proportion varying significantly by field, Federal agency, and the purpose for which the funds are provided.

- Recognize the educational as well as the scientific benefits that accrue from Federal R&D support to colleges and universities.
- Shift the distribution of Federal R&D support among academia, industry, and government,

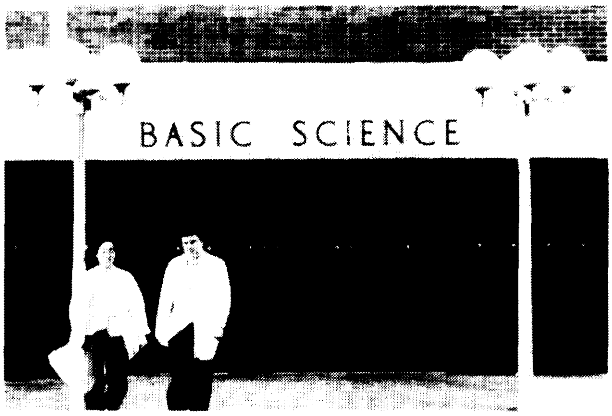

Photo credit: National Institutes of Health

Federal research and development funding bolsters and guides demand for scientists and engineers, graduate students as research assistants, and the universities and colleges that train future scientists and engineers. National Science Foundation support of basic scientific research forms the backbone of education and research in science and engineering. But the Federal mission agencies provide, overall, more funding, and dominate funding in fields related to their mission. Striking the balance between these two routes of Federal support never has been easy.

[7] Lewis C. Solmon, *"Factors Determining and Limiting the Supply of New Natural Science and Engineering Baccalaureates: Past Experience and Future Prospects," prepared for the National Science Foundation Workshop on Science and Engineering Manpower, draft manuscript, July 8, 1986; Eli* Ginzberg, *"Scientific and Engineering Personnel: Lessons and Policy Directions," The Impact of Defense Spending on Nondefense Engineering Labor Markers, A Report to the National Academy of Engineering (Washington, DC: National Academy Press, 1986).*

taking account of the different educational benefits that derive from spending in each of these areas. Consider shifting the balance of R&D spending between defense and civilian areas, and among basic, applied, and development-oriented programs, in light of their different educational effects.

- Increase overall R&D support as a way of improving the attractiveness of science and engineering careers and expanding the research work force.

Research Assistantships and the Mission Agencies.—In general, RAs provide vital bench research experience in state-of-the-art university research programs. Next to fellowships, they are the most sought--after form of graduate student support. Designating RAs for women and minority students encourages persistence to the Ph.D. and is thus a tool for altering the composition of new entrants to the science and engineering research work force.

Most RAs are provided through funds from NIH; its expenditures on health and biological research dwarf the total spending of NSF and many other agencies. Among other mission agencies, the Department of Defense is a prominent funder of engineering and mathematical research, the National Aeronautics and Space Administration dominates space science, the Department of Energy is prominent in energy and physics research, and the Department of Agriculture is a major funder of agricultural research. In some fields (such as geodesy, space science, and high-energy physics), the respective mission agency is the only supporter of research; it seems reasonable that each agency look after its own research work force as well. NSF, however, is entrusted with Federal support of basic research relevant to the general interests of the Nation rather than any particular mission. overall, four of five federally supported full-time graduate students are funded through the mission agencies.

One consideration in assessing the allocation of funds among the agencies is the variable proportion of academic research funds from each agency that goes to RAs. For example, the proportion is much higher for NSF grants than for those from the Department of Defense. In general, a greater proportion of academic, civilian, and basic research funding (as it is variously labeled) goes to support students than does defense and development funding.

Closer educational links could be forged between academia and the mission agencies' own laboratories. Mission agencies could be encouraged to find programs to provide graduate training (via fellowships or internships) for students at their laboratories. Such programs would improve the dissemination of students' research, help the laboratories to recruit talented students, and improve relations with universities. In some cases, the relevant legislation governing each agency's research activities might have to be amended to permit such programs to be established.

3. Control the Flow and Retention of Foreign Students

The vitality of U.S. universities attracts increasing numbers of foreign science and engineering graduate students and visiting scholars, many of whom stay in the United States after completing their degrees. In engineering, more than one-half of all graduate students and more than one-third of new faculty are foreign.

The unprecedented visibility and even predominance of foreign citizens in certain fields has raised concern. Most observers see the problem as a shortage of Americans rather than a surfeit of foreign scientists and engineers. (U.S. graduate students in engineering increased by 20 percent for 1975-85; foreign graduate students in engineering increased even more. It is important to look at absolute numbers as well as proportions.)

Immigrants make valuable contributions to U.S. research. They are highly selected, academically competent, and valuable researchers who have maintained many university departments as American student and faculty numbers have slowed. Student entry is now the dominant path of immigration for scientists and engineers. Relying on foreign talent in key areas is seen to have many drawbacks. Some consider foreign students and faculty as a national security risk; others cite their difficulty in "fitting in, " owing to language and cultural differences; and some worry that they drain talent from their home nations.

- Encourage Americans to undertake graduate study and academic careers in selected fields.
- Continue the selective entry and immigration of educated, skilled foreign scientists and engineers.
- Use immigration and naturalization policies, financial support eligibility, or employment regulations to open or close the doors to foreign students and/or immigrant scientists and engineers.

Apart from the widely accepted goal of encouraging American graduate students in science and engineering, a fundamental issue is whether to encourage foreign students and workers, or to restrict them. These people add skills, creativity, and energy to U.S. science. Although the greatest contributions are likely to come from immigrants who stay permanently, temporary visitors and graduate students also contribute to U.S. research while they are here. Furthermore, even after visitors leave they usually maintain contacts within the U.S. research community. Several mechanisms are available to broaden, selectively encourage, or restrict the entry, length of stay, and permanent immigration of scientists and engineers.

Most suggestions to encourage American study in fields with high proportions of foreign students, such as engineering, mathematics, and computer science, center on one tactic: increasing RA or TA stipends to make graduate study more competitive with employment, usually setting the target figure at half the average starting bachelor's-level salary. Similar measures have been used with young faculty members; universities have supplemented faculty salaries in competitive fields such as engineering, business, and medicine. This step can create jealousy on campus. In some cases, the supplements have been temporary, until the labor markets have adjusted and more Americans take faculty posts; in other cases, separate salary scales for faculty are instituted.

Most foreign scientists and engineers originally came to the United States as students (on temporary or nonimmigrant visas). Those who stay usually obtain visas as temporary workers (H-1 or H-2 temporary visas); under current Immigration and Naturalization Service (INS) policy, these visas are generally good for 5 years, renewed annually on the basis of continued need by employers. Some workers apply for permanent visas, with the sponsorship of employers, by a process known as labor certification. Graduate students who stay on are the largest source of permanent foreign entrants to the science and engineering work force. Direct immigration of experienced scientists and engineers is much less common and less of a policy issue.[8]

The Federal Government could use eligibility constraints to expand or restrict support of foreign students. Most Federal fellowships are not open to foreign citizens; the cost of graduate education for foreign science and engineering students must be defrayed by support from their home countries or the U.S. universities they attend. Making foreign citizens eligible for fellowships would allow agencies to recruit people in fields where American students are scarce. Another option is to restrict foreign eligibility for research or teaching assistantships, which would depart from the tradition of faculty autonomy in selecting assistants and deter many good foreign students from U.S. graduate study.

Other mechanisms include:

- Changing the approval criteria for labor certification.[9] The Federal Government could encourage foreign nationals in science and engineering to stay in the United States by eliminating the requirement for labor certification altogether.
- Changing the regulations that require students who have held exchange visitor (J-1) visas to return home before applying for a permanent visa. Extending this requirement to all students

[8]Perhaps 150,000 *foreign science and engineering students enter each year, mostly on temporary student visas (F-l), some on exchange visitor visas* (J-1). *They favor fields with rapid employment growth such as computer science and engineering, as do American graduate students. Under current policies, students can apply to extend their visas for 1 year of practical training, and then convert to a temporary worker visas (H- 1 or H-2) for up to 5 years. In 1985, about 12,000 foreign science and engineering students (or former students) converted to permanent visas, while about 5,000 immigrants in science and engineering occupations entered the United States. In addition, some students on temporary visas stay and work. Overall, about half of foreign graduate science and engineering students stay in the United States to work for a number of years. Dennis Keith, Immigration and Naturalization Service, personal communication, Jan. 29, 1988.*

[9]About *30 percent of immigrant scientists and engineers receive an employer-submitted labor certification, which demonstrates that the Secretary of Labor has determined that the job cannot be filled by a U.S. worker and that employment will not adversely affect U.S. workers similarly employed. The Immigration and Naturalization Service then has to consider the individual's petition for immigration (on the basis of quotas and occupational preferences).*

and/or to temporary workers would probably reduce both permanent immigration and student entry by decreasing the attractiveness of university study as a simple means of permanent immigration.

- Controlling the number of student and temporary visas issued by INS and the Department of State, possibly by field (currently there are no quotas). Such a measure would likely reduce the number of foreign students.
- Further restricting entry according to country of origin or field, thus reducing the number of immigrant scientists and engineers. In addition, certain occupations are exempted from certification; expanding this list could impose occupational preferences for immigration quotas.

4. Support Institutions That Make Special Contributions to Undergraduate Science and Engineering Education

Graduate education builds on the base laid by undergraduate education–the 4-year period in which the student pursues coursework in the fundamental subjects of science and engineering, may actively work in research projects, and first encounters faculty mentors who are research professionals. Although the Federal Government does not support undergraduate education in the same direct way as it does graduate education (primarily via research grants), it does provide considerable indirect funding. The routes by which these funds are supplied include overhead on research grants and student awards, and programs for improving institutional development, instructional equipment, libraries, and facilities. Much of this funding is not specifically directed to science and engineering education, although it does benefit these fields.

The bulk of this support goes to a small number of elite research universities, which graduate most of those who go on to science and engineering careers. Yet the large scale and research orientation (often at the expense of teaching) of these institutions may deter others from considering graduate study. There are other, smaller institutions that are strong in undergraduate science and engineering without having the research focus of the research universities. These smaller institutions, such as research colleges, historically Black colleges and universities (HBCUS), women's colleges, and primarily engineering institutions, in fact graduate large numbers of science and engineering students who go on to further study in these fields.[10] These successful, and often neglected, undergraduate environments may merit special Federal support, and certainly provide lessons that could be adapted to other institutions, including the research universities.

- Expand research, student, or institutional support of institutions that are especially productive of baccalaureate degree recipients who become science and engineering Ph.D.s. Doubling current special programs for research colleges would require $10 million to $20 million annually. Doubling current support for minority institutions would require $500 million to $750 million annually.

About 100 research universities train the vast majority of science and engineering Ph.D.s. They also produce most of the bachelor's recipients in these fields who go on for Ph.D.s. They receive nearly all of Federal academic R&D funds and are well-endowed; few argue that they need new Federal funding. Some observers contend, however, that they neglect undergraduates in favor of research and graduate training. Yet the academic reward system, based on success in research, is largely impervious to change. Institutions might be more productive of undergraduates if faculty were encouraged to pay attention to teaching through mechanisms that shift funds toward mentor grants and undergraduate research participation, or if research funds were somehow tied to overall teaching performance.

The research colleges–small, 4-year liberal arts colleges that concentrate on science and research–are especially effective in educating and encouraging students who go on to be research scientists. Ob-

[10] *A large category of institutions omitted from this list are the comprehensive universities. Seventy percent of these 600 institutions are State schools. They represent a point of access to higher education for many students who either do not qualify for or cannot afford more selective institutions. Some believe that their role in undergraduate science and engineering education, and as a feeder of the research universities, could also expand if resources to meet the same instrumentation and faculty needs of other teaching environments were made available. See Philip H. Abelson, "Science at the Four-Year and Master's Universities," Science, vol. 239, Feb. 12, 1988, p. 705.*

servers attribute this success to their emphasis on teaching, programs that prevent attrition, student research participation, and continuous personal contact between faculty and students. Current Federal support for research colleges rests with NSF, with programs supporting special instructional equipment and research. NSF's College Science Instrumentation Program is currently funded at $10 million per year. Less than $35 million, or 0.5 percent of Federal academic R&D funding, goes to the research colleges annually. Special programs could provide equipment and facilities for teaching and research, coordinate research and education activities that result in significant student participation in faculty research at the research colleges, and promote cooperation and resource-sharing among small colleges, and between small colleges and universities.[11]

HBCUs, numbering about 100 and located predominantly in the South, graduate about one-third of all Black bachelor's recipients. HBCUs have long received special Federal support, dating from legislation to ensure minorities' access to higher education. These institutions send many of their graduates on to Ph.D.s in science and engineering. HBCUs provide a supportive intellectual and social environment that heightens minority student retention and sparks graduate study. In addition to HBCUs, with their special legislative status, there are several hundred 2- and 4-year colleges with predominantly minority enrollments, including a growing number of institutions with large Hispanic enrollments. These institutions have underutilized potential for nurturing science and engineering talent.

Total Federal support of HBCUs is about $700 million per year, most of it general institutional support. Funds for equipment, facilities, faculty exchanges and development, educational materials, and various student services are awarded by the Department of Education (about $630 million under Title III of the Higher Education Act and $5 million under the Minority Institutions Science Improvement Program) .12 Little of the support under Title III has been directed at science and engineering. NSF, NIH, the Department of Agriculture, and other mission agencies have smaller, more informal programs that benefit HBCUs.

Setting aside special support for some group of institutions can be politically controversial. To what extent should existing productive environments be supported, and how much effort should go into identifying and reproducing the characteristics that foster productivity? A related question is whether more support would automatically make scientist- and engineer-producing institutions even more productive. Some have argued, for example, that funding large amounts of research (instead of teaching) at research colleges could undermine the emphasis on teaching. Federal initiatives such as the NSF Science Development Program have worked, although they are expensive even when costs are shared by State and private sources of funding. There is substantial inertia in the structure and culture of individual colleges, and in the overall hierarchy of institutions.[13]

5. Expand Undergraduate Hands-on Research Experience

Research experiences in actual research settings provide science students with valuable previews of scientific research careers. These programs take many forms—formal cooperative arrangements, apprenticeships, field work, undergraduate research fellowships and teaching assistantships, summer jobs, and internships. Extensive testimony and some re-

[11] The 1987 Oberlin *Report* calls *for a* 10-year *investment of $ 1 billion, half for "maintenance and enhancement of effective teaching and research" (e.g., faculty and student grants, and new instrumentation), 15 percent for construction and renovation of laboratories and classrooms, and the rest for additional faculty positions. See Sam C. Carrier and David Davis-Van* Atta, *Maintaining America Scientific Productivity: The Necessity of the Liberal Arts Colleges (Oberlin, OH: Oberlin College, March 1987),* p. 133.

[12] James *B. Stedman, Congressional* Research *Service, Library of Congress, "Title 111 of the Higher Education Act: Provisions and Funding, " issue brief, Mar. 31, 1987, pp. 4-6. Also see Margaret* Seagers, *Executive Director, White House Initiative on Historically Black Colleges and Universities, in U.S. Congress, House Committe on Science, Space, and Technology, Subcommittee on Science, Research and Technology, Federal Science and Technology Support for Historically Black Colleges and Universities (Washington, DC: U.S. Government Printing Office, Oct. 9, 1987), pp. 197-209.*

[13] Another concern is whether funding *special environments, such as women's and minority colleges, would perpetuate undesirable separate education and preserve an artificial "hothouse" environment that nurtures students while they are in it, but does not prepare them for mainstream research later. (There is some indication, for example, that women baccalaureates from women's colleges, while they are more likely than women from coeducational institutions to earn a science or engineering Ph. D., are less likely to continue in research careers.)*

Photo credit: Carl Zitzmann, George Mason University

Undergraduate research participation can be a highly effective way to encourage undergraduates to consider entering graduate school and becoming research scientists or engineers.

search data suggest that students who participate in undergraduate research are more likely to become productive scientists.

Engineering students planning to enter the work force with B.S. or M.S. degrees have a similar option in cooperative education. Cooperative education students alternate their regular academic studies with paid jobs related to their major, usually off-campus in industry or government. The work experience gained in a cooperative program—as in other summer or part-time work related to a student's major or in research projects for science students—provides early exposure to a planned career and a valuable head start on "real-life" workplace skills. Formal cooperative programs encompass only about 2 percent of science students and 10 to 15 percent of engineering students.

- Increase finding for undergraduate research by NSF and possibly the mission agencies, as special programs or supplements to research grants.
- Target women or minorities.
- Increase support for cooperative education (fund university programs, provide incentives to employers, and encourage Federal agencies to host more cooperative education students).

A line-item addition to grants could reward investigators and institutions for involving undergraduates, especially women and minorities, in research projects. NSF has built such an incentive into some of its research programs, and it could expand the effort. Adding student participation in research as a criterion when evaluating applications for support (or even accreditation) would raise consciousness about experiences that are critical to budding research careers.

Current annual Federal support of undergraduate research is in the $15 million to $100 million range, involving 7,000 to 12,000 undergraduates. NSF leads with a dedicated program, Research Ex-

Photo **credit: University of Tulsa and** *The Chronicle of Higher Education*

Cooperative education programs combine academic coursework with periods of off-campus industrial training. They give students valuable early exposure to "real-life" work skills, and help employers find *and* prepare students for employment after graduation. The Federal Government supports cooperative education programs both through its mission agencies and through a grant program from the Department of Education.

perience for Undergraduates ($9 million annually and 2,000 students). Other research, education, summer research, and outreach programs in NSF, NIH, and mission agencies generally, also involve undergraduates in special programs.

Federal support of cooperative education has included financial support to universities to set up and administer cooperative programs, incentives to industry, and the hosting of cooperative students by Federal agencies. Support under Title VIII of the Higher Education Act has helped universities establish and expand cooperative programs. Current Federal support is $15 million per year under Tide VIII for nearly 200,000 undergraduates in cooperative programs at several hundred institutions.

The main argument against expanding support of undergraduate research and cooperative education programs is the cost. Beneficial undergraduate research and cooperative study demands commitment to education by employers. Many employers are reluctant to invest in short-term apprentices, and this resistance limits the attraction of their participation in cooperative education without additional external funding.

6. Target Support for Undergraduate Science and Engineering Students

The Federal Government has expanded access to higher education for most Americans. College enrollments increased rapidly in the late 1960s and early 1970s as the baby boom generation grew up. With the help of Federal aid, especially programs authorized by the Higher Education Act of 1965, a larger proportion of high school graduates went on to college. Federal and State financial aid has been awarded primarily on the basis of financial need, regardless of the planned or declared major of the student.

- Link part of existing need- or merit-based college student aid programs (for example, Pen Grants) to field or institution of study. Certain groups, such as women, minorities, or talented and disadvantaged students, could be targeted.
- Create new programs to support science and engineering students regardless of need.

Federal financial aid is a powerful lever on students aspiring to college educations. This lever could be used to influence the field distribution of undergraduates. The tradition of egalitarian aid based on need and respect for individual choice, regardless of institution and field of study, must be weighed against the possible national benefits of directing more or selected students into certain institutions or fields (for equity, personnel, or institutional development goals). Federal aid linked to field is accepted as necessary support of graduate students and as a way to meet national needs; field-linked personnel training (at both the undergraduate and graduate levels) as a justification for Federal involvement can be traced to the Merrill Act.

There is a circularity to the Federal role in career choice and market demand: indirectly the Federal Government affects the market, without affronting individual freedom of choice. Should it explicitly set priorities on the supply side as well? One option might be for any or all agencies that support college students–Federal, State, or private—to award some or all need-based aid by planned or declared field of study. Congress might direct the Department of Education to consider field of study in offering and awarding need-based aid. (NSF's undergraduate programs already do this to some extent, but they are merit- rather than need-based, and very few in number.) This might be done in the junior or senior year, when fairly reliable near-term market demand for those students can be projected. However, most students will have made their choices of major by this time.[14]

[14] The most prudent course would *be to adjust aid at the broad* field *level (that is, science and engineering versus other fields) rather than to specific fields of science or engineering. The former builds a stock of human resources; the latter favors certain disciplines and skills within the stock.*

RECRUITMENT POLICY OPTIONS

The basic goal of recruitment is to expand and improve the talent pool. The years to do this are elementary school through the first few years of college. A particularly critical time is 6th through 12th grade, when course-taking becomes more specialized and career plans are formed. Policies to expand the mathematics and science talent pool differ from those to accelerate or improve the education of a small core population. Students who take early, enthusiastic likings to science and mathematics can be served differently from those whose interests are still developing.

For all students, the content and quality of their elementary and secondary education determine their academic preparation for college, their likelihood of entering college, and their ability to derive the greatest benefit from a college education. Better high school graduates mean better college graduates, and ultimately better scientists and engineers. Significant changes must occur in students' early preparation, awareness, and interest before they are drawn into college and science and engineering majors, and eventually to graduate and R&D programs. The continuing low participation in science and engineering of women and minorities indicates that the current educational system and career incentives must be made to work better.

There are two demonstrably successful ways to recruit young people to science and engineering: give special science and mathematics enrichment programs to selected students, and give all students good, enthusiastic teaching. An area of lively innovation is informal education—science museums, television programs, camps, and other experiences outside the formal school system.

In the near term, policies must work with existing teachers, schools, textbooks, and equipment, in a system with multiple educational objectives. Truly significant change is difficult to achieve incrementally. In the longer term, substantial improvements in recruitment might come through full-scale revision of elementary and secondary curricula, tracking, testing, and course structure. Such sweeping change should be undertaken with all students and all purposes of education in mind (not just science and engineering), but would be hard to achieve given the scale of American education and the inertia of the existing system.

1. Encourage Intervention Programs

"Intervention programs," within or outside of schools, can increase participation in science and mathematics by raising students' interest, opportunity, and academic readiness for science or engineering majors. Such programs are especially useful with students at greater risk or disadvantage in regular classrooms and curricula.

Most effective programs involve learning science by doing, rather than through lectures or reading; working closely with small groups of other students; contact with attentive advisors, mentors, and role models who foster self-confidence and high aspirations; and exposure to career information. Most programs work at the junior high and high school levels. Many have great success in sending participants on to college and to science and engineering majors. Programs vary greatly in duration, intensity, and expense; they range from fill-time summer research projects to occasional career seminars. The goal of most college-level programs is to help students complete their chosen science or engineering degrees. In addition to peer support and academic enrichment, college-level programs often sponsor scholarships, jobs, or research related to participants' majors.

- Fund new, ongoing, and expanding intervention programs for students defined in various ways: female, minority, learning disabled, handicapped, gifted, and talented.
- Encourage private investment in intervention programs, with matching incentives for Federal, State, and local government participation.
- Encourage Federal research agencies to participate in outreach programs.
- Gather and disseminate information on intervention and on its lessons for formal education.

The often impressive success of intervention programs argues strongly for Federal financial and other support. These programs are labor-intensive, but not extremely costly. At the precollege level, annual budgets are usually several hundred dollars per student. College-level intervention programs, often including costs for scholarships, may budget as much as several thousand dollars per participant. They are easy to mount and evaluate on a trial basis, but rely heavily on gifted and determined teachers. The main issues are the extent to which funding intervention programs "compete" with funding for regular education; where and to what extent Federal support is warranted, given the extensive State and private activity; and the groups to be targeted.

Most intervention programs serve limited populations, especially the needs of girls and disadvantaged minority children.[15] A few enrich the education of "academically gifted" children, traditionally a fertile source of scientists and engineers. Greater investment in gifted students would likely increase the quality and quantity of science- and engineering-inclined students. Broadening the ways "giftedness" is defined could produce a more intellectually diverse pool of students than is presently created by the use of aptitude tests. A possible Federal role is to help identify students who could benefit from special programs, but who are not being served, and then to let the interventions take over. Most intervention programs reach only a few students; a local program may reach 30 to 150 students each year. A few of the most successful programs have received substantial support from State governments and foundations and have expanded their reaches statewide, and in some cases nationwide, to thousands of students.

Intervention cannot compete with or replace the regular classroom. The long-term goal is to change the mainstream school system so that it promotes success for all children in science and mathematics. Intervention programs can exist side by side with diverse public and private schools, providing alternatives, experiments, and enrichment outside the classroom, as well as offering lessons for improving formal education.

2. Bolster Elementary and Secondary Teaching

There are no substitutes for good teachers. Education reform depends on getting better teachers and giving them better support, in the forms of curricula, textbooks, mathematics and science supervisors, equipment, preparation time, and training. From kindergarten through graduate school, it is the teacher who inspires or turns off the student.

- Increase support to improve preservice and in-service teacher training.
- Offer financial incentives and other rewards to science and mathematics minority teachers (through awards, forgiveable loans for aspiring teachers, a separate merit pay scale, or supplementary allocations to hire specialists).
- Increase support for enrichment programs for teachers, sue-h as research participation at Federal laboratories.

The quality of teaching and teachers is a perennial issue, as old as American schools. Although all fields need good teachers, mathematics and science face particular difficulties because of the rapidly changing nature of the material, the desirability of augmenting classroom instruction with laboratories, and the stiff competition teaching faces in attracting qualified science and engineering majors away from R&D careers. An imminent problem is a shortage of minority mathematics and science teachers.

A controversy in mathematics and science teacher training is whether future teachers should be expected to have a baccalaureate degree in specialist subjects in addition to some education training. Many elementary school teachers earn baccalaureate degrees in education, with only parts of their programs devoted to specialist mathematics and science courses.[16]

Several groups active in the current reform movement have studied the future of the teaching profession. The Holmes Group (an informal consortium of education deans in research universities) has attached particular priority to upgrading elementary and secondary teachers' subject-specific knowledge by insisting that they have a baccalaureate in a subject area. The group has called for much more subject-specific teaching, and for more subject-intensive preparation of those teachers. *7 Parallel-

[15]Attracting and sustaining the interest of girls in mathematics is a recurrent theme in many intervention programs. The opportunity to experience mathematics in the presence of other girls seems to change the learning process, remove the stigma attached to excelling in school mathematics, and feed self-confidence and determination. Such a transformation will have to occur if more girls, presently the largest untapped resource in the talent pool, are to entertain the possibility of careers in science or engineering.

[16]For example, virtually all elementary mathematics teachers and elementary science teachers have a degree in a subject other than mathematics or science. At the high school level, however, 40 percent of mathematics teachers and 60 percent of science teachers have a degree in those subjects, and another 36 and 24 percent, respectively, have either a degree in mathematics and science education or a joint degree, i.e., one that combines a mathematics or science field with science or mathematics education. See Iris R. Weiss, Report of the 1985-86 National Survey of Science and Mathematics Education *(Research Triangle Park, NC: Research Triangle Institute, November 1987), table 45.*

[17]Holmes Group, Inc., Tomorrow's Teachers *(East Lansing, MI: 1986). So far, only Texas has reformed its certification requirements in this way. Starting in 1991, new entrants to the profession will need*

ing these developments, the National Science Teachers Association and the National Council of Teachers of Mathematics both require considerable amounts of subject-specific coursework of applicants for their own voluntary certification programs. Most important is the content, not the labeling, of the courses that students training to become teachers take (such as mathematics education), but the long-term trend is to emphasize specific skills for specific subjects rather than an all-embracing "education" approach.

Two issues face the Federal Government: to what extent and on what basis does it enter the debate over what has traditionally been a State (and local) prerogative; and how does it spend money effectively on what works. A large part of the difficulty facing the Federal Government or any other actor trying to improve teaching is that society does not attach great distinction or reward to teaching. It is not certain to what extent higher salaries, merit pay, and other financial incentives attract and keep better teachers. While some teachers leave teaching because of low pay, many more probably leave because of poor working conditions. Teacher salaries have risen significantly since the education reform efforts of the early 1980s, although they continue to lag other professions. Indications are that with national laments over a teaching '(crisis" and "quality," incentives of merit pay and boosts in salaries and responsibility for teachers in many school districts have increased student interest in teaching careers.

The Federal Government has supported, especially through NSF summer institutes, inservice training for mathematics and science teachers. Current inservice training is limited in scale and can do only so much. While the teaching force is well-qualified and informed about the most effective teaching techniques, it often fails to use them. Boring textbooks are widely used in unimaginative ways. Teachers are not encouraged to use techniques such as hands-on science. Teachers' training does not always couple pedagogy to subject knowledge.

The main needs are:

- to determine what makes for good inservice and preservice education;
- to give the current teaching force much more inservice education than it currently receives;
- to give the current teaching force better access to research results and curriculum reform efforts;
- to impose a science and mathematics education requirement on new science and mathematics teachers, as part of State certification; and
- to recognize that elementary and secondary teachers have different problems and needs.

Finally, accountability pressures on teachers must change to encompass process and not just outcomes. "Teaching to the test" has been emphasized in many schools at the expense of broader educational objectives. Schools, teachers' unions, States, school districts, and the colleges and universities that train teachers must share responsibility for measuring accountability.

The Federal Government has some limited influence over teacher training through support for undergraduate education and through NSF programs in teacher preparation and enhancement. Two existing avenues could be used to bolster mathematics and science teaching: Title II of the Education for Economic Security Act ($80 million annually) and National Science Foundation programs ($22 million annually). NSF's Teacher Enhancement Program needs to be expanded and should continue to emphasize science and mathematics pedagogy together with content. Through inservice training and alternative certification, the teaching ranks could be opened to those with mathematics and science expertise who lack teaching degrees.

Current Federal support for inservice training totals about $160 million per year, reaching perhaps 10 to 35 percent of science and mathematics teachers. Other mission agencies reach a small number of teachers through a variety of programs. Additionally, of Federal education block grants for curriculum and staff development, OTA estimates that around 25 percent, or $10 million per year, go to science and mathematics teaching. *8

to *have both a subject-specific degree and a maximum of no more than 18 course-hours in education. Lynn Olson, "Texas Teacher Educators in Turmoil Over Reform Law's 'Encroachment'," Education Week, vol. 7, No. 14, Dec. 9, 1987, p. 1.*

[18]In contrast, during the heyday *of the* National *Science Foundation's science and mathematics summer institutes, the* 1960s, *Federal spending on teacher training was about $60 million annually (in* 1960s *dollars) and reached, over the decade, perhaps half the science teachers in America.*

3. Support Informal Education

Education and exposure to science outside of school offer alternative ways to get children interested in science. By augmenting classroom learning, science and technology centers—at least 150 in the United States alone—are excellent places for motivating interest in science. Science centers also conduct teacher training, especially for elementary science teachers. Many audiovisual techniques, especially science on television, are powerful teaching vehicles. Learning and research projects at camps and science fairs also reach children by offering a variety of sciences that cannot all be explored in the classroom. Together these sorts of experiences are known as "informal education."

- Increase funding of science and technology centers, particularly for education and teacher training.
- Increase funding of science television and other experimental teaching methods.

In terms of the supply of future scientists and engineers, science centers are excellent at motivating, but not at enhancing formal learning. Their contribution is more for enlarging the pool at an early age. Outreach programs are increasing access to science centers by minority and disadvantaged students, and minority teachers.

Current annual Federal support of informal education is about $13 million to $20 million for a variety of programs funded by NSF and the Department of Education. In addition, about $90 million to $100 million per year goes to science-related Smithsonian and National Zoo museum and education programs. Other actors are local communities, States, industry, and museum visitors (who pay to attend). Communities are quite successful at initiating the operation of centers; a possible Federal role is to capitalize on this success for education.

4. Improve Opportunities for Women

Women have made significant inroads into science and engineering over the past 15 years, on the heels of equal opportunity activism and legislation. This progress varies greatly by field; women are a substantial proportion of biologists and social scientists, but are still scarce in engineering and the physical sciences. Overall, women's interest in earning science and engineering degrees seems to be plateauing. This fact causes congressional concern, not only for reasons of equity, but because women could substantially augment the research work force if their interest in research careers burgeoned. Several factors combine to turn women away from science: pervasive, accumulating societal bias at home, in school, and among friends against the notion of girls as good science and mathematics students and against women as research scientists and engineers; difficulty juggling family responsibilities with graduate education and especially research; the disincentives of the often second-rate career opportunities and salaries for women in science and engineering; and weaker academic preparation than men through secondary school and college, particularly in science and engineering (which, to some extent, is a function of the first two factors).

Raising women's interest in science and engineering careers could go far toward compensation for the projected decline in bachelor's recipients in these fields. The research potential of women is great, though they still face pervasive social and economic barriers.

- Enforce more stringently Title IX of the Education Amendments of 1972 and other equal opportunity legislation.[19]
- Support intervention programs for women at all levels.
- Fund special fellowships and undergraduate research opportunities for women.

Federal legislation, in particular Title IX of the 1972 Education Amendments, has provided leadership, law, and most importantly a national commitment to sex equity, and has impelled substantial so-

[19] Title *IX prohibits sex discrimination in education. Other related Federal legislation includes:*

- *The Women's Educational Equity Act of 1972 supporting dissemination of model materials that promote women's educational equity;*
- *Title IV of the 1964 Civil Rights Act providing support to States (and originally to local education agencies and training institutes) to comply with Federal laws prohibiting discrimination in Federal programs; Title VII of this act prohibits discrimination on the basis of sex; and*
- *Cad D. Perkins Vocational Education Act of 1984 requiring States to set aside funds for programs for women.*

See Patricia A. Schmuck, "Administrative Strategies for Implementing Sex Equity," Handbook for Achieving Sex Equity Through Education, Susan S. Klein (cd.) (Baltimore, MD: The Johns Hopkins University Press, 1985), pp. 119-120.

cial and economic changes. Title IX eliminated overt discrimination and encouraged equitable treatment of men and women both inside and outside education. The greatest gains of women in science (and other traditionally male professions) were made during the early days of Title IX, during broad interpretation of the legislation, vigorous enforcement, national leadership, and social fervor.

Since its passage, enforcement of Tide IX has lessened, grant support for its implementation under the Women's Educational Equity Act has been reduced, and its applications have been narrowed by Federal and court rulings.[20] Inequitable access and discrimination still exist in education and research, as in the rest of society.

The past clear success of Tide IX in reducing discrimination and encouraging women to enter nontraditional fields argues that, to encourage further participation of women in science and engineering, the Nation recommit itself to equity and enforce Title IX and related legislation.[21] Rigorous enforcement is essential to eliminate barriers to careers for women in science and engineering as in other fields. This should require little new funding; most of the achievements of Title IX were made through changes in practice rather than Federal appropriations for new programs.

In addition to sex equity and civil rights legislation, the Department of Education, NSF, and mission R&D agencies also are charged with awarding fellowships and research grants equitably. Equity is part of a Federal package that also includes support of effective programs discussed earlier, especially intervention programs for women at all levels, and special fellowships and undergraduate research opportunities for women.

5. Improve Opportunities for Minorities

In comparison with women, non-Asian minorities (particularly Blacks) have made little progress in science and engineering education and careers. Only in the social sciences and health-related fields are there significant numbers of Black or Hispanic researchers. The civil rights victories of the 1960s and the resulting legislation raised awareness and launched programs, but entrenched social and economic barriers still deter many Blacks. Equal opportunity for participation in higher education and in research for all groups is a long-term social goal that will be achieved only with steady national commitment and investment.

- Enforce more stringently civil rights legislation.
- Expand support of intervention programs, particularly at the precollege level. Redistribute support for intervention programs among the Department of Education, NSF, and the mission agencies.
- Move the Minority Institutions Science Improvement Program from the Department of Education to NSF, which knows how to target and spend "science dollars" fruitfully.
- Support the HBCUs in all ways, from infrastructure to faculty and student assistance.

Title VI of the Civil Rights Act of 1964 prohibits discrimination on the basis of race, color, or national origin in federally-funded programs. Enforcement timetables and procedures by the Department of Education were mandated by *Adams v. Califano (1977), and* by *Adams v. Bell (1983)*, but enforcement by the Department of Education's Office of Civil Rights and the Department of Justice has been lax.[22]

[20] In 1984, the U.S. Supreme Court ruled in *Grove City College v. Bell* that Title IX applied only to the specific program that was federally funded, not to the entire institution that housed the program. Repeated legal challenges from women's and education interest groups have cited lax enforcement of Title IX by the Department of Education. Recent legislation has restored the original intent of the civil rights legislation.

Funding for model education programs under the 1974 Women's Education Equity Act and for technical support for compliance under Title IV of the Civil Rights Act declined substantially in the 1980s. Funding for the Department of Education Office of Civil Rights has declined. See Phyllis W. Cheng, University of Southern California, "The New Federalism and Women's Educational Equity," doctoral dissertation, December 1987, pp. 44-51.

[21] About half the States have laws that cover part or all of Title IX; of these, 13 have broad gender equity laws similar to Tide IX. State Title IX officers cite Federal Title IX legislation as more important than State legislation in achieving educational equity. "State sex equity in education laws are merely an addition to existing Federal provisions, not a replacement for them. " See Phyllis W. Cheng, Project on State Title IX Laws, Los Angeles, CA, "Can Educational Equity Survive Under the New Federalism?" unpublished manuscript, November 1987, pp. 14, 16.

[22] U.S. Congress, House Committee on Government Operations, *Failure and Fraud in Civil Rights Enforcement by the Department of Education* (Washington, DC: U.S. Government Printing Office, 1987). Also see Scott Jaschik, "Civil-Rights Groups Assail U.S. Ruling That 4 States Comply With Bias Laws," *The Chronicle of Higher Education*, vol. 34, No. 23, Feb. 17, 1988, pp. A 1, 24.

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6. Invigorate Elementary and Secondary Education

Policy initiatives to modify the structure of elementary and secondary education must be long-term, systemic measures. Reform in several areas—magnet schools, science-intensive schools, curricula and course-taking, tracking, and testing—could substantially improve and extend precollege science and mathematics education. Many have tried to improve education by changing some of its basic components, such as the school calendar, curriculum, teaching practices, class size, textbooks, grade promotion, and structure of the schools themselves. Many of these innovations have benefited the children they reached; much has been learned from the failures as well. However, most education reform makes little lasting difference. Most innovations, such as magnet and science-intensive schools, reach only a few percent of students. Even reforms in curricula and testing, which have the potential to reach all students, in practice reach only a few because of the dominance of the existing course structure and tests. The education system is large, with current practices and incentives firmly established.

The areas discussed here hold great, albeit uncertain, potential for the quality of science and mathematics education. Pursued at their current level and without accompanying changes in the education system that must adopt such reform, they can have only limited impact on limited numbers of students. Realizing the full potential of these reforms would require full-scale renovation of the existing system, from teaching and testing to course structure and content, with the substantial uncertainty and political challenges such an initiative would raise. Such full-scale reform would undoubtedly have. unexpected impacts on education, far beyond science and mathematics education. As a result, while such reform is desirable given the dismal state of U.S. elementary and secondary science and mathematics education, it should be pursued incrementally and carefully, but vigorously.

Magnet Schools.–Magnet schools are designed to desegregate school districts by offering special courses of study that attract students of different races. About one-quarter of these special schools emphasize science, mathematics, computer science, and pre-engineering. Magnet school programs are devised and operated by local school districts. They are funded by States and school districts. To support the special costs entailed in the process of racial desegregation, the Federal Government has also funded such programs, but the main actors are States and school districts.

Many science and mathematics magnet schools provide high-quality mathematics and science instruction for those enrolled in them. Many emphasize hands-on learning. Magnet schools probably sustain those students who are interested in science and engineering, and deter those who are not interested. Magnet schools increase the racial and ethnic diversity of science and mathematics students by bringing courses to science-starved areas, and by sorting students by their enthusiasm as often as by achievement. Magnet schools may socially set science and mathematics students apart from the rest to create a climate of intellectual support by peers and teachers. These schools also cost somewhat more than routine schooling.

The Federal Government could promote magnet schools on a basis other than that of racial desegregation (as is already proposed). Promoting magnets would probably improve the quality and variety of students planning science and engineering careers, but would not much increase the number of interested students. Current Federal support of magnet schools is about $75 million annually from the Department of Education, under Title VII of the Education for Economic Security Act, awarded competitively to a very limited number (less than one-half of 1 percent) of the largest school districts.

Science-Intensive Schools and Other Experiments.—The academic environment of special high schools can provide students interested in science and mathematics with excellent educations, and give them early exposure to and encouragement in research careers. They are powerful environments for the few students they serve. Such science-intensive programs and schools are State showpieces, demonstrating the virtue of encouraging the best and most eager. However, they reach only a tiny fraction of students.

Alternative social organizations of schools are also possible. For example, academically-bound students from several high schools could be brought together in one school or during the summer. Universities or community colleges could take over grades 11 and 12, and provide instruction at public expense. It is not clear that Federal support is needed, since States seem to be forging ahead; more appropriate Federal roles might be research and technology transfer.

Course-taking.–Taking advanced science and mathematics courses in high school is crucial to prepare students for science and engineering majors in college. But failure to take such courses in high school should not bar students from later participation in science and engineering. Community colleges and universities are offering more stepping-stone preparatory and remedial courses. Such alternative course-taking places additional and generally unwelcome burdens on universities and may unduly discourage course--taking in high school, although the number of college-level high school courses (for example, advanced placement calculus) is rising. Access to such advanced courses by many students, particularly those in inner-city and rural schools, is limited. Finding a better "math path" for the majority of students is essential. Removing the stigma of succeeding in such courses, especially among girls, and linking interest in mathematics with aspirations to a science or engineering career are central to improving course-taking patterns.

Taking more advanced courses (assuming they are taught well) probably enhances the quality and increases the number of students available for science and engineering majors. Imposing course requirements, however, puts a burden on teachers who may not be qualified, and may undermine provision of other good opportunities, such as hands-on experiences.

Access to more courses by more students does not automatically produce more learning or interest. The issue is whether to offer, recommend, or *require* more science and mathematics courses in high school. The proper balance lies somewhere between building on existing interest and fostering it through mandatory exposure.

Recognize the Strengths and Weaknesses of Tracking.– Given the continued existence of comprehensive education to age 18, differentiating and sorting of students by abilities, interests, and preparation are inevitable. Some form of tracking is practiced everywhere, but its potency and rigidity are declining. In mathematics and science, tracking favors those who show early, recognizable academic talent and are selected into the college-bound, mathematics- and science-intensive path of the academic track. When practiced from an early age, tracking erodes the self-confidence of lower-tracked students and can cramp academic potential, often suppressing the expression of talent when applied too rigidly.

The need is to break down the rigidity of tracks, build pathways between them, and improve the sorting of talent between tracks. Tracking based exclusively on IQ and multiple-choice achievement tests

Photo credit: William Mills, Montgomery County Public Schools

The curriculum development projects funded by the National Science Foundation in the 1960s, such as this one in physics, have generally proved to be successful, but only when teachers have been well trained and supported in the use of the new materials.

penalizes some groups of students. Although the alternatives lie in the hands of schools and teachers, the Federal Government could do the following:

- provide incentives, including financial ones, for school districts to improve the efficiency of sorting between tracks and to use better techniques for identifying potential talent; and
- continue to fund and disseminate research on tracking, and its particular effects on mathematics and science instruction, and on women and minorities.

Revise Testing Procedures and Tools.–The current national system of testing, which relies on standardized multiple-choice questions, is simple to administer, inexpensive, and is seen as largely scientifically objective. It has many harmful effects, however. It puts pressures on teachers to "teach to the test," and on students to learn for the test, emphasizing parrot-like repetition of facts at the expense of so-called higher-order thinking skills. It appears also to discriminate against those not exposed to certain courses and lacking test-taking skills. In mathematics and science, it emphasizes the contemporary belief that science is a system of facts to be memorized, rather than a system of tentative beliefs and a framework for understanding natural phenomena.

Testing could be improved by emphasizing:

- written responses, as well as multiple-choice questions;
- higher-order thinking skills, i.e., deductive and lateral thinking;[23]
- oral skills, using oral tests; and
- experimental and deductive skills, by doing experiments and practical manipulations in examinations.

The most likely Federal role in testing reform is supporting research on alternative forms and uses of testing, and in disseminating "better" tests. Refinement of the National Assessment of Educational Progress should continue, with special emphasis on eliminating any gender and ethnic biases and a search for more useful, wide-ranging test instruments.[24]

[23] The *National Research Council's Committee on Indicators of Precollege Science and Mathematics Education has proposed a national research center to facilitate the creation of student and teacher tests, especially measures of the higher-order thinking skills of students in kindergarten through grade five. These would augment, if not replace, multiple-choice tests. See National Research Council,* Improving Indicators of the Quality of Science and Mathematics Education in Grades K-22 *(Washington, DC: National Academy Press, 1988).*

[24] See *FairTest Examiner, "FairTest Wins NAEP Reforms: More Problems Remain," winter 1988, p. 3. The National Assessment of Educational Progress has already begun testing of hands-on skills in science.*

MANAGEMENT OF FEDERAL SCIENCE AND ENGINEERING EDUCATION

Federal agency leadership and interagency coordination are needed to raise the visibility of science and engineering education. The collection, dissemination, and use of data for evaluating outcomes and developing new programs are essential for improving the reach and content of science and engineering education.

1. Strengthen National Science Foundation Leadership in Science Education

Federal responsibility for the long-term health of the system of science education, from the early grades through postdoctorate study, rests in the hands of NSF. NSF has been the lead agency, ever since its inception, in Federal initiatives to improve science education, and has administered most Federal science and engineering education programs. Such programs form part of NSF's overall mission to support the education and training of research scientists and engineers and to promote basic research.[25]

Under its broad charge, NSF has supported, largely through the Science and Engineering Education (SEE) Directorate, a range of efforts to im-

[25] The National *Institutes of Health spend* more on such *Programs than the National Science Foundation does, although this funding is concentrated on graduate and postgraduate education. Other agencies also spend significant sums on education programs, primarily in order to interest young students in scientific and engineering careers or to channel students into particular fields.*

prove precollege and college science and mathematics education including:

- teacher institutes;
- curriculum development;
- student research;
- research, evaluation, and testing of advanced teaching technologies; and
- encouragement of partnerships among business, industry, professional associations, civic groups, and local schools to sustain the above activities.[26]

In addition, NSF has supported the familiar graduate fellowships, RAs, and traineeships administered by the research directorates.

Having a strong, central, competent, committed administrative home is crucial to the implementation of Federal science education programs. In addition, because of the local nature of American education, a visible national focus is important to provide leadership to support, inform, and capitalize on the many local initiatives that dominate American education. At NSF, with its commitment to the basic research community, the traditional emphasis on research and graduate education has been largely divorced from its elementary, secondary, and undergraduate education programs.

- Reinforce NSF's role as lead agency for Federal science and engineering education activities by altering NSF's administration of these activities.
- Require NSF to employ more staff experienced in the practice of elementary and secondary education in schools, school districts, and State education agencies, rather than those recruited from research environments in higher education.

There is no single home or central coordination for human resource programs at NSF. In addition to the SEE Directorate, considerable funds are spent by the other directorates on education and human resource programs and by research grants that fund RAs. NSF regards teaching and research to be inseparably related activities at the higher level of the education system, and is sensitive to the variability of educational problems from discipline to discipline. Thus, NSF considers it best for the research directorates to control programs with joint educational and research objectives.

Consider the main types of NSF programs that contribute to science and engineering education:

- direct support of educational initiatives, such as teacher institutes, curriculum development, and fellowships;
- support for research activities that have educational benefits, such as research projects in general or research participation by particular groups (such as undergraduates, high school students, or teachers); and
- support to enhance the opportunities for certain populations and types of institutions to do high-quality research through grants designed to improve or sustain research capability.

Taken together, support for these activities is often labeled as being for "Education / and Human Resources." NSF's fiscal year 1988 spending for programs of this kind will be over $350 million, of which $139 million is spent through the SEE Directorate. The difference between these two sums arises from the education and human resource spending of the research directorates, which includes programs in undergraduate science education, the Presidential Young Investigator program, and other programs intended to provide seed and institutional research support for either specific groups of researchers or institutions. Even then, NSF's designation of Education and Human Resources does not include the amount of NSF research awards that is spent on providing RAs to graduate students (an estimated $120 million in fiscal year 1988). At the precollege level, the research directorates spend nothing, so all of that funding comes from SEE. Table 4-4 indicates the distribution of these funds by educational Ievel, showing that the bulk of the broad category of "Education and Human Resources" funds goes to graduate and postgraduate education.

NSF spending on science and engineering education through SEE has fluctuated (see table 4-5, for fiscal years 1983-1988). Its golden years were the late 1950s and early 1960s, when never less than one-third of NSF's total budget went to its SEE Directorate. In later years, although SEE spending increased (reaching a peak of $134 million in fiscal year 1968), overall NSF spending rose even faster, giv-

[26] Ben Brodinsky, *Improving Math and Science Education: Problems and Solutions* (Arlington, VA: American Association of School Administrators, 1985).

Table 4=4.—National Science Foundation Fiscal Year 1988 Spending and Fiscal Year 1989 Requested Funding for Education, by Level of Education (In millions of dollars)

	Funds from the SEE Directorate		Funds from other Directorates	
	1988	1989	1988	1989
Precollege	$90.0	108.5	0	0
Undergraduate	19.0	23.5	21.0	41.4
Graduate fellowships, etc.	30.3	24.0	2.5	2.7
research assistantships	o	0	119.0	125.0 (est.)
Postdoctoral, including Presidential Young investigators	0	0	52.9	58.7
Research initiation and broadened participation in research	o	0	22.7	27.0
Totals	$140.3	156.0	217.1	255.0

SOURCE: Office of Technology Assessment estimates based on personal communications with the National Science Foundation, Office of Budget, Audit, and Control, 1988.

Table 4=5.—Requests, Appropriations, Spending, and Unobligated Funds for the National Science Foundation's Science and Engineering Education Directorate, Fiscal Years 1983-88 (in millions of dollars)

	Fiscal years					
	1983	1984	1985	1986	1987	1988
Request	$15.0	$39.0	$75.7	$50.5	$89.0	$115.0
Appropriation	30.0	75.0	87.0	55.5	99.0	139,0
Actual spending	16.0	57.0	82.0	[a] 84.0	99.0	
Unobligated (carried forward)	14.0	32.0	32.0	–	–	

[a]In fiscal year 1985, $5 million was transferred by the Science and Engineering Education Directorate to the Biological, Behavioral, and Social Sciences Directorate for support of a program on Research in Teaching and Learning.

SOURCE: Laurie Garduque, "A Look at NSF's Educational Research Budget," *Educational Researcher*, June-July 1987, pp. 18-19, 23. Based on *National Science foundation Budget Summary, Fiscal Year 198.3* (and annual volumes through 1988).

ing education a declining share. After fiscal year 1968, SEE spending fell every year until 1974, and held level in the 1970s at about $60-$80 million annually. In fiscal year 1982, the Reagan Administration attempted to cut out NSF's education spending altogether; at its nadir, the SEE Directorate funded only a reduced program of graduate fellowships. Since 1982, however, the SEE Directorate has slowly been resuscitated and will be funded at $139 million in fiscal year 1988. This appropriation, in actual dollars, is the largest ever in the history of SEE. The majority of SEE's spending is on K-12 programs.

Table 4-5 indicates that, in each year from 1983 to 1988, Congress appropriated between 10 and 100 percent more than NSF requested for the SEE Directorate. It also indicates that, in fiscal years 1982-1984, NSF did not spend all that it was appropriated and carried forward never less than 35 percent of each year's appropriation to the next fiscal year. Data on education spending in the research and related directorates appear in table 4-6. It is estimated that, in fiscal year 1987, NSF spent over $200 million on education in these directorates.

Persistent issues that arise in NSF's science and engineering education programs are:

- The balance to be struck between programs for the elite of potential researchers and the mass of science learners in schools and colleges who are less likely to become scientists. A recent congressionally mandated review urged that NSF "take the lead nationally in broadening the base

Table 4-6.—National Science Foundation Education Spending by the Research and Related Directorates, Fiscal Years 1982=87 **(in millions of dollars)**

	Fiscal years					
Level of education	1982	1983	1984	1985	1986	1987 (est.)
Postdoctoral	$43.0	$44,2	$51.0	$56.5	$56.0	$58.4
Graduate students (including RAs)	72.2	76.6	90.8	102.3	107.0	115.4
Undergraduate:						
Students	n.a.	n,a.	n,a.	7.9	8.0	19.5
Faculty	1.0	1,0	8.2	10.2	12.4	15.9
Totals	116.2	121.8	150.0	176.9	183.4	209.2

RAs = research assistantships.
n.a. = not available.

SOURCE: National Science Foundation Office of Budget, Audit, and Control; personal communication to Office of Technology Assessment, January 1988.

of science learners as their primary mandate rather than 'skimming the cream'."[27]

- The coordination of NSF education programs. Education groups, such as the National Science Teachers Association, urge that all funding for K-12 and undergraduate science and engineering education should be coordinated under a single head. NSF argues that the unique nature of advanced education in the sciences and engineering, which involves the union of teaching and research, means that some education functions are best conducted through the research directorates.
- Concern that the research-oriented culture of NSF skews the operations of SEE and other science education activities, and discourages SEE from undertaking any kind of replication of successful programs in favor of one-of-a-kind "experimental" research projects.
- Concern about transfers of funds from SEE to the research directorates, to be spent on research rather than education. Other than a $5 million transfer in fiscal year 1985 for a program of research in teaching and learning, there is no evidence that such transfers have occurred.

As it stands, particularly in the undergraduate area, science and engineering education appears to gain a bonus from the education programs conducted in the research and related directorates. In the case of undergraduate science education, NSF has created a new Office of Undergraduate Science, Mathematics, and Engineering Education to coordinate activities from all across NSF. Because NSF does use funds from research directorates to fund science and engineering education, there is a danger that any increases in the annual appropriation to the SEE Directorate will merely displace spending from the research directorates and not lead to a net increase in science and engineering education spending. For example, in fiscal year 1988, some activities, such as undergraduate curriculum reform efforts that were to be funded through the research directorates, will be funded through SEE (although the funding will still be controlled largely by the relevant research directorates). In fiscal year 1988, such reallocation of spending will only amount to a few million dollars.

Given the history of science education at NSF, some believe that its priority will be assured only by creation of a separate board, patterned on the National Science Board. Such a board would oversee all science education activities. Whether this board would be of status equal to the National Science Board, and how its decisionmaking and budget authority would be reflected in a revised table of organization for the National Science Foundation, are just two issues that deserve serious congressional consideration. A separate board would ensure that funding for science and engineering education and other human resource programs is centrally coordinated through the SEE Directorate, rather than being dispersed across the research directorates of NSF.

[27] Michael S. Knapp et al., *Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation*, vol. 1 (Menlo Park, CA: SRI International, June 1987), p. 6.

2. Improve Federal Interagency Coordination and Data Collection

Coordinating related programs among Federal agencies is a perennial problem in all mission areas, not just education and research. To facilitate coordination, information sharing, and to avoid fruitless duplication, Congress has mandated various forms of organized consulting mechanisms, such as interagency coordinating committees. Ad hoc, informal communication among colleagues—telephone calls, meetings, etc.—is as important as formal communications. Coordinating committees have been most commonly used in areas undergoing significant change, such as areas of new Federal involvement and regulation, or with important public or foreign policy interest (such as biotechnology). In science and engineering education, there seems to be no such motivation for extensive formal coordination. Congress could change the tone, if not the motivation, for interagency coordination.

Using the unique aspects of the education programs sponsored by the mission agencies could be an essential part of coordination. Regional laboratories and centers often develop close ties to local schools and universities. Mission R&D has an inherent attraction to youngsters (for example, space, aeronautics, and nuclear power) lacking in the basic research that NSF funds. The mission agencies also monitor and analyze their personnel needs, as in the Department of Energy-supported data series on energy-related manpower. (Although not a Federal agency, the Institute of Medicine likewise sets a high standard with its analysis of biomedical and behavioral research personnel supply and demand.)[28] Such planning may be easier to do in a narrow, applications-oriented field than for science and engineering as a whole.

Mission agencies should have the authority and funds to capitalize on their strengths, including science education. Often they must scavenge education money from research programs. NSF is needed to ensure the renewal of the research work force for basic, long-term research; the mission agencies need to handle their shorter-term, more volatile science and engineering personnel needs.

There is also no comprehensive and systematic summary of all Federal science and engineering education programs. Many Federal agencies involved in scientific and engineering activities have education programs, but these programs are not centrally coordinated. The National Science Foundation collects and publishes reliable data on the funding provided by each Federal agency for R&D at universities and for support of graduate students. These data also include funding for instructional equipment. Although NSF has historically been the lead agency for science and engineering education programs, more funds for such programs are provided by NIH than by NSF.

- Raise the level and visibility of interagency planning and coordination of science and engineering education programs. Foster informal exchanges of ideas and information among NSF, the Department of Education, and the mission agencies. Establish a Federal coordinating committee on science and engineering education among these agency representatives.
- Attach higher visibility to science and engineering education programs (and possibly expand them) in R&D mission agencies by requiring reports or by giving such education programs line items in budget proposals.
- Require NSF to assemble a biennial report on the overall state of Federal programs in science and engineering education. Or ask the Office of Management and Budget to do a special budget analysis on Federal science and engineering education, which would tabulate the net result of all types of programs, categorized by level of education and the destination of funding (including students, faculty, and institutions).
- Support data collection, analysis, and dissemination at the Department of Education and NSF, especially longitudinal studies.
- Redivide NSF and Department of Education data responsibilities by mandating reports, allotting budgets, and requiring the Department to collect science and engineering education data.

[28]U.S. Department of Energy, *Energy-Related Manpower 1986* (Washington, DC: annual); and Institute of Medicine, *Personnel Needs in the Biomedical and Behavioral Sciences 1987* (Washington, DC: biennial).

- Continue to revamp the National Center for Education Statistics.[29]
- Improve the use of education data, in particular, information dissemination and technology transfer of successful research and practice. Expand the Department of Education's National Diffusion Network and support networking efforts (through agency funding of newsletters, professional societies, and conferences).

Department of Education Contributions

Occasional proposals have been made to move lead Federal responsibility for precollege science and mathematics education from NSF to the Department of Education. Proponents of such a step cite the massive funding that flows through the Department, and its extensive ties to local school districts and other education authorities. The Department of Education has been concerned mainly with the welfare of the education system as a whole. The large formula grant and student aid programs it administers already make substantial demands on its resources. As the agency most closely associated with the scientific research community, NSF has remained the administrative home of, and lead agency for, precollege science and engineering education.

At the undergraduate level, the Department of Education could enlarge its contribution through greater emphasis on science and engineering programs and students, for example, by using its resources to advertise and build on NSF pilot programs and research. The Department also administers programs to develop local activities in science and engineering education, primarily under Title 11 of the Higher Education Act of 1965. Such programs to support science and engineering dents as a population meriting special attention in the national interest could be expanded. But shifting primary responsibility to the Department, given the changes in mission, spending, and staffing that would be required, seems unwarranted at this time.

[29]National Research Council, *Creating a Center for Education Statistics: A Time for Action* (Washington, DC: National Academy Press, 1986).

Federal Programs: Data and Evaluation

Several studies have looked at the provisions of all Federal agencies for a particular aspect of science and engineering education,[30] and some agencies publish reports that describe their own programs.[31] Appendix B lists the major Federal science and engineering education programs along with their current levels of effort and estimated numbers of students or institutions served. While collating such information on a regular basis would take time and money, it might help Federal policymakers coordinate the regions, populations, and institutions affected by Federal programs and to identify groups that have "fallen through the cracks" of the different agencies. A one-time in-depth review of science, mathematics, and engineering education support, including the role of agency research programs in education, might also be fruitful.

The Department of Education and NSF have long collected data relevant to their respective missions—the Department of Education on the condition of elementary, secondary, higher, and vocational education, and NSF on higher education of research scientists and engineers.[32] Three national longitudinal studies have provided valuable information on students moving through the educational system.[33] NSF data and analysis on U.S. science and engineering is widely used and internationally emu-

[30]See, for example, U.S. General Accounting Office, *No Federal Programs Are Designed Primarily to Support Engineering Education, But Many Do*, GAO/PAD-82-20 (Washington, DC: U.S. Government Printing Office, May 14, 1982); and U.S. General Accounting Office, *University Funding: Federal Funding Mechanisms in Support of University Research*, GAO/RCED-86-53 (Washington, DC: U.S. Government Printing Office, February 1986).

[31]See, for example, U.S. Department of Energy, *University Research and Scientific Education Programs of the U.S. Department of Energy*, DOE/ER-0296 (Washington, DC: U.S. Government Printing Office, September 1986). The National Science Foundation collects extensive information on its own programs and publishes some of it.

[32]A 1987 Rand Corp. study to explore indicators for the performance of precollege mathematics and science education in the United States called for development of a comprehensive indicator system and offered several options for improving the National Science Foundation's current ad hoc data collection and analysis efforts. See Joseph Haggin, "Assessment of Precollege Science Training Probed," *Chemical & Engineering News*, Oct. 12, 1987, pp. 20-21.

[33]These are the National Longitudinal Survey (following the 1972 high school senior class), High School and Beyond (following 1980 high school sophomores and seniors), and the National Education Longitudinal Survey (beginning in 1988).

lated. In general, however, the production of statistical and evaluative information on education has declined noticeably in the last decade.[14]

Data help policymakers identify trends and evaluate the impact of programs. However, large amounts of new national-level data would be expensive and are not desperately needed. New data collection is a burden to Federal agencies and the information sources (usually schools and universities); education data from mission agencies should minimize new reporting requirements (information can be extracted from existing proposal and reporting data). Systematic evaluation of education programs would provide accountability and information on what works. (There are some models: at the precollege level, the Department of Education's *What Works* series, and in higher education, evaluations of NSF's Science Development Program and University-Industry Cooperative Research Centers.) Modest evaluation of student support mechanisms would also be useful. Better, more timely data based on careful survey and analysis design and budget allocation are needed. Even more pressing is better dissemination and use of the data that already exist.

Congress can continue oversight of data collection and management, the use of data in program evaluation and design, and be unflagging in its call for education data. The Federal Task Force on Women, Minorities, and the Handicapped in Science and Technology is another impetus for the Collection and analysis of information. Efforts such as this, in turn, should mobilize the research community, perhaps through umbrella organizations such as the American Association for the Advancement of Science,[35] to take a greater interest—as information clearinghouses and symbolic leaders—in science, mathematics, and engineering education. The Nation requires such a concerted effort.

[14] U.S. General Accounting Office, *Education Information: Changes in Funds and Priorities Have Affected Production and Quality*, GAO/PEMD-88-4 (Washington, DC: U.S. Government Printing Office, November 1987). Also see Marcia C. Linn, "Establishing A Research Base for Science Education: Challenges, Trends, and Recommendations," *Journal of Research in Science Teaching*, vol. 24, No. 3, 1987, pp. 191-216.

[35] For example, see American Association for the Advancement of Science, Office of Science and Technology Education, *The Continuing Crisis in Science Education: The AAAS Responds*, A Report to the Board of Directors (Washington, DC: 1986).