Education Programming at the National Science Foundation: A Fifty-Year Retrospective [1]

Norman L. Fortenberry
National Science Foundation

James J. Powlik
National Science Foundation

Maricel Quintana-Baker
National Science Foundation

Abstract

Since its inception, the National Science Foundation (NSF) has supported two distinct yet interwoven missions: research and education. Education has been especially affected by changes in ideology, economic trends, and new technologies. Cogent lessons from this experience reveal avenues in need of attention now and in the decade to come.

The development of intellectually agile and professionally capable scientists, mathematicians, engineers, and technicians has been a fundamental goal of the National Science Foundation since the agency's inception in 1950. Yet as Lomask (1976, p. 121) observes, even "in the face of the public clamor for more scientists and engineers [after the launch of *Sputnik*], NSF's managers clung to their conviction that the country stood to gain more from a limited number of able and properly trained professionals than from a plethora of inadequate ones." According to England (1982, p. 228):

> *"The Foundation's advice boiled down essentially to this: Improve mathematics and science instruction in schools and colleges. Motivate more bright students to go to college. Sift choice grain from the baccalaureate chaff for graduate training in science and engineering. Furnish greater opportunity and more money for basic research. Through such an interrelated program, NSF would brush up the old Jeffersonian design for providing the nation with an aristocracy of talent."*

Over the past half-century, experience and the prevailing attitudes of the day have modified this philosophy and fostered NSF's present cadre of educational programs, which tend to be somewhat egalitarian in design. Particularly noteworthy is the Foundation's early recognition of diversity issues. The original National Science Board had two women and two African-Americans among its members and included representatives from a variety of institution types located in several states (England, 1982). Alan Waterman, NSF's first director, referenced the need to attract women into scientific careers. By 1958, however, the Foundation counted only two women on its advisory committees (of 30 members and both representing Scientific Personnel and Education) and four among the 155 members on NSF advisory panels (NSF, 1958). Programs devoted to diversity (primarily ethnic diversity) were not created until the 1970s, and then mostly in response to urban unrest.

An Early Focus on the S&E Workforce

From its inception, NSF was allowed to support pre- and post-doctoral graduate fellowships as well as undergraduate scholarships. However, the agency's earliest focus was on fellowship support for the brightest students at the most prestigious institutions. In 1952, NSF expended $1.5 million on fellowships and $1.1 million on research (England, 1982). Thus, educational activities (discounting graduate research assistantships within research grants) comprised over 58 percent of NSF's first budget.

In 1953, NSF supported two summer research-training sessions for college faculty in an effort to strengthen collegiate instruction in science and engineering, particularly at undergraduate institutions. Not coincidentally, in addition to evincing concern for the quality of education, these activities also "helped counter charges of elitism" (England, 1982, p. 232). This emphasis on providing research experiences for undergraduate faculty is reflected today in the Research Opportunity Awards (ROA) and the Research Sites for Educators in Chemistry (RSEC) programs.

Instructional Workforce and Curricula in K-12

NSF funded its first institute for secondary teachers in 1954 to address out-of-field teaching by high-school science teachers, a concern that remains today. Within three years, expenditures for teachers' institutes had overtaken expenditures to enhance college faculty. In 1959, NSF enlarged the program by adding elementary teachers and administrators (Lomask, 1976). The Foundation was less enthusiastic about its move into K-12 education, concerned primarily about the sheer magnitude of the target audience, possible adverse impact on NSF's prestige, and potential conflicts with the Office (now Department) of Education (England, 1982).

Two factors led to the rapid growth of the teacher and faculty institutes as well as other non-fellowship education programs. The first was the perceived disparity in the preparedness of future scientists and engineers in the United States and the Soviet Union, a notion given credence by the launch of *Sputnik I* on October 5, 1957. The second factor was the attractiveness for Congress in the possibility of developing another source of funding for their districts (Lomask, 1976). With at least one facility in each of 45 states by 1957, the NSF-supported institutes solidified an emphasis on scientific content knowledge by secondary teachers. Concurrently, there was a relaxation of the narrow interpretation of the Foundation's legislative authority regard-

[1] The opinions expressed by the authors do not neccessarily reflect those of the National Science Foundation, its reviewers, auditors or awardees.

ing education.

In Fiscal Year (FY) 1965, the last year of substantive growth in this area, $44 million was spent in support of 518 summer institutes, 183 academic-year institutes, and approximately 2,000 in-service seminars and conferences attended by a total of more than 43,000 teachers, mostly at the high-school level. The budget appropriation for NSF as a whole rose from $40 million in 1958 to $134 million in 1959 and continued to rise, reaching nearly $500 million in 1968 with approximately one-half of the funds used for education programs.

In addition to teacher-training institutes, there were fledgling efforts to try other approaches to strengthening science, mathematics, engineering, and technology (SMET) education, particularly the design of new high-school curricula in mathematics, biology, physics, and chemistry. A new high school level Course Content Improvement Program grew from less than $1 million in 1958 to $20 million in 1968 (Lomask, 1976). Congressional support at this time was fueled by expert testimony about the antiquated content of many high-school textbooks still in use, some of which were out of date by sixty years (Lomask, 1976). Leading these efforts were study teams comprised of eminent scientists at the nation's most prestigious universities—early examples of the current NSF emphasis on the integration of research and education.

Comprehensive Activities in Higher Education

Several programs to strengthen college and university instruction emerged in the 1960s. Starting in 1962, the Science Development Program (SDP) provided five-year grants of $3 to $5 million (1962 dollars) to colleges and universities other than the Top 20 to upgrade their research and instructional activities. In FY 1970 a second program, the College Science Improvement Program (COSIP), targeted predominately undergraduate institutions with grants limited to $300,000 for up to three years.

It was not a great stretch for the Foundation to move from enhancing faculty at non-research universities to providing research opportunities for the most promising students at non-research universities. By 1965, the Undergraduate Research Participation (URP) program—one of several incarnations of the same core idea—provided student stipends and cost allowances. In the 1970s, NSF added the Student Originated Studies (SOS) program to develop proactive research skills among talented undergraduates and to respond to the desire for independent action and increased social relevance being advocated by students. By 1987, a program called Research Experiences for Undergraduates (REU) provided new awards to special sites developed expressly to give undergraduates enrolled at a variety of institutions the opportunity to participate in summer research projects. The Graduate Traineeships Program, initiated in 1964 in response to a perceived shortage in the supply of engineers, expanded to encompass all NSF-supported sciences by 1967 (Lomask, 1976).

During the 1980s, a group of liberal-arts colleges known as the Oberlin 50 took advantage of an existing NSF program to revitalize their science, mathematics, and engineering faculty, who were principally engaged in teaching undergraduates. The program arising from this initiative—Research in Undergraduate Institutions (RUI)—was funded from the *research and related activities* line item in the budget.

Large-scale and comprehensive (but more elusive) funds for extensive curricular overhauls offered by programs such as Alternatives in Higher Education (FY 1974), Comprehensive Assistance for Undergraduate Science Education (FY 1978), and Development in Science Education (FY 1981) disappeared due to Federal budget cuts in the 1980s. The mandates of these programs, however, were later revived in the Recognition Awards for Integrating Research and Education (RAIRE) and Awards for Integrating Research and Education (AIRE) competitions in the 1990s.

Applied Research and Education

The shift toward applied research and higher-education programs was an expression of the popular view that Neil Armstrong and Edwin Aldrin's 1969 walk on the moon had all but conquered the frontiers of basic research. Just as *Sputnik* had spurred enhanced NSF support for basic research, it now appeared that another milestone in space exploration would mark the end of this era. The 1969 Mansfield Amendment to the Defense Procurement Authorization Act (which required that the Department of Defense only support basic research with "a direct and apparent relationship to a specific military function or operation") and the extension of NSF programming to applied research both contributed to the Foundation's next period of significant growth. The new emphasis on applied principles was also reflected in programs that focused on addressing special needs within academic institutions. Basic improvements in individual institutions began as Science Curriculum Improvement (SCI) in the 1960s, then revised to Local Science Curriculum Improvement (LOCI) in the mid-1970s. Under LOCI, grants of up to $30,000 (with a 2:1 matching ratio) were allowed.

Introduced in the early 1960s, the first undergraduate laboratory/research equipment effort was known as the Instructional Scientific Equipment Program (ISEP). However, ISEP was suspended in FY 1971 because of an overlap with Title VI-A of the Higher Education Act of 1965. The program evidently filled an essential niche since the NSF Office of Experimental Projects and Programs soon issued a *Consumers' Guide to Instructional Scientific Equipment* (NSF E75-43). The guide provided information to faculty and departments concerning new equipment purchases through Title VI-A or with their own funds. Several years later ISEP returned, structured as a matching-grants program from which applicants could request up to $20,000 with at least 100 percent in matching funds.

The Division of Undergraduate Education in Science was replaced by a number of new "Divisional" and "Office" creations during the mid- to late-1970s as NSF sought to accelerate the pace of technological improvement in undergraduate education. The Alternatives in Higher Education (AHE) program included science education for undergraduate majors and non-majors as well as graduate education. The program had three tracks: 1) instructional materials and modes development; 2) alternative-degree programs (in search of interdisciplinary-degree program development); and 3) continuing education of practicing scientists and engineers. AHE sought new ways of disseminating curricular materials and instructional approaches rather than relying on conventional published articles and papers presented at meetings. The program also sought new hardware in support of science education and tried to identify networks for developing materials beyond and between individual faculty and publishers. There was also a new emphasis on evaluating the outcomes of such projects.

In K-12 education efforts, NSF endeavored to support the production of new materials and textbooks while avoiding any inference that these materials, in turn, would be required at NSF's teacher-training institutes and workshops. Elected officials needed reassurance that the Foundation was not attempting to create a federally approved set of educational materials that would usurp local authority in such matters. This is not to suggest that such efforts were always successful. In the mid-1970s, a congressional review of the Foundation's budget request raised concerns that *Man: A Course of Study* (MACOS), a curriculum developed with NSF support, was causing children to reconsider the values, beliefs, and loyalties of their parents (Lomask, 1976). According to *Newsweek* (1975), MACOS was then being taught in 1,700 schools in 47 states. The series is still in use today, but it is believed to have caused some real harm to public support for NSF education programs in the appropriations process.

Economic Decline and Budget Cuts

In the wake of the energy crisis and substantial inflation, 1975 to 1983 was a period of zero or minimal economic growth. Education programs accounted for only 10 percent of NSF's overall budget (SEI, 2000) and the Foundation witnessed the near elimination of science-education programs under President Reagan's budget. The fine line between local autonomy in education and federal programming had become almost invisible, dominated by the President's belief that local autonomy should prevail.

Much of the 1980s was spent rebuilding from these budget reductions. The policy basis for this new expansion was the 1983 publication of *A Nation at Risk* (NCEE, 1983). In addition, a 1986 report generated by the National Science Board (NSB 86-100, the "Neal Report") argued that the passage of the baby-boom generation through college was associated with a significant deterioration in the state of undergraduate laboratories. The report considered this alarming, stating that there was a strong need for NSF leadership in efforts to renew undergraduate teaching laboratories and teaching faculty.

One of the first consequences of the Neal Report—even prior to its publication—was the establishment of the College Science Instrumentation Program (CSIP) to support projects designed to improve the laboratory curriculum of undergraduate SMET students. This program evolved into the Instrumentation and Laboratory Improvement (ILI) program with annual appropriations rising to more than $20 million in the early 1990s. Weis (1991) discussed some of NSF's initiatives to attract women and other underrepresented groups into SMET at this time. In quick succession, the Division of Undergraduate Science, Engineering, and Mathematics Education (USEME) added the Course and Curriculum Development (CCD) and Undergraduate Faculty Enhancement (UFE) programs to support stronger undergraduate education for all students. In the late 1990s ILI, CCD, and UFE were merged into the Course, Curriculum, and Laboratory Improvement (CCLI) program.

Comprehensive or Systemic Approaches

Renewed attention to undergraduate education in the late 1980s spawned several comprehensive efforts. Examples included the Engineering Education Coalitions (a systemic workforce effort initiated in 1989), a broad interdisciplinary curriculum initiative in mathematics, a more focused effort in chemistry, and new efforts to engage minority students. Included in the latter category were the Research Careers for Minority Scholars (RCMS) and the Louis Stokes Alliance for Minority Participation (LSAMP) programs. LSAMP set quantitative goals for its students to increase baccalaureate awards in selected SMET fields.

Attention was also directed to other workforce elements where strong SMET knowledge was essential. There was a refocused, discipline-centered teacher-preparation effort (FY 1995) and a popular foray into the education of technicians with the Advanced Technological Education (ATE) program (FY 1996). Under Director Neal Lane, higher-education initiatives at NSF were marked by an increased emphasis on the integration of research and education, exemplified by the RAIRE and AIRE competitions mentioned earlier. State, urban, and rural systemic initiatives characterized NSF's K-12 initiatives in the 1990s.

Surveying the Landscape

By the mid-1990s, definite changes were occurring with the national science and engineering workforce. The problem of an adequate supply of trained professionals was receding. Employment opportunities in traditional fields were also diminishing in response to more selective hiring practices in academia and a reduction in the amount of research and development conducted by the military. Concurrently, there was a steady increase in the rate of college matriculation of high-school graduates and a clear preference by industry for knowledge workers with a broad education and flexible skills. The personal computer and the Internet revolutionized the way in which knowledge workers were utilized in many large corporations. In general, employers could become more flexible in accommodating shifts in demand for products and services.

Such changes brought corresponding implications for undergraduate SMET education. In response, NSF's advisory committee for Education and Human Resources released *Shaping the Future* (NSF 96-139) in the summer of 1996 (NSF, 1996; see also Fort, 1995 and Metzenberg, 1997). Concurrently, the National Research Council's Committee on Undergraduate Science Education produced *From Analysis to Action* (NRC/CSMEE, 1996). Both reports established the need to modernize and improve undergraduate SMET education, attempted to reach all students, and centered undergraduate education in quality research and laboratory-based education.

From 1983 to 1999, NSF expanded its

funding for undergraduate-education programs in the aggregate. The challenging balance between quality and quantity in developing the technical workforce is reflected in current NSF undergraduate initiatives such as the Advanced Technological Education (ATE) program, which emphasizes the production of *more* and *better trained* technicians. The current Integrative Graduate Education and Research Training (IGERT) and the Grant Opportunities for Academic Liaison with Industry (GOALI) programs can be seen as descendants of the *Research Applied to National Needs* initiative of the 1970s, which was "designed to prepare and motivate science students in the graduate schools for work in industry or in other non-academic environs" (Lomask, 1976, p. 255). To this day, despite the early authorization to do so, the foundation does not offer direct support for undergraduate scholarships. However, in 1999 the Computer Science, Engineering, and Mathematics Scholarship (CSEMS) program began to offer awards to institutions in support of scholarships. This means of support was expanded in 2000 by Scholarship for Service, a Reserve Officer Training Corps-like program for producing government information-technology managers.

Year-to-year growth was also achieved by adding new programs. Probably the most significant new addition for this period was 1999's National Science, Mathematics, Engineering, and Technology Education Digital Library (NSDL). This initiative seeks to leverage information technologies to enhance student learning and erase boundaries between and among students, researchers, and teaching faculty. It represents a new approach to teaching and learning as well as the manifestation of NSF's first virtual-user facility. Another effort projected for the near term is support for assessment of student-learning outcomes in order to establish the educational research base for linking instructional activities to student learning.

In FY 2001, the Directorate of Education and Human Resources has been apportioned approximately $800 million of NSF's $4.4 billion budget. Other education and training efforts across the Foundation (excluding research assistantships) probably account for an additional $300 million.

Using the Past to Look Ahead

Based on the NSF's past experience in SMET education, we propose six areas that would benefit from the Foundation's attention in the next decade and beyond.

1. Systemic Reform of Higher Education Curricula and Institutions.

Two different kinds of infrastructure building are critical: *reform within institutions across disciplines and departments* and, in recognition of the realities of the current faculty-reward system, *reform across institutions within disciplines*. Whether one is discussing students, faculty, courses, laboratories, curricula, or institutions, even changes with significant short-term impact are difficult to maintain unless they are endorsed by all components of the system.

2. Demonstration of Student Progress.

A critical need exists for cogent assessment of undergraduate students and measurable indicators of their progress. Especially useful will be assessments developed with attention to the knowledge, skills, and abilities expected of recipients of undergraduate degrees. Such assessments could be applied at various levels of examination, enabling individual faculty to improve their instruction, departments to improve their programs, and institutions to progress further toward systemic reform.

3. High Quality Faculty Instruction.

Effective undergraduate instruction requires faculty who have access to: 1) high-quality educational materials; 2) methods of proven efficiency; 3) the latest knowledge and methods from the disciplines; and 4) role models and mentors drawn from senior faculty. A fifth aim is equally important: extending the supply of exceptional faculty through the proper preparation of their successors. Institutions must develop strategies that coherently address these needs.

4. Educational Materials and Methods Using Information Technology.

Effective educational materials and methods developed from an empirically verified discipline *and* education research allow students to emulate the experiences of professional practice. Institutions need to better encourage such efforts at the undergraduate level. The Internet and its successors will have startling implications for how we care to teach and choose to learn.

5. Diversity.

Because of their relatively higher political visibility, rapidly productive and innovative approaches are required if the United States is to achieve the desired impact on selected student groups including prospective teachers, two-year college students, and underrepresented populations. We must recognize not only demographic differences, but differences in learning styles, personal values and career goals. For the past thirty years, SMET majors have fairly consistently represented about 25 percent of all undergraduates. In an increasingly technological society, we must reach and engage the remaining 75 percent, many of whom will be making decisions that determine the professional latitude and respect afforded to scientists and engineers.

6. Attention to the Whole Student—Curricular, Co-curricular, and Extra-curricular.

Educators must recognize and understand what happens outside the classroom and find ways to make curricula more supportive of these influences. Conversely, the curriculum must be made relevant to students' lives. Instruction cannot take place if students are not ready or receptive to learning. Readiness for education involves decreasing the detrimental effects by a lack of personal encouragement and financial support. Institutions of higher education must determine how to better integrate these fundamental considerations into program design.

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Norman L. Fortenberry, Sc.D. has been Division Director of NSF's Division of Undergraduate Education (DUE) since November 1996 and is NSF's Official Liaison to Community Colleges. Since January 2000, Dr. Fortenberry has also served as Acting Division Director of the Division of Human Resource Development (HRD). Dr. Fortenberry's previous position was as Executive Director of the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc. (The GEM Consortium) after serving as Associate Program Director, Program Director, and Staff Associate in DUE from 1992 to 1995. Before joining the NSF staff in 1992, Dr. Fortenberry was Assistant Professor of Mechanical Engineering and Associate Director of Minority Engineering Programs at Florida A&M University/Florida State University College of Engineering in Tallahassee, Florida. Dr. Fortenberry was awarded the S.B., S.M., and Sc.D. degrees (all in mechanical engineering) by the Massachusetts Institute of Technology.

James J. Powlik, Ph.D. is an information dissemination specialist who has been a consultant to the National Science Foundation since 1995. He is currently an assistant program director in NSF's Division of Human Resource Development. As director of Raggedtooth Productions, Inc., and as a consultant for numerous private-sector companies, Dr. Powlik has advised on technical content, education efficacy, program design and outreach strategies for clients including NASA, the U.S. Department of Commerce, the Environmental Protection Agency, public attractions and non-profit organizations. As a biologist, oceanographer, and author he has also worked in the areas of science literacy, animal morphology, aquatic ecology, ecosystem management, and ocean science methodology.

Maricel Quintana-Baker, Ph.D. has been a consultant to the National Science Foundation's Division of Human Resource Development since 2000, after completing her dissertation on the role of Hispanic Serving Institutions in national SM&E degree production at the American University in Washington, DC. During her tenure at NSF, Dr. Quintana-Baker has been the principal investigator in a research project studying the role of recruitment and retention strategies and institutional culture on the production of future doctorates at selected Hispanic Serving Institutions. The study is a collaborative effort partly funded by the Sloan Foundation, under the auspices of the American Association for Higher Education, and with in-kind contributions from the National Science Foundation. Prior to coming to NSF, Dr. Quintana-Baker has several years of senior level experience in the education, business, government, and non-profit environments.