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ABSTRACT

In March, 1986, the National Science Foundation (NSF) commissioned a study designed to assess initiatives available to NSF to address problems and opportunities in K-12 science education. The first part of this volume presents a detailed discussion of "core functions" for the NSF in K-12 science education (promoting professional interchange, building the base of information and knowledge about science education, and supporting innovation). Part 2 of the document discusses the basis for strategic investment in three key areas. These are: (1) designing initiatives; (2) developing an overarching strategy; and (3) building NSF's strategic capacity. The volume's remaining three parts include a discussion of study methods, a summary of NSF's 30-year history of funding in K-12 science education, and three commissioned papers (regarding NSF's role in mathematics education, computer science education, and efforts to serve minority students in science). The appendix contains tables delineating the suggested initiatives to implement overarching strategies, along with resource estimates indicating the funds needed for each initiative over the next five years. (TW)

OPPORTUNITIES FOR STRATEGIC INVESTMENT IN K-12 SCIENCE EDUCATION

Options for the National Science Foundation

Volume 2: Groundwork for Strategic Investment

June 1987

Prepared for:

THE NATIONAL SCIENCE FOUNDATION

NSF Contract No. SPA-8651540
SRI Project No. 1809

Prepared by :

Michael S. Knapp
Marian S. Stearns
Mark St. John
Andrew A. Zucker

with the assistance of:
Catherine P. Ailes
Debra M. Richards
Dorothy E. Stewart

SRI International

The results of this study are reported in three volumes:

The *Summary Report* contains a brief overview of all findings and conclusions regarding NSF's mission in K-12 science education, the opportunities for the Foundation to make a significant contribution to solving problems in K-12 science education, and how NSF can approach these opportunities more strategically.

Volume 1 - Problems and Opportunities presents full discussions of NSF's mission, the problems in K-12 science education that are susceptible to NSF's influence, and the opportunities to address these problems. Essays on each opportunity present an analysis of:

- The rationale for NSF's involvement.
- How current (or projected) NSF programs and policies, carried out by its Directorate for Science and Engineering Education (SEE), relate to the opportunity.
- Promising alternative initiatives for SEE to take advantage of the opportunity.

Volume 2 - Groundwork for Strategic Investment (this volume) contains extended discussions of:

- NSF's "core" or basic functions in science education (promoting professional interchange, building a base of information and knowledge about science education, and supporting innovation).
- The basis for strategic investment in K-12 science education (design of initiatives, development of strategies and strategic capacity).

Volume 2 also includes a discussion of study methods, a summary of NSF's 30-year history of funding in K-12 science education, and three commissioned papers (regarding NSF's role in mathematics education, computer science education, and efforts to serve minority students in science).

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PREFACE

In 1984, Congress included in the National Science Foundation's (NSF's) appropriations bill (P.L. 98-371) a requirement for "a contract to develop a science education plan and management structure for the Foundation." This and a related mandate, that the Foundation "develop a strategic plan for science and engineering education" (P.L. 99-159), were partly a result of congressional dissatisfaction with the programmatic plans that NSF initially proposed when its Directorate for Science and Engineering Education (SEE) was reinstated in 1983. The legislation and associated events underscored Congress' wish that NSF resume its role in education in the sciences and renew its programs, which had come under fire several years before and had been terminated (except for the Graduate Fellowships program).

Along with the mandate to develop a science education plan, Congress indicated that NSF should get help in putting together its education-related activities and Education Directorate. The language of the legislative mandate also expressed concern about the lack of compelling evidence regarding the efficacy of NSF support in science education.

The Study

As part of the Foundation's response to the mandate, NSF (SEE) awarded a contract to SRI International in March 1986 "to assess initiatives available to NSF to address problems and opportunities in science education."* Science education was defined broadly to include mathematics, the sciences, and technology, but the project's scope was limited to the K-12 level.** The project had two major phases:

(1) *Assess initiatives available to NSF in K-12 science education.* This phase required SRI to investigate NSF's current and alternative initiatives in science education, clarify their objectives, and examine their

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* NSF had earlier awarded a contract to Research Triangle Institute to assess initiatives related to science education (excluding mathematics) at the middle/junior high school level. Subsequently, NSF convened a series of panels concerning NSF's role in undergraduate-level science, mathematics, and engineering education.

** Throughout this report, we use the terms "science education" and "education in the sciences" generically to include education in mathematics, the natural sciences, engineering, and technology (as both a tool and object of study), except where differences between the disciplinary areas are specifically indicated. Similarly, we use the term "K-12" to encompass all science learning activities for children and youth from 5 through 18 years of age, both inside and outside of school.

advantages and disadvantages, based on lessons learned from previously supported educational programs.

(2) *Develop an assessment plan and procedures so that NSF could assess its own initiatives on an ongoing basis.* This phase required a pilot evaluation of a current NSF initiative in K-12 science education.

This volume is the final report of the first phase.

SRI's assessment of initiatives available to NSF proceeded in two stages; each involved multiple methods and many sources of information. In the first 6 months of the project, working groups were assembled to review from five different perspectives all current NSF programs in K-12 science education and examine alternatives to them:

- School-based education in the natural sciences
- School-based mathematics education
- Out-of-school (informal) science and mathematics education
- Technology in science and mathematics education
- Development and support of science and mathematics teachers.

Activities during this stage included (1) a historical review of NSF K-12 programs from 1952; (2) interviews of NSF staff, other executive and legislative branch staff, members of the scientific and engineering community, and experts in science and mathematics education regarding current activities, needs, and opportunities in the field; (3) literature reviews and commissioned papers; and (4) analyses of current and projected NSF initiatives. An important step in this stage of the project was a series of meetings to review the working groups' preliminary findings. Reviewers were invited from the scientific and science education communities; participants included university-based science and mathematics educators and individuals with special areas of expertise, such as cognitive science, the publishing industry, or teacher education, depending on which of the five perspectives was under discussion. Subsequently, the project team revised the working-group findings on the basis of the reviews, and presented them to the staff of NSF's Education Directorate.

The second stage of the assessment activity required us to consider findings about current initiatives and potential alternatives in a larger framework. To provide guidance to the Foundation and satisfy the congressional mandate for a science education plan, we developed a prospective framework for viewing NSF's options, including what had been learned from the more retrospective view of initiatives during the project's first stage. Also, our analysis did not focus only at the level of programs and initiatives, but included NSF's overall strategy in K-12 science education as well. Thus, the question "What are the advantages and disadvantages of current and alternative initiatives?" became part of the larger issue, "What are NSF's most promising investment options, given the problems and opportunities in K-12 science education?" The five earlier perspectives evolved into a framework of opportunities and strategies. Our synthesis of working-group findings, supplemented by further interviews within the science education community and a review by representatives of scientific and professional associations, was directed at identifying the most promising opportunities available to NSF and strategies for addressing them.

This Volume*

This volume of SRI's report presents a detailed discussion of "core functions" for the National Science Foundation in K-12 science education (promoting professional interchange, building the base of information and knowledge about science education, and supporting innovation). In addition, this volume discusses the basis for strategic investment in three key activities:

- Designing initiatives
- Developing an overarching strategy
- Building strategic capacity within the Foundation

This volume also includes a discussion of study methods, a summary of NSF's 30-year history of funding in K-12 science education, and three commissioned papers (regarding NSF's role in mathematics education, computer science education, and efforts to serve minority students in science).

As explained in the *Summary Report*, our analysis assumes that NSF's primary goal in K-12 science education is to contribute to broadening the pool of competent and interested science learners; throughout this volume, we refer the reader to the detailed discussions of 10 opportunities for NSF to address this goal.

Michael S. Knapp,
Marian S. Stearns,
Co-Principal Investigators

June 1987

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* The findings and conclusions from Phase I are also presented in two other volumes: *Summary Report* (an overview of all findings and conclusions) and *Volume 1 - Problems and Opportunities* (extended discussion of NSF's opportunities to address problems in science education).

ACKNOWLEDGMENTS

This study represents the joint efforts of a large and diverse professional team, supplemented by the ideas and advice of many resource people from the science education community. We wish to acknowledge their many contributions to the project and to this report and thank them for their patience and flexibility as the study unfolded.

First, we owe a great deal to our consultants, who participated as members of working groups during the first stage of Phase I and subsequently as critics of our draft reports. Their contributions to the project's conceptual design, data gathering, and initial analyses are too numerous to describe; we could not have produced this report without the ideas, debate, and constructive criticism these individuals generated:

- Charles Anderson, Michigan State University
- Alphonse Buccino, University of Georgia
- Robert Bush, Stanford University (emeritus)
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- Judy Diamond, San Diego Natural History Museum
- Kristina Hooper, Apple Computer
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- Glenn Kleiman, Education Development Center
- Barbara Pence, San Jose State University
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- Pinchas Tamir, Hebrew University
- Robert Tinker, Technical Education Research Centers
- James Wilson, University of Georgia.

We wish also to acknowledge the efforts of four other consultants, all from Stanford University, who contributed to the groundwork for Phase II of the project as well as to the overall conception of Phase I: Edward Haertel, Milbrey McLaughlin, Ingram Olkin, and Cathy Ringstaff. The fruits of their labors will be incorporated into the final report from Phase II of the study.

Several other individuals prepared commissioned papers for the study and thereby supplemented the pool of ideas from which we formulated the study's conclusions: Joel Aronson, independent consultant; Gerald Kulm, American Association for the Advancement of Science; and Elliot Soloway, Yale University. Others did extended critiques of an earlier draft of this report and Volume 1 among other of their contributions to the process of developing and refining conclusions: Jill Larkin, University of California at Berkeley; Barbara Scott Nelson, the Ford Foundation; Senta Raizen, National Research Council of the National Academy of Sciences; Iris Weiss, Horizon Associates; and Wayne Welch, University of Minnesota.

All these people generated ideas and helped distill the thinking of diverse groups within the science education community in conjunction with the SRI core staff, which consisted of the authors and several others. In particular, we wish to thank Wayne Harvey (now with Education Development Center) and Margaret Needels (also a faculty member at California State University at Hayward), each of whom participated as active members of the core staff, in addition to leading working groups dealing with technology in mathematics and science education, and the development and support of teachers. Other members of the SRI staff participated in the project's conceptual design, data collection, analysis, and the monumental logistical and support tasks: Catherine Ailes, Marie Brewer, Carolyn Estey, Mary Hancock, Klaus Krause, Debra Richards, Patrick Shields, Dorothy Stewart, Joanne Taylor, Annette Tengan, and Mary Wagner.

Staff of the National Science Foundation (NSF) were remarkably forthcoming throughout the project: their plans and ideas, reflections and self-criticisms, and constructive critiques of our work helped in many ways throughout the project and the preparation of this report. We owe a particular debt to the professional staff in the Directorate for Science and Engineering Education whose responsibilities center on K-12 science education. Those who especially helped during the study and report writing are: Myron Atkin, Jerry Bell, Richard Berry, Dorothy Gable, Raymond Hannapel, Larry Hatfield, Martin Johnson, Mary Kohlerman, Rodney Mansfield, Elizabeth Martin, Andrew Molnar, Alice Moses, Charles Puglia, William Schmidt, Truman Schwartz, Bassam Shakhashiri, Susan Snyder, Arnold Strassenberg, Michael Templeton, Jerry Theise, John Thorpe, George Tressel, Vincent Lunetta, Robert Watson, and Peter Yankwich. Other officials of the Foundation and Executive Branch agencies gave us perspectives that helped in framing our findings.

Members of the Advisory Committee of the Directorate for Science and Engineering Education helped us clarify our assumptions and sharpen our perceptions of the scientific community's views on K-12 science education. In particular we wish to thank the current chair and vice-chair of the committee, Gerald Holton and Margaret MacVicar.

More than 600 individuals from the science education community--mathematicians, scientists, and engineers; practicing educators and teacher educators; former NSF staff and grant recipients; science education researchers and developers--gave generously of their time as interviewees or as resource persons in other capacities. They are too numerous to list, nor can the richness of their thinking be adequately summarized, beyond what appears in the three volumes of this report. However, certain individuals and groups made an extra effort as reviewers or participants in project meetings of various kinds. In particular, we wish to thank the following individuals who took part in refining the thinking of project working groups:

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Zalman Usiskin, University of Chicago
Daniel Watt, independent consultant.

Representatives of various professional societies critiqued an earlier version of the findings presented in this report and helped us to reflect the diversity of viewpoints within the science education community:

Audrey Champagne and James Rutherford, American Association for the Advancement of Science
Jack Wilson, American Association of Physics Teachers
Sylvia Ware, American Chemical Society
Laurie Garduque, American Educational Research Association
Doris Lidtke, American Federation of Information Processing Societies
Donald Eklund, Association of American Publishers, Inc.

Robert James, Association of Educators of Teachers of Science
Ellen Griffee and Bonnie Van Dorn, Association of Science and Technology Centers
Robert Kenney, Association of State Supervisors of Mathematics
Peter Renz, Conference Board for the Mathematical Sciences
Leon Ukens, Council for Elementary Science International
Rolf Blank, Council of Chief State School Officers
Jack Gerlovich, Council of State Science Supervisors
Susan Adler and Jane Armstrong, Education Commission of the States
Alfred Willcox, Mathematical Association of America
David Butts, National Association for Research in Science Teaching
Patricia McWethy, National Association of Biology Teachers
Bernard Pipkin, National Association of Geology Teachers
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James Gates, National Council of Teachers of Mathematics
Sharon Stroud, National Earth Science Teachers Association
Harold Pratt, National Science Supervisors Association
Bill Aldridge and LeRoy Lee, National Science Teachers Association.

We have been invigorated by the insights and energy of all of the individuals we have named and others too numerous to mention. Not even the three volumes in this series do justice to the full range of their thinking, but we hope that in this report we have distilled the issues and options in a way that helps to energize the professional community in which these individuals participate and improve the role that NSF plays in science education.

PART ONE:

CORE FUNCTIONS

- Promoting Professional Interchange

- Building the Base of Information and Knowledge About Science Education

- Providing Support for Innovation

PART ONE: CORE FUNCTIONS

Each of the opportunities described in the *Summary Report* and *Volume 1* implies that NSF invests in goal-directed activities. The success of these investments depends, in part, on the Foundation's support for other activities, which are focused less on a particular educational improvement goal than on the underpinnings for all improvement efforts: the interchange of ideas within the professional community, the development of information and knowledge about science education, and the encouragement of innovative ideas. Through these kinds of support, which we call "core functions," NSF (SEE) accomplishes two things: it prepares the science education community to take advantage of the opportunities, and it aids its own process of designing effective initiatives. Simultaneously, the Foundation provides an essential national resource to the professional community.

In this part of the report, we explain why each function is essential, why the Foundation is uniquely suited to carry it out, what NSF (SEE) is currently doing to fulfill the function, and what remains to be done (if anything) to establish the function more securely. We argue that, with some exceptions, the Foundation should invest more resources and pay greater attention to these functions than it now does; for each function there are a series of attractive initiatives for accomplishing this end.

The Core Functions

We organize and define the three functions as follows:

- *Promoting professional interchange:* activities aimed at (1) maintaining the link between educators and the scientific community, (2) developing networks within the science education community, and (3) establishing mechanisms for archiving and disseminating materials or information among prospective users.
- *Building the base of information and knowledge about science education:* activities aimed at (1) investigating science learning and learning environments (including the study of science learning processes, teaching, educational technologies, alternative settings, etc.), (2) learning about science education systems (including national and international assessments, monitoring, studies of system functioning, etc.), and (3) documenting or evaluating the results of NSF (SEE) interventions.
- *Supporting innovation:* activities that encourage innovation in science education on an open-ended basis, that is, not in relation to a particular target of intervention but as defined by creative individuals in the professional community (e.g., as displayed in proposals that "fall between the cracks" in SEE's current program structure).

NSF's Role

These functions represent a different kind of role for NSF; rather than directing its funding toward specified targets, the Foundation acts as a central, national resource to the science education community by encouraging the exchange of ideas, supporting the development of knowledge about science education, and responding to unanticipated or innovative ideas that supplement and extend the efforts of others in these areas.

Aside from the service they represent, these functions bear an important relationship to NSF's efforts to address the opportunities described in other volumes of this report. Extensive interchange among project directors (and others in the science education community) can encourage cross-fertilization while projects or programs are under way. Designing effective strategies for addressing opportunities depends in part on accurate information about the state of the field and on a clear understanding of the learning process. And if the results of individual projects are to cumulate, be interpreted, and be made available to others (especially important in the case of demonstration projects), effective documentary evaluation and archiving are required.

These functions are especially appropriate for the Foundation. As the most centrally positioned and visible national-level institution concerned with education in the sciences, NSF (SEE) is able to orchestrate the interaction among diverse groups in the professional community. The Directorate can muster a sufficient body of discretionary resources to support open-ended inquiry. By the nature of the work it supports, the Foundation is naturally located at the intellectual center of the science education community.

One may well ask whether NSF (SEE) needs to support distinct activities to accomplish these functions, or whether the functions can be accomplished as a by-product of investments aimed at particular opportunities. To some extent, these core functions can be, and are, carried out in the course of projects focused on targeted goals--the development of particular kinds of curriculum, teacher education for prospective science or mathematics teachers, etc. For example, efforts to reconceptualize the content of mathematics and science instruction rest, in part, on the participation of members of the scientific community, as well as on the findings of research on science learning.

However, those research findings and participants will only exist if an ongoing "intellectual infrastructure" is maintained. Members of the scientific community who wish to make useful contributions to reconceptualizing the content of school instruction need to be familiar with schools and K-12 educational issues. Some form of open-ended support--intellectual "risk capital"--must also exist for scholars to pursue interesting avenues of inquiry. In other words, a critical mass of scientists (or scientifically trained professionals) and educational researchers, among others, must commit substantial amounts of time--even whole careers--to pursuing these issues. NSF's role, then, is to provide a secure base of support for this intellectual infrastructure over the long term.

PROMOTING PROFESSIONAL INTERCHANGE

The fact that the disciplines of science and mathematics are in rapid flux is well known. Because of the constant change in content, and for a wide variety of other reasons (increasing use of technology, new goals, state mandates, etc.), the system of science education at the K-12 level is also changing rapidly. For the hundreds of thousands of professionals engaged in science education to be successful, they need to be exposed to a wide variety of ideas and people who will provide information necessary for them to do their jobs well.

Many people and agencies share responsibility for promoting professional interchange, ranging from science and mathematics teachers themselves to textbook publishers and state education agencies. In addition, NSF has a very strong interest in helping to promote professional interchange because it will help NSF to fulfill its mission in science education. In several areas, NSF is particularly well suited to carry out this function, notably in fostering the exchange of ideas between scientists and educators, and in helping to disseminate knowledge about work that NSF (SEE) itself has supported in science education. In these and other ways, NSF has a responsibility to help promote professional interchange of ideas and materials as a means of improving science education.

The Need for Professional Interchange, in Context

In science education, as in science itself, there is a need to maintain an "intellectual infrastructure." Without suitable interaction and exchange of ideas (e.g., in-service training, professional journals, meetings), the field would quickly become moribund. Many individuals and institutions contribute to this infrastructure, including professional societies (e.g. NCTM, NSTA, ACS, AAAS), school districts, and universities. However, NSF also has a responsibility to act in this area. In this section, we discuss NSF's role under three broad headings: maintaining links between educators and members of the scientific community, developing networks within the science education community, and establishing more effective mechanisms for archiving and disseminating SEE's own materials and information.

Maintaining the Link Between Education and the Sciences

In principle, at least, many members of the scientific community have a unique and important contribution to make to K-12 education in the sciences. They know the craft and culture of science firsthand. They know that the disciplines of science are intellectually exciting, alive, and evolving. They are in a better position than teachers to distinguish enduring, underlying principles from the mass of information about their discipline. Drawing on their immersion in the subject discipline, scientists, mathematicians, and engineers have the ability to help science and mathematics teaching accurately reflect the nature and excitement of science. Through their involvement they can also contribute to the prestige of science education and K-12 education generally, and serve as role models for students (both of which are important functions).

At present, however, the reality is that few avenues are available for science-trained professionals at all levels, from undergraduate science students through professors emeriti, to participate in the K-12 educational process. Scientists, for the most part, are intensely involved in their own research work, with little time or encouragement to pursue educational issues, especially at the K-12 level. Present professional reward systems offer few incentives and considerable disincentives for such involvement. Moreover, the realities of districts, schools, and classrooms are foreign and uninviting to many scientists. As a result of these barriers, scientists have largely abandoned the teaching of the fundamentals of their own disciplines to others who are less familiar with the nature and structure of the scientific enterprise.

The *American Journal of Physics* (AJP) bemoaned this abandonment in a series of editorials:

> Let us compare, for example, typical members of the American Association of Physics Teachers [AAPT] with typical members of the American Physical Society [APS]: I suggest that in 1986 there is a greater distance between these two groups than there was in 1940. Further, I suggest that both the AAPT and the APS are, in 1986, the worse for it. Even sadder, I believe that contemporary culture is the worse for it--and profoundly so.... (Rigden, 1986a)
>
> From the perspective of general education, contemporary physics is a far richer resource than was the physics of the 1940s. Yet, if the pages of AJP from the two eras are compared, the conclusion must be drawn that physicists were more concerned about general education then than they are now. Why? (Rigden, 1986b)

A well-known scientist, on the other hand, explained it to us this way:

> "For the young scientist, the reward structures are all wrong; they are fully involved in their own work. For the older scientists, by the time they get there, they are fully socialized into science and have come to spurn education.... Also, scientists are somewhat self-selected against those who can communicate or write well.... Really, scientists are no more and no less narrowly focused on their own myopic agendas than those in any other profession.... It is all a question of reward structures."

NSF's close connection and familiarity with the university-based scientific and engineering communities creates an opportunity for arranging interactions between scientists and educators. NSF has prestige and credibility in both worlds, enabling it to bring together good scientists and educators. Additionally, SEE now has years of experience in understanding the nature of the collaboration that is needed to create successful K-12 programs, both in and out of the schools. With the cooperation of the other directorates, SEE is ideally positioned to establish a range of creative and diverse programs that bring scientists into the world of education and educators into the world of science.

It is important to point out that we do not believe it is feasible (or even desirable) for NSF to return to the pattern of the 1960s, when scientists led the Sputnik-inspired improvement of science and mathematics education. The need to address all students means that the opportunity now is to facilitate collaborative interactions between scientists, science educators, and other educators. In addition, NSF can continue to support the educational development of science professionals who decide to address educational issues with the same fervor and rigor as they do scientific problems.

Thus, in addition to its current priority on funding projects that bring together scientists and educators (for research, development, and teacher training), two general approaches are promising for SEE. One is the establishment of long-term arenas of collaboration between scientists and educators for carrying out a wide range of research, curriculum development, and evaluation projects. Specifically, NSF could:

- Support regional science centers that are dedicated to improving the curricula and teaching. Typically centered in science museums and universities, such centers could serve as prestigious arenas for scientists, science educators, and local teachers and administrators.

The second promising approach is for NSF to support opportunities for scientists to further their interests, skills, and careers in the educational domain. For example, NSF could support:

- Graduate-level programs and fellowships for students trained in science at the graduate level to pursue research and careers in science education.
- Collaborative work with professional societies to provide opportunities for scientists to participate in internships, conferences, and sabbaticals.

All of these options are described in more detail in the section on promising initiatives.

Developing Networks within the Science Education Community

One of the Foundation's richest resources is the large number of grant recipients who are actively working on projects under NSF support at any one time. Grants related to K-12 education in the sciences number in the hundreds at current levels of funding; many of them are working on related topics and could benefit considerably from one another's experiences, if the occasion and means to do so were at hand. In addition to those who have NSF grants, there are many more whose activities and thinking are a potential source of direction for NSF and who are one of the key audiences for the results of NSF projects. Given its position and roles in science education, the Foundation has a core function of stimulating the interchange with and among these members of the science education community.

There are, of course, naturally occurring linkages among professionals within the science education community. As in any area of endeavor, professionals tend to make it their business to know about other activities related to their own. However, unlike the well-defined community of scholars engaged in a particular line of scientific research who are likely to be in close touch with relevant developments in their field, the participants in efforts to improve science education in schools or informal institutions are highly diverse, representing subject fields as different as early childhood development, chemistry, and materials design, or institutional settings as diverse as a publishing house, a professional society, and an elementary school district. Generally, there is no natural meeting ground for such people. Occasions for interchange among such groups must be created. NSF has done well over the years to stimulate collaborative arenas, primarily within individual projects and occasionally through meetings or conferences that bring larger groups together.

Why should NSF support such activities? Its position between educators and the scientific community and its ongoing relationship with many who are directly involved with research, training, development, and other activities related to education in the sciences make it a logical stimulus for such interchange. It shares this responsibility with existing forums afforded by professional societies (such as the AAAS, the National Council of Teachers of Mathematics, the American Chemical Society, and others) or occasionally convened through the auspices of private foundations or universities. But with few exceptions (AAAS is one), NSF is in touch with a greater breadth of activities at any one time than any other group, by virtue of the amount of grant funds it has and the scope of its programs. Hence, NSF can act as an intellectual broker or "switchboard" in ways that facilitate productive interchanges among groups that are unlikely to relate to one another.

The greatest potential lies in communication between science education groups that have hitherto remained apart--for example, university-based science education researchers working with advanced learning technology, industry-based hardware and software developers, and practicing educators, all of whom need to join forces more effectively if the promise of advanced technology is to be realized. NSF can do much to put these kinds of groups in touch with one another. Further experimentation with network mechanisms, meetings, and other forums should be considered.

Establishing More Effective Mechanisms for Archiving and Disseminating Materials and Information

Science education professionals require easy access to the tools of their trade. Yet the science education community as a whole faces a perennial problem in making high-quality materials and research results available and useful to disparate groups within the community, especially teachers. SEE's own approach of leaving most materials and research dissemination up to individual project directors is widely recognized as inadequate. Now, as a large number of new research and development projects are coming to fruition, is an appropriate time for SEE to develop better archiving and dissemination capabilities, drawing on advanced technologies where necessary. Supporting additional mechanisms for archiving, interpreting, and disseminating information and materials would also be appropriate.

NSF is quite familiar with the problem. In the last several decades, many high-quality instructional materials have been developed for use in elementary, middle, and high school science and mathematics classrooms and in teacher training programs. Some of the best of these materials, many of which were partly or fully paid for with NSF funding, have remained in circulation, particularly through commercial publication and distribution channels (e.g., *Elementary Science Study* and *Science: A Process Approach*, materials developed 20 years ago for elementary science, are still available). However, other fine materials quickly became lost from view, sometimes as much for want of an appropriate distribution mechanism as for lack of demand.

Over the same period of time, many items of inferior quality have continued to be readily available; these typically include materials that are most easily marketed to the mass school market, including those without complications entailed by accompanying kits or the risk associated with innovative formats. In short, there is a major and perennial challenge facing science education: maximizing the spread and longevity of existing high-quality materials (those that enhance students' learning of desirable scientific content, skills, and attitudes), as distinguished from the larger set of inferior materials.

There is a parallel problem regarding the spread of knowledge. During the past few decades, a good deal of wisdom has been developed about promising approaches to science education, based on research studies and the testing of teaching practices. Yet the accumulated knowledge available to practitioners about these practices and insights is relatively meager. Once again, the lack of effective mechanisms for assembling this knowledge, interpreting it, and making it available to the various audiences that might use it, especially practicing teachers and program planners, is largely responsible.

Conceptually, there are four activities that need improvement: (1) assembling large amounts of information about science education research and materials at central points; (2) synthesizing and interpreting it, including making judgments about more and less effective materials; (3) indexing or otherwise reducing the information so that users can quickly find what they want; and (4) dispersing the information (at least in reduced, synthesized, or interpreted form) throughout the decentralized system of users (schools, science teachers, researchers, teacher educators) so that large numbers of people can and do make use of it.

NSF is not alone among the institutions that have been or might be concerned with this problem, but in science, mathematics, and technology education, NSF is very well positioned to promote a comprehensive and satisfactory solution to it (because of its independence from commercial interests, close connections with both educators and the scientific community, an excellent reputation among science and mathematics teachers, etc.). Several kinds of efforts have been undertaken by others over the last three decades:

- *ERIC Clearinghouse.* The ERIC Clearinghouse for Science, Mathematics and Environmental Education at Ohio State University has been funded for many years by the U.S. Department of Education as part of the ERIC (Educational Resources Information Center) system. ERIC, consisting of 16 clearinghouses in various subject fields, exists to meet the needs of researchers and practitioners for easy access to information about education research, curriculum, and other matters. A substantial collection has been assembled, and each year nearly 1,000 documents and 1,800 journal articles are added to it, including compilations and syntheses produced by the Clearinghouse. ERIC is comprehensive in certain areas (notably research), but, although there is some provision for sorting out items of poor quality, some users report that they are overloaded with document abstracts or references to journal articles, many of which are of questionable value. ERIC has historically placed priority on research documents; consequently, less attention has been paid to curriculum documents or other practitioner-oriented materials. Hence, despite the fact that ERIC annually sells more than 15 million microfiche and is accessible via computer telecommunications at hundreds of locations, the ERIC system is not as well known among educators, and especially teachers, as one might expect. Interestingly, one curriculum area that is apparently well represented is materials produced under SEE grants. Boxes of materials were submitted to ERIC at about the time that SEE was disbanded; others are submitted by principal investigators. However, there is apparently no general procedure whereby NSF, after receiving final reports (including curriculum materials), submits such materials directly to ERIC.

- *International Clearinghouse.* The University of Maryland's International Clearinghouse on Science and Mathematics Curricular Developments, which is no longer operational, did not focus on research. It concentrated instead on curricular materials from the United States and other nations. It had some gaps in its collection, but cataloged approximately 300 curriculum projects in science between 1956 and 1977. In contrast to the ERIC Clearinghouse, the International Clearinghouse never had mechanisms comparable to microfiche, computer networks, and floppy disks by which to disseminate its material.

- *Other centralized collections.* Other centralized collections of materials and information exist, often with a more specialized focus (e.g., the Teachers' Clearinghouse for Science and Society Education in New York City, the science textbook collection of the U.S. Library of Congress), but they, too, fall short of fulfilling a complete curriculum clearinghouse function. Not only is the scope of each limited, but users must generally travel to the collections. Some of these organizations (e.g., the Teachers' Clearinghouse) publish excellent newsletters and bibliographies for teachers' use.

- *Reviews*. Science education journals and professional societies have a continuing review function that highlights the availability and merits of new materials, as well as interpreting and disseminating research-based knowledge among science educators. For example, *The Mathematics Teacher*, published monthly, regularly reviews high school mathematics textbooks and, from time to time, reports some research results (such as findings from the National Assessment in mathematics). The AAAS publishes a periodical, *Science Books and Films*, whose sole purpose is reviewing materials, including science books for children and, beginning in 1985, high school textbooks. Although highly useful, these activities are generally incomplete; usually only a few materials are reviewed at a time in these settings, the reviews are brief, and reviewers (and the journals) are often reluctant to appear too negative. Nonetheless, one suspects that sources such as these are underused and are more valuable than is generally recognized.

- *Syntheses*. Several science and mathematics teachers' associations distribute research syntheses of interest to practitioners. For example, the National Council of Teachers of Mathematics (NCTM) distributes *Classroom Ideas from Research on Secondary School Mathematics*. These organizations also compile information about various materials, such as *Mathematics Tests Available in the United States and Canada*. Other organizations also sponsor such work, including the ERIC Clearinghouse (see above) and the Department of Education's "education laboratories," which produced a series called *Research Within Reach*, including several volumes on science and mathematics teaching.

What can NSF do to improve on this situation? First, the availability of research and research syntheses seems on the whole to be more effectively organized than are the collection, analysis, and dissemination of curricular materials and information about them. (However, research synthesis and interpretation for particular audiences still deserves NSF's attention; see the discussion of initiatives below.) Teachers, department chairmen, parents, and others interested in learning about, and perhaps examining, a broad array of instructional materials available for some area of the science and mathematics curriculum (including written materials, computer software, videotapes, assessment instruments, etc.) find that there are not enough services or guides available to make the job easy or straightforward.

A low-cost, "bare-bones" approach to both the research and materials problems would be for NSF (SEE) to begin to archive results of all (or a selection) of its own research and development projects, notably including products of the Instructional Materials Development and Applications of Advanced Technology programs. Archiving might be done centrally, such as in a library, or it might be done in a format suitable for electronic distribution (e.g., on CD-ROM discs). In either case, the objective would be to assure permanent and relatively easy access to knowledge and curricular resources produced under support from SEE.

NSF (SEE) can, however, think in terms of a larger response to the problem. By virtue of its central position in the field and the kinds of discretionary resources it commands, NSF can spearhead the establishment of a more sophisticated archiving and dissemination capability for curricular materials. This might be accomplished in part by supporting research into appropriate ways to carry out the task, in part by connecting existing efforts more effectively (e.g., by telecommunications) and by funding the creation of new kinds of centers and distribution mechanisms.

The biggest contribution NSF can make to this need may have more to do with its capacity to select from, and interpret, the array of materials available than with efforts to assemble and index all materials. Comprehensive archiving without interpretation (or, at the least, a sophisticated query system) may be of less use than a selective representation of the best materials available across a range of possibilities. The *Best of the Best of ERIC* series is one model: some ERIC clearinghouses, for example, do an annual selective compilation of abstracts in particular "hot topic" areas and publish this as a small volume for interested users. In meeting the need for archiving and dissemination, less if often more.

NSF would bring several key strengths to bear on the problem: access to scientists who can participate in the review of materials, familiarity with the science education community and with its past and present work, resources to support the development or adaptation of appropriate technology, and a reputation for attention to the quality of science education materials. Few other institutions, if any, are likely to concentrate effort on this problem.

In addition, this is a time that the spotlight of reform is on the schools. Now, while states and districts are reconsidering the structure of their curricula in these subject areas, is the most appropriate time to make a wider range of ideas and materials available, to stimulate and assist the process of choosing programs at the state and local levels.

NSF (SEE) Activities in Relation to This Core Function

SEE already has activities under way in the general area of promoting professional interchange. For example, there is a general priority on projects that involve professional scientists, mathematicians, or engineers, in addition to science educators. Also, SEE currently operates a Science and Mathematics Education Networks program to facilitate communication among science educators (and others). A more detailed description of SEE's activities, along with a discussion of their strengths and weaknesses, follows.

SEE Policies Aimed at Maintaining the Link Between Education and the Sciences

In the 1950s and 1960s, NSF appealed to the scientific community to lead large-scale curriculum projects aimed at upgrading and revitalizing K-12 science, mathematics, and technology education. A large number of scientists and mathematicians did become leaders in this effort, including (among others) Beberman, Begle, Fehr, Holton, Karplus, Pimentel, and Zacharias.

In addition, throughout its history, SEE project review criteria have specified that all projects must be judged on both scientific and educational merit. Accordingly, staff of NSF-funded projects have typically included scientists or those with sufficient scientific expertise to ensure that the scientific aspects of the project would be of high quality. Consequently, a significant proportion of NSF-funded principal investigators have been scientists or mathematicians located in universities and museums.

In line with this tradition, SEE currently makes the active involvement of scientists, mathematicians, or engineers a major priority for proposed projects in all of its programs. In some cases, members of the scientific community are the principal investigators (for example, of teacher institutes and of some materials development projects); often, they are included in projects as collaborating members of the project team. The Directorate's policy represents the strong conviction of SEE planners that the success of science education efforts depends in part on the participation of individuals active in the subject disciplines.

This policy has clearly made it possible for a number of highly motivated individuals to gain exposure to issues of science education and, in some cases, take the lead in shaping projects. But SEE planners and program officers confess difficulties with the policy. The demanding SEE guidelines for proposal preparation discourage a number of potentially interested scientists from submitting proposals, and those who do often find their proposals noncompetitive. Scientists are more used to the relatively open grantsmaking process in the rest of NSF. Second, the quality of collaboration elicited by the current policy varies considerably; proposers are tempted to include "token" scientists in situations where an appropriate individual is unavailable for the project in question. Third, scientists frequently lack the requisite expertise in educational issues to be of great help, until they have been involved for substantial periods of time. Fourth, interested members of the scientific community often find the specificity of SEE programs too confining; their own ideas don't fit. Finally, some of the emerging directions in SEE programs (e.g., the emphasis on the elementary level for materials development or the shift toward district-centered training in teacher enhancement projects) make it difficult for large numbers of scientists to participate.

These difficulties may have been exacerbated by recent trends in SEE funding priorities and guidelines. For example, SEE is now strongly encouraging the use of consortia and collaborative teams in the structuring of its projects, so as to include all the relevant constituencies and expertise required for projects that will be successfully implemented in the schools. For example, the latest guidelines for teacher training projects suggest that proposed projects might include classroom teachers, teacher educators, educational researchers, curriculum developers, school supervisors, and subject-matter scholars. This emphasis coincides with an increasing focus on the school or district as the "center of gravity" for the project. Collaborative arrangements such as these that are centered more in the schools provide fewer incentives and present more barriers to the participation of scientists. One of the costs of the present emphasis on collaborative teams may be to discourage the best, most creative (and autonomous) scientists from participating.

One can imagine alternatives to the current SEE strategy that would not alienate the scientific community as much. SEE could encourage greater differentiation of projects so that some involved working scientists more than others. SEE could also find and support appropriate roles within a teamwork structure for scientists to play (e.g., as reviewers and critics). Further, SEE (and NSF as a whole) could stimulate the creation of appropriate mechanisms for providing scientists with professional rewards and incentives for educational work (e.g., *Science* magazine has recently agreed to publish research articles that deal with science education if they meet accepted social science research standards).

SEE's Investments in Network Development

SEE currently encourages interchange among members of the science education community, including grant recipients, in several ways that represent a promising step toward a more satisfactory exchange of ideas. First, within programs, regional or national gatherings of project directors are periodically held, typically to "show and tell" project progress. Second, agenda-setting conferences or meetings are occasionally organized (these are not limited to grant recipients, nor should they be). Third, the Science and Mathematics Education Networks program funds projects that create or extend information-sharing arrangements, which may include grant recipients, although they are not focused primarily on this category of user.

These activities achieve some degree of interchange, but they are limited in several ways. The potential synergy among grant recipients remains a largely untapped resource. With the exception of project directors' meetings, none of these activities explicitly aims at grant recipients. Grant recipients from different programs are unlikely to be exposed to each other's work, except through their own professional grapevine. Large gatherings of principal investigators are not likely to be organized frequently, for obvious logistical reasons. Finally, the show-and-tell mode of many principal investigators' meetings discourages thematically based or issue-oriented interaction.

To its credit, NSF has begun to experiment with principal investigators' meetings, by organizing them around important issues in the field that confront a group of project directors. For example, a recent gathering of individuals directing teacher enhancement projects devoted much of the time to an exploration of the "leadership teacher training" concept and the problems or progress encountered in projects that sought to achieve this goal. Other kinds of thematically organized meetings are possible, as are numerous devices that increase the incentive or establish the means for project directors whose projects address similar goals to exchange information with one another.

At relatively little additional expense, SEE could significantly improve the interchange among grant recipients (and others) through other means such as:

- A telecommunications network among principal investigators. It could become a stipulation of the grant award (and thus a small part of each project's budget) that all project directors participate in a telecommunications network throughout the duration of their grants; subsequently, they might be allowed to continue at their own expense. The network might feature topical bulletin boards, electronic forums, or other means to link project directors with similar interests.

A more substantial amount of resources would be required for the following kind of communication device, which would serve a much wider audience than grant recipients:

- A regular NSF journal on education in the sciences, patterned after *Mosaic*, the Foundation's journal for publicizing developments in scientific research, that features sections on grants in progress, syntheses of research, etc., organized by issue or theme.

These possibilities are discussed in more detail in the description of initiatives later in this section.

SEE's Current Contribution to Archiving and Dissemination of Information and Materials

In the 3 years following SEE reinstatement, programmatic attempts to assemble, interpret, and disseminate materials and information to practicing science educators have not been a high priority for NSF. The following kinds of activities in fiscal years 1984-1986 have addressed this need:

- A few projects have reviewed and synthesized research studies (e.g., regarding the effectiveness of homework in science) or cataloged existing materials in particular areas (e.g., the elementary science materials available regionally).

- Projects funded to establish communication networks on a local, regional, or national basis are, among other things, sharing information about effective practices and available materials.

- Some individual principal investigators have disseminated the results of their research, development, or training projects to wider audiences, with varying degrees of success.

- NSF produced its own listing, by state, of all projects funded by SEE during this 3-year period.

One should add that for a certain category of projects--large-scale materials development done with publication in mind--commercial channels offer effective distribution mechanisms, but only as long as the materials "sell."

SEE's current approach to these needs has encountered difficulties:

- *Documentation*. The starting point for any attempt to archive or disseminate the results of projects is the creation of a descriptive record of project activities and results. This is generally left to principal investigators, who are required to furnish annual reports and a final report. The thoroughness of these reports varies (see the next core function--building the base of information and knowledge about science education--for a more detailed discussion of project documentation). Projects are documented in other ways, as well--for example, the initial abstract in the proposal, publication of research results in journals, or publication of materials by commercial firms. The abstracts, when edited and published by SEE, are an important source of information about both projects and programs--often the only information that is publicly available. As far as results are concerned, research projects that are published in journals are typically published in a journal with limited readership; few research results are known by teachers. Similarly, few of the development projects now being supported are likely to reach commercial distribution (note that recent collaborative development efforts with publishers are an exception here).

- *Archiving*. Beyond an annual published directory of awards (listed by state, with no programmatic or topical index) and published grants summaries by program (e.g., NSF, 1987a, 1987b, 1987c), NSF currently maintains no archiving system through which project documentation, evaluation, or products can be made accessible to those who want them. For example, the minimal solution--a library of final project reports at NSF--does not exist.

- *Dissemination*. As with the two functions described above, project directors are given responsibility for developing dissemination plans, which vary in effectiveness and are typically short-lived. Long-term storage and retrieval (if any) is left to the U.S. Department of Education's ERIC system. SEE planners are considering plans to establish a clearinghouse for all SEE-supported products and project results, but, the exact nature of this facility remains a matter of debate.

These functions are not easily accomplished for a number of reasons. They take considerable staff time and resources, which are in extremely short supply. In the case of archiving, questions of physical storage space and the ongoing operational costs of maintaining an archiving system are difficulties not easily overcome. Debate continues on the relative importance of selection and interpretation versus comprehensive archiving.

The shortcomings of these efforts with respect to the core function under discussion are obvious and familiar to NSF (SEE) staff. For example, principal investigators are often not the most effective dissemination agents; and, given scarce resources for research, synthesis and dissemination activities have necessarily taken second place to support for new research.

Currently, SEE is considering more ambitious steps to meet the needs for archiving and dissemination:

- A set of published directories, including abstracts that describe SEE projects (similar to what was done in the 1970s).
- The possibility of a national evaluation and dissemination center for all NSF-supported materials, combining archiving with aggressive dissemination. This would represent a big step forward in addressing some aspects of the opportunity.

But even these measures will fall far short of the overall goal. New initiatives are needed that will improve archiving and dissemination of information and materials.

Promising Initiatives

SEE is particularly well situated to promote professional interchange among the recipients of its own awards. Similarly, information and materials produced under grant or contract from SEE are (at least in principle) those most easily archived and/or entered into some network through which the science education community can become better informed. In addition, because of its extensive ties with the scientific community, NSF is particularly well suited to foster exchanges between educators and members of the scientific community.

Despite the fact that NSF is in a good position to do so, in reality, for a number of reasons (notably limited resources), SEE is doing less than it might to promote or encourage professional interchange. Below we present a number of promising initiatives that SEE could undertake to increase its effectiveness in promoting professional interchange and strengthening science education. (These initiatives are especially promising; others are certainly possible.

Initiatives That Establish Stronger Links Between Education and the Sciences

We see two broad categories of initiatives that are likely to stimulate more diverse and useful collaboration between educators and members of the scientific community: (1) creating arenas of collaboration, and (2) supporting the development of "scientist-educators."

At the K-12 level, high-quality science instruction requires an intelligent and sensitive blend of science content and pedagogy. Without a careful integration of the two, an imbalance may occur, resulting in science instruction that too heavily reflects the scientist's point of view (making it pedantic, difficult, and inappropriate for the audience) or the educator's point of view (leaving it weak in scientific substance or clarity).

At the K-12 level, the integration of science and pedagogy is happening in various ways--for example, in research that focuses heavily on the subject-specific processes of learning; in teacher training workshops that give teachers appropriate knowledge of the disciplines and how to teach them; in television productions and museums that artfully blend science content with attractive pedagogy.

Integration of good science with good pedagogy requires the joint effort of people who understand both the educational and scientific worlds. But to bring thes people together in productive ways, structures for collaboration and rewards for participation are required. Because of its experience and prestige with both the education and scientific communities, NSF can create arenas of work that will attract and reward the best in education and in science.

Support national and regional science education centers--NSF could fund a small number of national centers, each focusing on a different aspect of science, mathematics, and technology education, where a critical mass of scientific and education expertise could be brought together to work on new developments that might significantly advance the field. Centers could be established to focus on technology, mathematics, informal science education, leadership teacher developmen curriculum development, and research. Not only could they serve as places where innovative projects occur, but they could foster interaction between professionals in a way that develops national science education leaders. They might also be places where graduate programs in science education are centered.

At the regional level, NSF could create and support resource centers that support and upgrade the regional quality of science education. Such resource centers could have a small permanent staff and offer a chance for local scientists and educators to come for periods of a few days up to several years to work on science education projects. Specifically, such centers could enhance the quality of (1) curriculum framework and development projects for states and local districts, (2) inservice training capabilities, (3) preparatory training of new teachers, (4) local evaluation and research projects, and (5) the local public understanding of science. Such regional centers might look like the partnerships of university, industry, and local schools described in *Volume 1* of this report (see Opportunity 4), or they might have a more flexible collaborative form, with teachers at the core (Ford Foundation, 1986).

The main function and advantage of NSF-sponsored national and regional center is that they might provide a nucleus for the meeting and cooperation of leading scientists, science educators, and educational scholars who do not specialize in science-related issues. In the past, NSF has resisted the notion of supporting centers per se; indeed, there are well-documented pitfalls to the center approach, as the U.S. Department of Education's experience with regional "laboratories" and research centers attests. These centers might be established in an informal rather than a formalized way (e.g., the Harvard Technology Center), with a 7- to 10-year mandate and a threshold level of funding to avoid some of the pitfalls of long-term center support.

Depending on the size and configuration of the centers it supports, SEE would need to invest between $25 million and $35 million over the next 5 years to make these centers a reality.

In addition to establishing collaborative arenas such as these, NSF (SEE) could do much to improve the incentives for scientists to make long-term commitments to work in education. Over the years, a small number of practicing scientists have become actively involved in education, while maintaining their ties to their respective research disciplines. These "scientist-educators" include physicists working in science museums, mathematicians working with national television shows, and computer scientists studying teaching and learning using the most advanced ideas of cognitive science and artificial intelligence. Many of the staff at SEE belong to this category of professional. NSF has been instrumental in stimulating the emergence of this type of person; the Foundation could foster the development of scientist-educators more extensively and develop avenues for their skills to be used to a maximum degree.

Although no one expects all, or even most, scientists to be strongly interested in K-12 science education, our interviews suggest that a small proportion of the scientific community (typically young scientists with children in the schools and scientists toward the end of their careers) have a very strong interest in contributing to, and being involved in, education. These individuals enjoy the intellectual rigor of science, but they want to use their intellectual skills to study and solve educational problems, rather than in a laboratory. They like to work with people and are interested in transmitting the culture and understanding of science to others.

One scientist described why he became involved in education:

> "I do it for myself.... It is a great intellectual challenge for me to put the important ideas of science clearly--with the same conceptual density--but using popular language.... So essentially I do it to fulfill myself, just like somebody else plays basketball. After all, man can not live by science alone...."

Each of the following initiatives describes programs that would support science-trained professionals to develop their own skills in education and to serve in an educational teaching, research, or leadership position. Each initiative focuses on the community that NSF knows best--the scientific community in academe and private industry.

Graduate-level programs and fellowships--NSF could support programs that provide graduate-level research and development opportunities for students in science and engineering who wish to pursue an educational interest rather than a research one. The Berkeley Search for Excellence in Science and Mathematics Education program (SESAME) is one model of how a science-based program in education can yield high-quality graduates who have credibility in both the scientific and education communities. SESAME graduates have played effective roles in science education, both in and out of the schools. By heavily supporting a few high-quality graduate programs, NSF could help to create a new and needed cadre of national leaders in science education.

NSF could also provide graduate fellowships for students who wish to pursue combined science and educational research. This would require additional funds if the current number of science graduate fellows is to be maintained. The rationale for supporting such fellowships seems strong. In addition to providing students with support, the allocation of graduate fellowships to encourage science-oriented students to pursue educational issues would begin to shift the overall reward structure and provide some incentives on the education side. The symbolic value of such fellowships might be as important as the fellowships themselves. If NSF is serious about its educational mission, graduate fellowships are an easy way to demonstrate its commitment. Finally, by supporting promising graduate students (and thereby faculty) to do education research, NSF would both create leaders in science education and cultivate science education activity within science departments.

An investment of $6 million to $7 million over a 5-year period would support the creation of four graduate programs (at $250,000 per year), as well as 20 to 40 fellowships (e.g., offering $10,000 per year for 2 to 3 years). Collectively, these investments would support 15 to 25 graduates annually, starting in several years' time.

Supporting the work of professional societies in encouraging educational activities within their memberships--NSF could work in collaboration with, and further support programs of, the professional societies that aim at fostering scientist-educators. The AAAS Education Fellows program, for example, aims at giving a young scientist an intense experience in an educational domain. NSF may wish to discover such programs and search for ways to extend them or broaden their impact. There are also examples of internships within informal science institutions that make natural arenas for the involvement of scientists in educational projects (Semper et al., 1982). All such programs provide avenues for interested scientists to work and develop their skills in the education arena. Other mechanisms that NSF may wish to consider are year-long sabbaticals, conferences, and seminar programs.

Emphasis might be placed on professional societies' extending a formal "invitation" to potentially interested members. Our interviews with scientists who were engaged in activities relevant to K-12 education underscored the importance of having an avenue and invitation for scientists to participate in education. One scientist wrote a monthly column in a magazine because he was asked to. Another did a television show because he was approached by the producer. Another was at an elementary science conference because of an invitation. NSF could do much to foster the participation of science-trained professionals by supporting groups that provided these scientists with invitations to participate in appropriate roles.

Four to seven grants per year over 5 years (at $150,000 per grant on average) would enable most of the major scientific societies to offer a variety of ways to participate in science education, along the lines just described. This kind of investment would total $3 million to $5 million over 5 years.

Initiatives for Improving the Networks within the Science Education Community

Even apart from the scientific community (with which it is most familiar), NSF (SEE) has excellent opportunities to develop networks within the science education community, starting with its own grantees. We have identified three particularly promising initiatives.

Thematically organized principal investigators' meetings--When SEE occasionally organizes meetings of principal investigators, the common element is that all the projects represented are funded by a particular SEE program. There is a natural diversity of projects (in most cases) within a framework or activity (e.g., instructional materials development) that is common to all. This combination of similarities and differences can make meetings of principal investigators lively and profitable.

There are times, however, when it would be more profitable for such meetings to cut across program lines. For example, to focus attention on the status of teacher education (e.g., current practices, recommendations for change, barriers to change, etc.), SEE might want to involve researchers, people involved in materials development for teacher education, practitioners, and others. Principal investigators working on SEE projects in each of these areas would provide complementary perspectives, making the meeting a richer one than if only one perspective were available. It might be advisable in some cases to invite additional expertise from outside the group of SEE principal investigators to make such a meeting as useful as possible--useful, that is, to the principal investigators, to SEE, and to the science education community as a whole.

Within a program, thematically-organized principal investigators' meetings could be organized more purposively, to get beyond the natural tendency for these meetings to lapse into "show-and-tell" sessions. SEE has begun to experiment with meetings of this sort in several programs; more could be done, with more ambitious agendas related to important strategic planning issues confronting NSF.

Much of the cost of such meetings could come from the principal investigators' own grants: travel, lodging, subsistence, etc. (These, in turn, would ultimately be borne by SEE's budget.) Some additional expenses, such as the cost of facilities, would be separate costs to SEE. In all, to support 8 to 10 meetings per year, at a cost of approximately $200,000 per meeting, would take $8 million to $10 million over 5 years.

Telecommunications networks for principal investigators--A related possibility for increasing the exchange of ideas within the science education community is to link principal investigators electronically, rather than through face-to-face meetings. A stipulation of the awards (and thus a small piece of each project's budget) could be that all project directors participate in a telecommunications network throughout the duration of their grants. The network might feature topical bulletin boards, electronic forums, or other means to link project directors with similar interests. (The Fund for Improvement of Postsecondary Education at the U.S. Department of Education has successfully experimented with such a network.)

These networks could be made up of principal investigators from a specified program, from clusters of programs within a division, or from SEE as a whole. People who are not principal investigators might also be included. For example, after an award expires, principal investigators might be permitted to stay on the network at their own expense.

The costs of operating such a network are now quite low. At an estimated $100,000 per year, the cost over 5 years would be $0.5 million.

A new NSF journal, patterned after Mosaic--The Foundation currently publishes a journal, *Mosaic*, through which it can distribute information about developments in scientific research. The periodical includes sections on grants in progress, syntheses of research, etc., organized by theme; or sometimes an entire issue is devoted to a single topic. (Occasionally, articles deal with education-related matters.) *Mosaic* is published four times per year.

The science education community would benefit from the creation of a similar journal devoted exclusively to education in science, mathematics, and technology. Grants (and contracts) in progress would be one focal point of interest, concentrating on awards funded by NSF, but not exclusively so. Issues devoted to a single topic (e.g., elementary school life science, or school-museum partnerships) would also be of interest. The journal would help to open up communication among different components of the science education community (e.g., those in different disciplines, at different levels, or in different institutions, such as schools and television stations).

Income from subscriptions for a publication such as this is not likely to cover the full costs. NSF would need to cover the balance of the costs, estimated at $1.5 million over 5 years.

Initiatives Aimed at More Effective Mechanisms for Archiving and Dissemination

Because much is known about what works and what doesn't work in this area, NSF has some attractive options before it that imply a fairly immediate impact on the current system, if successful. This is not an area of opportunity requiring long-term investigation or experimentation, even though there are significant unresolved questions about the most effective way to accomplish the long-term goal, especially regarding demand for disseminated information. Also, the options are more focused than in some other areas because the nature of the task can be specified concretely; there is little to gain by opening up the area to diverse, field-initiated solutions.

We discuss below three initiatives in this area, each of which provides NSF with significant avenues for improving the situation.

National/regional science and mathematics education materials exchange--NSF might establish a sophisticated archiving and dissemination capability, based in a single central location or in a small number of regional centers, to provide a highly visible and widely recognized means for users to locate information about science/ mathematics education materials, practices, or research. This may be thought of as an elaboration of NSF's existing plans to establish a clearinghouse. A key feature of the exchange would be a capacity to review materials and interpret their appropriateness to different kinds of instructional situations. The exchange might also publicize selected materials the way that the ERIC system occasionally highlights the year's best research work regarding "hot topics."

Some thought would need to be given to the desirability of a single location versus multiple locations. The nature of the interface between this capability and existing clearinghouses would also have to be carefully thought out. It would not be advisable to have such a facility duplicate what has already been done; rather, NSF's resources should concentrate on the more difficult problem of selecting the best from among the array of resources, coordinating what already exists, finding creative ways to make it more available and visible to a mass audience.

NSF would not necessarily need or want to be the sole supporter of this enterprise, although it would be reasonable for it to support some portion of the operating expenses of such a system on a long-term basis. The most important NSF contribution would probably be in getting the work under way.

Several factors make this a timely initiative to pursue at the present time. First, following its hiatus in the early 1980s, NSF is once again supporting research and development in science education. In the 3 years following the reinstatement of SEE, approximately 100 development projects have been supported that aim at school-based science or mathematics education; about half that many were supported in research; a somewhat small number of developmental projects in informal education settings have also received NSF funding. Before it supports many additional instructional materials development efforts, this is an opportune time for NSF to set up mechanisms to make results of all the projects available for wide distribution. The mechanisms would be far more effective if they included (or, at least reviewed) as many instructional materials as possible, because NSF-supported materials are only a small part of the total universe of available materials and practices.

This initiative is also timely because technologies have recently become available that make the storage, retrieval, and distribution of masses of information by thousands of people technically more feasible. In particular, various forms of electronic storage and communication make it possible to handle, distribute, and search large data bases, such as an entire encyclopedia, in seconds. Video technology (e.g., videodisc) adds an important visual dimension: both materials that are not in a print medium (e.g., kits, laboratory setups, computer software) and their application in different classroom environments can be efficiently documented, displayed, and accessed through currently available technology (e.g., CD-ROM).

Indeed, experiments have begun in science education that partly demonstrate the potential of an archival system or systems. For example:

- The Carnegie Foundation is supporting an elementary science archiving project focusing on curriculum materials produced in past years with NSF support. Large amounts of data are being stored on CD-ROM discs, for easy retrieval.
- The Educational Product Information Exchange's (EPIE's) elementary mathematics curriculum alignment data base will help teachers, school boards, or others to locate appropriate textbooks, software, or other instructional materials that match specific teaching objectives for any grade level (EPIE, 1986). EPIE calls its system IIIR, for Integrated Instructional Information Resource. Copies of the instructional materials themselves are not available through IIIR (which can be used either on-line or via a paper copy of the data base.)

This may be the time for NSF to support demonstrations of the larger potential suggested by these projects. Relatively inexpensive technologies have made it possible to provide services now that were far too expensive to provide in the past.

Support for the individual ERIC clearinghouses averages several hundred thousand dollars annually. Because of the start-up costs and use of a new technology (new for this purpose), $1.5 million to $2 million a year over a 5-year period may be needed to support this materials exchange (for a total of $7.5 million to $10 million). Efforts could be made to phase in funding from other long-term partners (e.g., scientific societies, NSTA).

This initiative provides both good prospects for collaborative involvement of other organizations and a key role for scientists, mathematicians, and engineers (in reviewing materials). Further, it provides widespread access to a variety of materials, and many of the elements of a functioning system are already in place or are being developed.

In addressing this opportunity area, NSF's greatest risks are two: NSF will discover that the system it contemplates is impractical or excessively costly, or NSF will create such a system but it will not be extensively used. In either case, NSF would fail to achieve its ultimate goal of enhancing the use of knowledge and materials for science education developed by NSF or others. Other key disadvantages include the difficulty of avoiding controversial judgments about quality of the materials, if they are reviewed; and, of course, the effectiveness of dissemination as an improvement strategy is inherently limited by the capabilities of users (e.g., teachers and teacher educators).

Commissioned reviews of existing materials and research--At relatively little cost, NSF might sponsor a series of reviews of (1) the materials available in all areas of the science and mathematics curriculum, with emphasis on developing scientific and pedagogical profiles of the materials; and (2) syntheses of the existing research literature, interpreted for different audiences, notably publishers/developers, teachers, support staff (e.g., district-level science specialists), and teacher educators. NSF (or a grantee) would commission recognized authorities in the field to prepare the reviews. Some efforts might be made to get provocative or contrasting reviews to sharpen thinking about the items being reviewed and to guard against accusations of one-sided judgment. An alternative strategy would be routinely to use multiple researchers in a kind of survey approach.

Some of this kind of activity happens already under the auspices of professional societies. The National Science Teachers Association, for example, puts out an annual synthesis volume called *What Research Says...* for its membership, and, for a time, the Northwest Regional Laboratory reviewed instructional computer software. Other examples have been cited above.

Typically, when items are reviewed in periodicals, the reviewer receives no payment for his or her work. Such an arrangement might be possible for the reviews contemplated here, but it would not necessarily be advisable. If costs were $100 to $200 per item, to cover the hours of work involved in a review, $100,000 to $200,000 would cover the costs of reviewing 1,000 items. Hence, this initiative would be relatively low in cost.

In addition to its low cost, a strength of this initiative is that, by making reviews available, it would meet important needs. A large number of scientists, mathematicians, engineers, and teachers could be involved as reviewers, strengthening the ties between the science community and elementary/secondary education.

Disadvantages include the potential difficulties involved in having NSF associated with reviews that assess materials produced by third parties. Regardless of the purity of the motive, strong feelings are not uncommon reactions to reading reviews.

Based on the costs shown above, this initiative would require about $0.5 million to $1 million over a 5-year period.

Research on demand and usage--The mechanisms for supplying information implied by the preceding options will be effective only to the extent that there is a strong and continuing demand among teachers, researchers, developers, and others for the kind of information to be disseminated. The nature of "market demand" for this information is not well understood. NSF could support studies to uncover the nature of demand for the information that might be disseminated and to understand what makes users aware of the information, capable of requesting it, and motivated to seek further information about materials, practices, etc. Price sensitivity might also be explored.

A targeted program of research on these and related topics might cost $600,000 to $800,000 annually. Synthesizing what is already known would be an important place to begin. For example, in recent years there has been extensive research on "teletext" and "videotex" information services for the general public, leading, for example, to better understanding of the demand for information in relation to its cost.

Advantages of this initiative include its relatively low cost and the fact that additional investments would be informed by research. Existing clearinghouses (e.g., ERIC) or research-based materials (such as synthesis volumes) might be improved using information from such a research program.

Disadvantages of the initiative are that policymakers may wait for results from research indefinitely before implementing other initiatives designed to make research results, best practices, and information about instructional materials more accessible. Also, research of this nature is not simple, especially to the extent that it asks people about products or services with which they are not familiar.

Based on the costs above, we estimate that $3 million to $5 million would be needed for this initiative over 5 years.

Establishing a usable, NSF-based library of project results--Each project funded by SEE is potentially one from which the science education community could learn. But the potential is not always realized. In most cases, dissemination is left up to the principal investigators, with very mixed results. Even simple descriptive information about the projects funded has, at times, been difficult to obtain. Of equal or greater concern is the ability to access, in a reliable way, products of the projects, such as final reports, instructional materials, videotapes, etc. The lack of more satisfactory solutions in this area is perceived by many outside the Foundation as a weakness in NSF's science education effort. Thus, attacking this problem head-on constitutes an important opportunity for the Foundation.

No single solution will address each of these problems. However, the simplest solution, conceptually, to the problem of documenting and archiving SEE projects is for the NSF to establish and maintain a library that would handle progress reports, final reports, evaluation records, and, to the extent possible, products produced with SEE support, such as instructional materials and computer programs.

To maintain such a library would require a full-time librarian, as well as space and assistance from other SEE staff. To cover the costs of space, salary, materials, communications, and other items (e.g., experimentation with the use of CD-ROM for storage and searching), we estimate that $250,000 per year would be required, for a 5-year cost of $1.25 million.

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BUILDING THE BASE OF INFORMATION AND KNOWLEDGE ABOUT SCIENCE EDUCATION

Supporting the search for knowledge about science and mathematics education has always been held among NSF's educational responsibilities and functions. From its inception, NSF's mandate to "strengthen science education programs at all levels" has included specific authorization to support research on science education; a recent restatement of the Foundation's mandate includes:

> Research on methods of instruction and educational programs in mathematics, science, and engineering...and such studies may include (1) teaching and learning research...and its application to...instructional materials development and to improved teacher training programs; (2) research on the use of local and informal science education activities; (3) research on recruitment, retention, and improvement of faculty; and (4) analysis of materials and methods...used in other countries and their potential application in the United States.
> (42 U.S.C., 1986)

At earlier stages in NSF's history, this mandate has been asserted as well. For example, when other programs were to be transferred to the newly formed U.S. Department of Education under the organizing act for that body (20 U.S.C. 3444), the "conduct of basic and applied research and development applied to science learning at all educational levels and the dissemination of results concerning such research and development" were among the few functions specifically excluded from the transfer, specifying it as central to NSF's educational role.

The Knowledge Base in Science Education and NSF's Role

As in any area of professional endeavor, science education is informed by an accumulating body of information and knowledge about the goals and methods of practice, the state of the field, and the results of efforts to improve it. What is known about science education specifically adjoins the wider bodies of knowledge developed by educational researchers, developmental or cognitive psychologists, and others trained in the social sciences.

NSF has played a central role in establishing the science education knowledge base as a distinct stream of inquiry within this broader intellectual tradition. In fact, NSF's commitment of a significant level of resources to this purpose over the last decade probably has been one of the most critical forces in the development of the science education knowledge base. This fact, combined with the absence of comparable institutions as either a source of support or a focus of intellectual energy, underlies the essential ongoing role that the Foundation must play in this area.

Types of Information and Knowledge Building in Science Education

NSF and the science education community as a whole need to engage in three generic kinds of learning on a continuing basis: about the science learning process itself, about the state of the field, and about the results of NSF's interventions.

Investigating science learning and learning environments--There is a need to examine the processes of science education at the level of the individual learner, teacher, classroom, or other setting for learning. Any attempt to educate young people in science or mathematics rests on assumptions, often unexamined, about the learner, the learning process, and the environment for learning. How, for example, do learners construct a picture of the physical world? What motivates them to change it? How does the answer differ for contrasting types of learners (boys vs. girls, bright vs. average students, etc.) or for different subject disciplines (mathematics vs. life sciences, chemistry vs. earth science)? What kinds of instructional settings evoke the greatest interest among learners? A decade of investigations have advanced our understanding of these kinds of issues. But in the course of developing that understanding, new questions have naturally arisen.

Learning about science education systems. Science education systems as a whole have a dynamic of their own. Here, too, are important, enduring questions that must be answered, regarding such topics as the status of student performance in aggregate, the nature of the teaching force, the interaction of systemic forces that inhibit or enhance student opportunities to learn science, and so on. These questions need to be answered with respect to either formal educational systems (public school districts, private schools, state education policy systems) or informal systems (educational media, institutions such as science museums), or both. Questions arising at the national level--e.g., regarding the incentives encouraging entrance into mathematics teaching or the aggregate effect of state reform initiatives--are especially appropriate to NSF-supported inquiry. But so, too, are investigations at any level that promise to advance general understanding of educational system functioning. How do schools create and sustain effective environments for learning? How do institutions within a region or state interact to support the efforts of elementary teachers to introduce science into their classrooms? How does the presence of a science museum alter the patterns of recreational science activity in a city? These and similar questions invite inquiry.

Documenting and evaluating the results of interventions (and policies) designed to affect the system--NSF and others attempting to improve science education are engaged in a continual process of trying to reshape science education systems so that they operate better. What are the results of these efforts? Are these interventions carried out as planned (and if not, what do they look like)? How do interventions in one part of the system (e.g., the creation of magnet schools for science and mathematics instruction) influence other parts of the system (e.g., science enrollments in non-magnet schools), either by design or happenstance? These kinds of questions beg to be answered, even though they are extremely difficult to study and resist conclusive findings.

The general development of educational and social science research methods over the last decade provides increasingly powerful intellectual tools for addressing these questions. The research community has moved well beyond the once dominant paradigm of controlled experimental studies; now questions about science learners and learning environments are answered through longitudinal studies, surveys, anthropological investigations, quantitative observational methods, and other approaches.

Scholars draw on an equally broad range of techniques to learn about education systems, including descriptive research, longitudinal investigations, explanatory studies, and other forms of investigation drawing on numerous research traditions.

Investigations aimed at this sort of question take many forms, too, from small-scale descriptive accounts of the way a particular technology or classroom method is implemented to national or international assessments of student progress, from evaluations of innovative approaches to training to examinations of policy reforms and their effects.

Purposes for Building the Base of Information and Knowledge

NSF's support for knowledge building in science education can accomplish several broad purposes: advance the state of the art, understand more clearly the realities of current educational practice, and find strategies for closing the gap between the state of the art and the state of practice.

Advancing the state of the art--Given its historical success in supporting innovation in the sciences and engineering, it is not surprising that NSF has always provided funding for forward-looking projects that seek to advance the state of the art of K-12 science education. In supporting collaborations of talented researchers working in the natural sciences, social sciences, technologies, and education, NSF has helped to advance the understanding of the processes of learning science as well as generate new instructional possibilities.

Some science education researchers we interviewed have argued that K-12 science education is so deeply embedded in larger complex social and economic systems that NSF's efforts at fostering incremental change are wasted--that is, the system is so overconstrained that we find ourselves in a "gridlock" situation. In this state of educational gridlock, they argue, efforts to improve curriculum or train teachers will be frustrated by forces from other parts of the system (e.g., unions, testing practices, publishers, administrators). This pessimistic assessment drives some scholars to conclude that NSF's best investments lie in long-term efforts that explore radically new alternatives and experiment with bold innovations. A physics educator and cognitive scientist commented:

> "I am very pessimistic about improvements without radical changes.... I just don't see...short-term direct solutions doing much. But what if a smart team of basic researchers came up with a computer tutor designed to work with a class and an unskilled teacher, and helped them all to learn physics? I don't know

> what the effects of that would be, but I think the short-term prospects look sufficiently bleak that some investment in longer-term, more radical solutions is essential."

Even if one does not accept the gridlock premise, there are still good reasons for NSF to invest in basic research and in highly innovative instructional approaches. High-risk, high-gain experiments draw on NSF's unique strengths (e.g., its connections with the research disciplines in the academic community) in a natural way. Treating education as worthy of the most basic kinds of research will attract a number of NSF's constituencies (e.g., those working in educational technology, natural and cognitive scientists) that otherwise would not be interested in educational pursuits, as a cognitive scientist we interviewed observed:

> "No one can foresee the future, but if SEE were to decide that science education does NOT include the science of education, it cuts off the chance that some really influential discoveries might be made. It also pushes away smart researchers who might turn their expertise to educational research, but probably not to educational development or application."

Over the long term, the work of basic researchers and innovative developers may yield powerful ideas that provide NSF large returns on its investment in terms of their "intellectual leverage" over the practices of K-12 science education. For example, developing appropriate uses for the new technologies, reconceptualizing the way we think about the content (knowledge, attitudes, and skills) of what should be taught and learned, and gaining insight into the processes of learning science and mathematics (and into the formation and function of attitudes toward science) are all activities that have large potential for influencing K-12 science education. More specifically, in terms of helping to develop a broader pool of interested young science learners, a range of basic research efforts may help us to understand how science/mathematics learning occurs for a wider spectrum of students, to know better how to serve this full range of students, and even to understand more fully why there is such a discrepancy between knowledge and practice--between what we know to do and what we actually do.

Also, in terms of advancing the state of the art, probably NSF alone has the ability to bring together the cross-disciplinary combinations of talent required to explore innovative, creative, and revolutionary ideas. NSF is, in fact, unusual among government agencies in having the latitude of mission and the magnitude of discretionary resources to explore intellectual terrain that in all probability would not be explored by anyone else. One researcher put the matter succinctly:

> "If NSF is not experimenting with ideas that will come into practice 10 years from now, who else will do it?"

Understanding current educational practice and systems--In addition to exploring and inventing "what might be" in science education, NSF can support basic research, national status studies, and evaluative studies that seek to understand better the "what is." That is, NSF can support work that furthers the understanding of the important elements of the complex K-12 educational system and how they interact. How well NSF understands the status of science education in the current educational system and the nature of current educational practices will determine, in part, how effective its change-oriented initiatives can be.

NSF and others in the science education community need ongoing access to information that provides a picture of science education as it is actually happening, both in and out of the schools. The "actual" curriculum that exists at the point of instruction may be quite different from the "ideal" curriculum that exists in the state and district syllabi (Shavelson et al., 1986). Natural histories and case studies can help to portray more accurately what is actually happening in the schools, the skills and needs of teachers, and the barriers to change and how they can be overcome. National-level surveys (e.g., Weiss, 1986) can paint a broader-brush picture of the status and condition of science education in the nation and provide some sense of the representativeness of problems and issues. International studies (e.g., Ailes and Rushing, 1986; Stevenson et al., 1986; McKnight et al., 1987) can provide an important outside perspective that illuminates in a unique way the overall health of science education in the country. Studies aimed at shedding light on particular issues (the relationship between testing and curriculum, for example) can help provide insight into critical relationships that exist between different parts of the educational system. Finally, policy studies (such as this one) can help NSF and others not only identify needs and problems in science education but also study in more detail the initiatives and mechanisms most likely to pay off in addressing them.

Closing the gap between practice and potential--Ground-breaking research and studies of current practice are not enough, however. NSF also must understand the discrepancy between what is possible and what is actually happening and seek effective strategies for intervention that can bring the two closer together.

Part of this understanding is accomplished by examining interventions aimed at improving the system to determine how successful they are, or other forms of evaluative inquiry (e.g., research that tests the assumptions on which interventions are based). But part happens through the effort to translate and interpret what is learned from research and evaluation into terms on which the science education community can act. A major synthesis of needs in science education put the matter this way:

> A challenge which needs immediate attention is [finding] a means for translating new research findings into programs for affecting practice; a profession must have a philosophical basis, a research base, a means for change to occur based on new information. Separation of researcher from practitioner is a major problem in science education: all facets of the profession must work in concert for major progress to occur.... (Harms and Yager, 1981)

Through support for networks, collaborative arrangements, partnerships, conferences, interdisciplinary centers, and other mechanisms, NSF can support efforts that aim primarily at engineering the application of research to practice. Such application of research findings, if done in ways that are both effective and practical on a large scale, can close the gap between the level of practice in the field and the state-of-the-art possibilities generated by high-quality research.

Why NSF?

The rationale for NSF to support research and evaluation as an ongoing function independent of specific opportunities has several underpinnings. First, knowledge generation of the sort we have described is critical to guiding NSF's own efforts as well as supporting the field in an important and fundamental way. The ideas and intellectual activity that derive from high-quality research can enrich and sharpen the Foundation's education initiatives at all levels. If NSF is to take a proactive role and pursue strategic goals, it needs an ongoing capacity for gathering intelligence about the field it is trying to influence. A research and evaluation program can also provide early warning signals that NSF initiatives need to be modified, and it can suggest new arenas for future initiatives. Thus, without being a major expense, a focused research program can contribute to an intellectual underpinning and rationale for the Foundation's investments in science education.

Second, NSF has strengths that give it a comparative advantage in doing such work vis-a-vis other public and private agencies. One is that it already is sponsoring most of the major experiments in science education through its programs in informal science education, materials development, teacher education, etc. Research can be designed that complements these projects; in effect, nearly all NSF-supported projects can be exploited as an opportunity to learn about science education and ways to improve it. Another advantage is the sheer level of discretionary resources that NSF can muster. Its aggregate funding for K-12 science education last year exceeded the combined funding of all major private foundations in this area.

A third advantage is that the Foundation as a whole is oriented toward research and knowledge generation: it is closely connected with academia and with the larger scientific research community. SEE, particularly, is well connected with those who are knowledgeable about, and sympathetic to, the subtle and significant issues of science education research. These connections make NSF uniquely capable of identifying productive avenues of inquiry in science education, as well as the individuals most able to carry out this inquiry.

Fourth, the widely recognized need for an interdisciplinary approach in addressing the problems and opportunities in science education makes NSF an even more logical candidate to lead research and evaluation efforts on a national level. Over the years, there has been a growing recognition of the need to address problems in science education in a holistic and systematic way. Fragmented research approaches generally fail to bring about an understanding of how to make systemic changes:

> Some domains of inquiry fit less well into the disciplinary structure than others. One domain that fits badly is research on mathematics, science, and technology education. Understanding and improving education in science requires three distinct kinds of knowledge: first, the structures and processes of the subjects to be taught; second, the fundamental...process involved in learning these subjects; and third, the contexts in which teaching and learning take place--the wide range of formal and informal instructional experiences that are, in turn, embedded in contexts of interacting social and political institutions and norms.... (March et al., 1987)

As a foundation intellectually centered in the field, NSF is ideally suited to serve as a coordinator of information and to facilitate its flow between the diverse groups involved in science education (as noted earlier in this volume in discussing the promotion of networks within the professional community). Like other foundations,

> [NSF] occupies a central position in the intricate web of personal and institutional influences that gives it a power that less strategically located institutions do not have. Its activities bring it into regular contact with individuals from academia, science.... It is a marketplace and nodal point for the exchange of information about trends, problems and emerging ideas.... Its resources are maneuverable.... It can affect the character of other institutions and whole fields of research.... Most important of all, it can assemble the specialized competencies needed to deal with major and complex issues. (Nielsen, 1985)

The absence of adequate investment (by NSF) in knowledge-generation could further entrench the status quo and, at the very least, would waste many opportunities for learning from NSF's own projects. In addition, it would deprive the science education community of its major source of funds for self-examination and future exploration. As one SEE program officer put it, "Research is certainly one of SEE's core functions. Without the research function, SEE would be like an organism without a cortex."

NSF's Past and Present Investments in Building Knowledge About Science Education

Although research is the paramount activity of the other NSF directorates, it has not received equivalent emphasis or status within SEE. Before 1978, there was no identifiable program of basic and applied research in the Science Education Directorate; however, some research was done in the context of the large curriculum development projects. Mostly performed by doctoral students under the supervision of the scientists carrying out the curriculum projects, this early research pursued questions that arose in connection with the projects and was mostly hidden from view. NSF did not have the programmatic means, however, to examine the important part, that the professional community and the commercial marketplace would "evaluate" the results of NSF support, such as the products of curriculum development funding. Nonetheless, a few studies were done of particular investments through the Problem Assessment and Experimental Projects program (in 1974-76); a few large-scale retrospective reviews of NSF's effects were also undertaken, such as the "Platt report," which communicated a shift in NSF's strategy for funding curriculum and course improvement (NSF, 1970) and a comprehensive evaluative review (NSF, 1975) of the Foundation's investments in response to congressional concerns raised by "Man: A Course of Study" (MACOS).

Establishing Research and Evaluation in the Late 1970s

With the establishment of the Research in Science Education (RISE) program in 1978, a long-term effort was begun to build a research infrastructure and a community of people in different disciplines working on related educational problems. In some respects, the program attempted to couple research and development by treating development projects funded under the Development in Science Education (DISE) program as a natural laboratory; at the same time, most of the projects supported by DISE had no formal research component. Attempts were made to couple research with development in other ways; for example, a joint program with the National Institute of Education (NIE) attempted to integrate the perspectives of cognitive researchers, many of whom had no particular focus on science, with those of science product developers.

The ideal of close and vigorous interaction between development and research was not fully achieved in the RISE and DISE programs. There also were no subsequent efforts to synthesize the individual research projects that were carried out under these programs, nor were there mechanisms for making relevant research findings available to those proposing and planning development or teacher enhancement programs.

The RISE program encountered other persistent difficulties:

- The program was "swamped" with proposals for psychological studies focusing on the study of general learning processes, with the science education applications being relatively peripheral.

- Efforts to disseminate research findings widely never got off the ground. Although often interdisciplinary, the existing avenues--journals, conferences, etc.--rarely reached the full community of groups involved in science education. NSF's own efforts to archive and disseminate research findings were not extensive.

- Research in mathematics and science education was generally perceived to be less rigorous (and of lower quality) than research sponsored in the scientific directorates.

An overarching strategy to coordinate and focus the research effort over the long term was largely absent. Infrastructure building, growth in conceptual tools, and the development of research skills take time. The disestablishment of SEE 3 years after the start-up of the RISE program put an end to any sustained research program that might have been developing.

Alongside the establishment of RISE, NSF undertook other forms of knowledge building during the latter part of the 1970s, chiefly through the activities of the Office of Program Integration (OPI). Formed in 1976 with a mandate to gather data on science education and conduct internal evaluative reviews of various kinds, OPI carried out a diverse series of activities, among them:

- Annual compilations of statistics relevant to science education, published as "databooks," which were used internally by SEE staff and distributed externally, as well (e.g., Buccino et al., 1982).

- A series of large-scale status studies, aimed at capturing the state of science education through a survey of science teachers (Weiss, 1978), a set of case studies of science education programs in action (Stake and Easley, 1978), and a review of the science education literature (Helgeson et al., 1977). The results of these studies painted a comprehensive picture of K-12 science education for the first time and became, thereafter, a basic reference point throughout the science education community.

- Follow-up activities to these status studies, e.g., Project Synthesis (Harms and Yager, 1981), which sought to develop a statement of goals and direction for science education based on a synthesis of the status studies and NAEP data.

- Evaluative studies of various sorts that examined the implementation and effects of particular NSF investments.

Although it accomplished a good deal in the years before it was disestablished in 1981, OPI's role and relationship to other programs in the Education Directorate remained a matter of controversy, in particular, with regard to its evaluative function (was it to be a watchdog over program quality?) and its fiscal relationship (was it to undertake its activities by, in effect, "taxing" other programs' budgets?).

SEE's Current Approaches to Research and Evaluation

Following the reestablishment of SEE in 1983, knowledge-building activities resumed once again, alongside other programs. Present (and projected) approaches to knowledge building can be seen as an outgrowth, with modifications, of the pattern established in the late 1970s. We review the nature of current investments in the three types of knowledge building below.

Current investments in understanding science learning and learning environments--SEE invests in the first type of knowledge building primarily through two programs: Research in Teaching and Learning (RTL) and Applications in Advanced Technology (AAT). RTL was set up to "support basic and applied research on significant factors that underlie effective teaching and learning of precollege science and mathematics" (NSF, 1983). Especially encouraged were studies of how students learn and apply complex concepts, and of the factors that are most influential in governing their participation and performance in science and mathematics courses.

The projects funded by this program in the last 3 years cover a wide range--for example, several comparative international studies, applications of information-processing models to the learning of science concepts and problem solving, studies of teachers' cognition and belief systems, and longitudinal studies of factors affecting career choice and attitude formation.

Recent grants have placed increased emphasis on studying factors that affect the quality of instruction and that determine the attitudes and participation of students. For example, present priorities include:

- Investigations of the relationship between teachers' knowledge and their performance in the classroom.
- Studies of the effects of direct personal experience in learning science and how it affects later learning in the classroom.
- Examination of the beliefs and preconceptions of the young learner.

These emphases reflect SEE's growing intent to have its research program generate knowledge that will support and guide the initiatives and priorities of the Directorate.

The AAT program is devoted largely to the purpose of advancing the state of the art in instructional technology (chiefly, the computer) for mathematics and science education:

> This program is concerned only with issues at the forefront of technology applications to science and mathematics education. Projects should be innovative, have national impact potential, and utilize advanced applications in instruction made possible by advanced technology.... We seek to support innovative projects that will lay the research and conceptual foundation for new technologies that will be available in the near term (5-10 years)...we seek not only to focus on current problems, but wish to support new innovations that will create new opportunities for learning and teaching in rapidly changing areas of science and technology. (NSF, 1987b)

The future orientation of these investments is evident not only from program announcements but also from an analysis of projects funded. Investments in computers account for the bulk of SEE's support under the AAT program and, for the most part, are aimed at developing innovative instructional materials that take advantage of the computer as an interactive, visual medium. Most projects are experimental, combining development and research. Projects that lead students to discover algorithms, learn estimation skills, develop geometric relationships, or even promote general problem-solving skills are all pushing the frontiers of educational technology.

Both of these programs represent an effective blend of open-ended support for the best researchers in the science education community and focused attempts to set up and sustain productive lines of research. In both cases, SEE staff have made active use of the professional community to define the agenda for ongoing investments, for example, through an invitational conference on research priorities (Linn, 1986) or small-group consultation with an informal panel of experts on promising targets of R&D in advanced computer technology. Thus, although the two programs have not issued formal solicitations to target the use of their funds, they have devoted a substantial portion of their limited resources ($3.5 million for RTL and $5.2 million for AAT in FY 1987) to a few specific research topics, such as the development of authoring systems or the next generation of intelligent tutors.

Current investments in learning about science education systems--In addition to its research investments just described, SEE has been pursuing over the last 4 years a vigorous program of studies and other investigations aimed at understanding science education systems, chiefly through the Studies and Analyses Program (SAP) within the Office of Studies and Program Assessment (OSPA), an organizational unit within SEE created at the same time as the Directorate in 1983.

To date, SAP has concentrated on descriptive and analytic work that contributes to a better descriptive picture of the state of science education and its needs. To this end, the program has supported, fully or partially, a variety of investigations, including several international comparative studies, examinations of teacher supply and retention, analyses of the science education pipeline, and others. This research has been useful both internally and externally. The program officer in charge of SAP prepares the "science education chapter" for NSF's annual volume *Science Indicators* (e.g., NSB, 1985) and draws heavily on the projects he supports (and on smaller-scale analytic work supported by purchase orders) for this purpose. At the same time, the science education community has treated SAP-supported studies as basic reference points regarding the state of the field. For example, the most recent Forum for School Science convened by the American Association for the Advancement of Science (AAAS), which addressed the state of curriculum development, featured SAP-supported analyses heavily in its compendium of background materials (AAAS, 1986).

SAP has also contributed in several ways to extending the state of the art in this area of research through investments in the development of more advanced national monitoring systems for science and mathematics education and improved assessment instruments (these are discussed in more detail under Opportunity 8 in *Volume 1 - Problems and Opportunities*).

Other activities within OSPA, not part of SAP, have been undertaken (or are projected) to further understanding of science education systems and policies or programs aimed at improving them:

- A large-scale assessment of the Foundation's options in K-12 science education (this study) and a smaller-scale companion study of program options related to middle school science (Weiss, 1986).
- A newly announced program of "assessment studies" (no awards have yet been made) that can "address issues related to the ongoing appraisal of the Foundation's many educational programs" (NSF, 1987a). (This thrust is not the same as direct evaluation of programs or projects, discussed below.)

As in the case of research on teachers, learners, and learning environments, all of the activities supported by OSPA have evolved toward a more focused conception of the Office's mission that both provides a resource to the field and meets SEE's (and NSF's) need for analytical work on which to base its policies. The most recent program announcement puts it as follows:

> The goals [of OSPA] are: to serve as a major source of research, policy data, and appraisal information for strengthening science, mathematics, and engineering education in the United States; and to provide analytical and policy support for the leadership efforts of the Foundation in these critical areas. (NSF, 1987a)

More specifically, OSPA has recently announced priorities that are closely linked with many of the opportunities identified in *Volume 1*, including the study of issues related to participation in science, teacher supply and qualifications, the role of tests and textbooks, the implications of local and state reforms, and international studies. These emphases seem appropriate, not only from the point of view of NSF's role as national overseer of the status of science education but also from the perspective of evolving a Directorate-wide strategic approach to broadening the pool of K-12 science learners.

OSPA's investments in learning about science education systems--in particular, through studies supported by SAP--appear to have been effective, within the limits of the resources allocated to this program (e.g., $2.2 million in FY 1987), and promise to continue to be so in the future. (It is too soon to judge the contribution of other OSPA-supported activities to this goal.)

Current approaches to documenting and evaluating NSF's (SEE's) interventions in science education--Over the past few years, SEE has done little to learn systematically from the experience or results of the projects it funds. In this regard, the Directorate can, in principle, (1) document the activities and results of each project, (2) assess projects in midstream to provide formative feedback to project participants or SEE itself, or (3) evaluate the outcomes and long-term effects of projects once completed. These activities can be done with respect to each project taken by itself or sets of related projects; they can be carried out, in principle, by the project directors themselves, SEE staff, or third parties hired for this purpose. The generic purpose for all these activities is the same: to maximize what is learned from SEE-funded interventions. From these kinds of activities, two kinds of things can be learned: first, about the phenomenon (middle school science inservice, high school mathematics curriculum development, etc.) and ways to address it; second, about the way SEE has sought to contribute to improvement activities.

There is a growing recognition that SEE's current approaches to these activities are inadequate, and some steps are being taken to rectify the situation. SEE must do much more if it is to carry out these functions effectively.

Documentation is typically left to project directors, who submit annual reports of project activities and, at the completion of the project, a final report. These reports vary greatly in quality and are often treated as a requirement to be satisfied, rather than as a means of communicating something essential about the project to interested audiences. SEE project officers tend to do little with these reports when they are received, nor are they assembled in such a way that interested SEE staff or outsiders can easily gain access to them later, as discussed under the previous core function in this volume (see the discussion of mechanisms for archiving and dissemination in "Promoting Professional Interchange"). To date, SEE staff have not experimented with alternative approaches to documenting projects--for example, by using third-party contractors--nor has the importance of the documentation function been emphasized in the grant award process (e.g., by insisting on an adequate plan and budget for this activity within the project proposal).

Formative evaluation of projects while they are under way, either by project staff or by SEE staff (e.g., through on-site visits for monitoring purposes), is relatively rare, also, with one exception. Formative research of some kind is often part of larger-scale development projects, for example, in SEE-supported children's television series. Other than that (and the informal process of feedback that occurs naturally within most projects), systematic attempts to assess what is being done while the projects are in process are the exception rather than the rule. On their part, project directors either feel no need for such evaluation or lack the expertise to do it, or both. SEE staff, on the other hand, find little time for on-site visiting during the bulk of the grantsmaking year, despite their desire to do so. Periodic meetings of project directors can, and sometimes do, provide informal formative feedback, although the full potential of this mechanism for formative evaluation (or documentation) has not been exploited. As in the case of documentation, other mechanisms have yet to be tried, although SEE has begun to consider some possibilities: a midstream assessment of its investments (nine long-term developmental projects funded last year) in middle school teacher preparation is on the drawing boards.

The pattern for evaluating results of longer-term impacts of completed projects is similar. SEE requires, as part of each final report, an evaluation of some sort.

But, for understandable reasons, this requirement is often not taken seriously. Project directors and teams are often not particularly interested in evaluation (it takes time and resources away from what they perceive to be their "real" purpose--development, training, or whatever), nor are they necessarily expert in it. Furthermore, the evaluation task is elusive and difficult, at best: capturing the subtle effects of a network development project, for example, may require observation of network users and exploratory interviews with them to understand how the network's existence opens up new possibilities for users. In addition, the most important effects may not manifest themselves in the short term--that is, at the project's conclusion; a careful evaluation may need to examine the network's effects several years later.

In a few instances, SEE has supported summative evaluations of several kinds. A grant award made by the Informal Science Education program, for example, is currently supporting an evaluation of the science television series "3-2-1 Contact," aimed at understanding long-term viewing patterns and effects on students' interest in or learning of science, among other things. Other grants in the last few years have supported several meta-analyses of the effects of NSF-funded curriculum projects. Although not at the K-12 level, SEE's College Science Instrumentation program has recently issued an RFP calling for an evaluation of that program's numerous investments in upgrading instructional instrumentation (this evaluation will accomplish both summative and formative purposes). It appears that this and other assessment activities coordinated by OSPA (e.g., the assessment studies discussed earlier) represent an increasing commitment by SEE to systematic evaluation of the Directorate's interventions in science education improvement.

Promising Areas for NSF Investment in Knowledge Building

In each of the following areas NSF currently has the opportunity to support a mixture of projects that help to advance the state of the art, understand current practice better, and translate research into practice. The choice of these areas arises from their strategic importance to the goal of broadening the pool as well as from the fact that they represent areas where current and productive lines of research converge.

Further Research on Learning and Learning Environments

Several recent reports synthesize the current state of research in science education and recommend promising directions for future research (Welch 1985; March et al., 1987; Linn, 1986; NRC, 1985). We sketch below several promising directions for research, based on these reviews.

The learner as constructor of knowledge--There is a strong consensus about the need to change the long-standing view of the learner as a passive absorber of information. The learner as absorber (and the accompanying view of teacher as broadcaster) is a metaphor that underlies much of the current practice of science education.

Understanding the learner as inventor and constructor of his or her own knowledge on the basis of interactions with the surrounding environment (including the teacher and the textbook) offers a new perspective for thinking about learning and instruction (Linn, 1986). This active and more autonomous view of the learner presents a range of new possibilities for both instruction and research into science education. A recent NSF-sponsored conference stated it this way:

> The new consensus about the learner reflected in recent studies extends the constructivist view of Piaget by recognizing that learners build conceptual frameworks that are complex, highly organized, and strongly tied to specific subject matter.... There is widespread agreement that learners actively construct an individual world view based upon personal observation and experience and that they respond to formal instruction in terms of this preexisting intuitive perspective.... Teaching correct scientific ideas... requires restructuring the concepts that children have, rather than simply supplying correct concepts. (Linn, 1986)

This view of the learner also has implications for the processes and factors that are highlighted in a research agenda. For example, it suggests that it may be very important to understand the ideas and cognitive structures that "naive" students bring with them as they begin their study of science, and that it may be important to observe in considerable detail what students actually do and think in the course of their instruction. Knowing more about why they change (or don't change) their existing views, intuitions, and problem-solving processes, as well as comparing these processes with the processes of those who are more expert in the subject matter, may yield important insights about the design of effective instruction.

Examples of research questions that NSF might address within this perspective and that support some of the other opportunities NSF now faces include:

- What are the cognitive skills that are part of learning to learn? What knowledge and/or skills are required by those students (the majority) who will not become professional scientists? What additional skills are needed by those who will pursue scientific careers?

- How do teachers currently think about science and science education? What conceptions of science do they bring to their teaching and students? How do they solve the problems they ask their students to solve? Can they model and transfer the same intellectual processes that scientists use?

- How does the use of technology interact with the teacher's and learner's thought processes? Cognitively, what advantages and disadvantages does it offer?

- What kinds of cognitive (and affective) processes are involved in informal science learning experiences?

The report of the National Research Council's Committee on Research in Mathematics, Science, and Technology Education (NRC, 1985) describes cognitive and instructional sciences as one powerful lever available for the improvement of curriculum and instruction:

> Such research has produced better understanding of the components that make good instruction effective, which include: (a) models of correct performance (e.g., of physics or mathematics problem-solving), (b) models of uninstructed performance (e.g., preconceptions of scientific phenomena that interact with the theories being taught), and (c) models of effective instruction (e.g., principles of design for effective instruction).

The advances in research have not taken place in subject-free problem-solving domains; rather, students' reasoning skills seem inextricably linked to the structure and knowledge of the discipline involved. The committee's report describes it this way:

> It appears that problem-solving, comprehension, and effective reasoning are based on subject-specific knowledge. Therefore, it seems best to teach reasoning skills in the context of specific subjects that students are learning. This finding implies that research on reasoning needs to involve experts in a particular discipline as well as cognitive scientists and experienced teachers....

This need for interdisciplinary expertise and collaboration makes NSF the agency that is ideally suited to support this particular research program.

The nature of the learning environment--Complementary to this view of the learner is a more systemic and ecological perspective on the learning environment. Within this perspective the learner is seen as actively interacting with his or her surroundings, which include teachers, other students, the school and classroom climate, and available materials and technologies. Collectively, all of these environmental factors provide a context within which self-generated and self-determined learning is supported (or thwarted). Self-determined learning has been the prevailing view of the learner in informal science education settings for some time; it now appears equally useful for thinking about instruction in the school setting.

Clearly, learning environments are not simple. School climate, teacher attitude and competence, availability of resources, and competencies of other students all interact to provide a context that shapes each student's learning. The interactive nature and complexity of the learning environment invite a more holistic and ecological perspective for NSF's research and development efforts:

> The past decades have seen an accumulation of knowledge...and the development of new technologies, but their application to science and mathematics education... has been episodic, unsystematic and limited in scope.... In other enterprises this integrative function has been called systems design and engineering...

> it has been widely used wherever it has been recognized that proper design involves more than just assembling various components that have been designed in isolation.... Modern educational activities, too, should be considered a system in which improvement of components in isolation may not lead to improvement of the overall system. (NRC, 1985)

Priority should be given to the investigation of the important qualities of different learning environments. What are the unique advantages and constraints of the learning environments in the home, schools, and informal education institutions? To what degree can NSF penetrate or influence these environments? What must individuals developing materials or training teachers know about these environments? How can the learning in one environment reinforce learning in another?

Environmental factors extend beyond the immediate learning environment. Educational researchers have long recognized the influence of the larger context that surrounds individual achievement and motivation. Recent international studies (Stevenson, 1983; Stevenson et al., 1986; Fetters et al., 1983) have dramatized the influential role that parents and home environments play in school achievement, particularly in relation to mathematics achievement. Other research suggests that community norms may play a large part in determining motivation and achievement of different ethnic and racial groups:

> A more satisfactory explanation [for overall group performance differences on tests] is simply that the communities...maintain different norms, standards, and expectations concerning performance within the family, in school, and in other institutions that shape children's behavior. Young people adapt to these norms and apply their talents and energy accordingly. (Bock and Moore, 1986)

For these reasons, it makes sense that questions of how environmental conditions in the home, school, and classroom influence science learning became one of the top priorities for research and possibly development projects (Welch, 1985; NRC, 1985).

In addition to investigating the nature of different learning environments, NSF could support research projects that actively design and explore alternative learning environments (e.g., technology-rich environments, new informal arenas for learning science). (Several of these areas are included in initiatives described in opportunities in *Volume 1*). Many of SEE's present development efforts (most of those within the AAT program, for example) fall within the domain of designing alternative learning environments.

In addition to technological environments, there are new settings and arrangements that can be designed to encourage science education activities:

> Research reviewed in the paper on contextual factors in education...makes it clear that coordinated attention should be given to educational activities that cross the boundary between school and out-of-school learning. For example, after-school learning activities...using such settings as community centers, churches, libraries, and school facilities themselves...could effectively

> increase active learning time for mathematics and science.... Joint school-community and school-museum programs hold promise for mathematics and science education.... What does not exist and needs interdisciplinary research to develop is an overall understanding of the potential and limitations...of such activities. (March et al., 1987)

By bringing together the best minds from diverse university-based communities (the social sciences, cognitive sciences, education research) and the science education community with material developers and those knowledgeable about school environments and practices, new environments can be invented and explored. Specific areas for experimentation, relevant to the goal of broadening the pool, require this range of interdisciplinary research expertise, for example:

- Efforts to apply the methods and findings of cognitive science research to the design of new mathematics and science curricula and learning environments that are suitable for a wide range of learners. Not only would such interdisciplinary efforts lead to improved approaches and materials in science education, but they could help advance the field of cognitive science by providing a rich subject-specific domain for its work.

- Development efforts that investigate the use of technology to create learning environments that are highly effective in interesting and motivating a wide range of learners in activities relevant to science and mathematics learning.

- Experimentation with approaches (products and programs) that help teachers apply the emerging powerful ideas of the cognitive sciences and the new information technologies in their own classrooms.

These examples are not meant to be all-inclusive; rather, they are intended to illustrate how the current high-quality and largely academic research efforts in learning and technology might be productively brought to bear on the major problems in the educational system. As one researcher told us:

> "The problem is that within education there are very challenging and intriguing problems that are being addressed with trivial research efforts...while at the same time in academia there are very bright researchers working in cognitive science and computer technology who are addressing trivial problems."

Understanding the determinants of attitudes, motivation, and career choices--The understanding of attitudes toward science and the formation of an interest in studying science is of the utmost importance to NSF in broadening the base of science-competent and science-interested youth.

> Less is known about the formation and alteration of student attitudes than is known about their cognitive processes. The relationship between attitudes and performance is also not well understood. That this is an important area is underscored by the relatively negative attitudes most students hold toward science and math and by their continuing decline. (Welch, 1984)

For science and mathematics education, the relation between attitude, motivation, and achievement is relatively unexplored. We not only need to find how these link but, more basic than that, we need to explore their measurement:

> More fundamentally troubling is the lack of sophistication and confidence in our ability to assess attitudes in a meaningful way. There is a high degree of consensus in the field that the whole domain of interest and attitude formation is a high priority for study. (Welch, 1985)

Research on interest, attitude, and motivation might benefit from NSF's support for longitudinal studies. Such studies could help to determine how students develop a lifelong interest in science. Models of success are needed in motivating students over long time scales corresponding to the actual period of an individual's career development (Linn, 1986). Such longitudinal studies might include studies of scientists (Bloom, 1985) as well as students.

New conceptualizations of science, science learning, and science education--The challenge of reconceptualizing K-12 science education has already been described in *Volume 1* as a major opportunity before NSF. Underlying this effort is the continuing need to explore the theory and direction of science education. The need for clarity about the goals of science education has been voiced repeatedly (e.g., Hurd, 1986a; NSB, 1983). Conceptual research on the essentials of scientific thinking, the goals of science education, and the concrete manifestations of science literacy could do much to clarify and refine fundamental visions of what science education should be. For example, the meaning scientists attach to the term "scientific literacy" (which to them emphasizes attitudes and evaluative skills, as well as knowledge of the process of inquiry), often differs from the response of the schools to the call for scientific literacy (which is to push an encyclopedic view of science). Better and more specific definitions of goals for "general" science education are needed (Harms and Yager, 1981). More viable ways are needed to define what is meant by critical thinking, problem solving, and basic skills in science (AAAS, 1985). A mixture of philosophically based conceptual analysis and real-world experimentation could help further the fundamental aim of formulating, describing, and illustrating the basic aims of science education.

The current mechanism for supporting research in these areas--through open grants competitions and targeted priorities within them--is appropriate for continuing support in this area. Other mechanisms (most of which presume a somewhat larger overall level of investment in this function) ought to be considered as well:

- *More extensive agenda building*. For example, through conferences convened on a regular basis, SEE could play a more active and continuing role in shaping the agenda for research on science education.

- *Formal solicitations on focused research topics*. For example, some of the research areas sketched above could be more productively pursued by drawing attention to them and earmarking a certain level of funding for them.

- *Research "add-on" grants.* With relatively little additional funding (e.g., grants in the $50,000 to $150,000 range), project directors of existing larger-scale development projects might add a research component to examine unanticipated research questions that arise in the course of development.

NSF (SEE) could maintain adequate support for research on learning and learning environments for an estimated $4 million to $6 million a year. (More than this would make sense, if SEE's overall strategy placed greater emphasis on advancing the state of the art, as in the "fundamental change" strategy discussed in the *Summary Report* and earlier in this volume).

Further Investments in Understanding the Status and Functioning of Educational Systems

NSF (SEE) should continue its support for studies of the state of science education, along the lines described above. Several areas of investigation not emphasized in OSPA's plans for the future include:

Barriers and facilitators of students' exposure to science education opportunities--Given NSF's vision of providing the nation's youth with widespread opportunities for rich and diverse educational experiences in science and mathematics, the study of what constrains and facilitates interactions with science resources can provide crucial information for implementing this vision. A recent review of possibilities for research in science education gives exposure to science activities top priority:

> This research question is based on the assumption that students need to be exposed to science learning opportunities by enrolling in courses or by participating in out-of-school activities. Science enrollments are low and little is known about procedures for changing this. Furthermore, our understanding of informal science learning opportunities is minimal. To improve science learning, we need more students participating in more science learning activities. Research aimed at discovering ways to do this seems essential. Without students in classes, the best instruction is for naught. (Welch, 1985)

The report of the National Research Council's Committee on Research in Mathematics, Science, and Technology Education discusses in a similar way the importance of finding ways to increase both the amount and the quality of engagement that youth have with science resources:

> Expanding the capabilities of the educational system to increase the amount of quality learning time--that is, time devoted to effective teaching in contexts that engage the learner--should therefore be a primary objective of a research agenda. (NRC, 1985)

Similarly, lack of time on task has been identified as a crucial constraint in the present science educational system (e.g., NSB, 1983). International comparisons also show American students spending far less time on science and mathematics in grades K-12 than students in many other nations (e.g., McKnight et al., 1987).

We need to know in much more detail what in the educational system and its context inhibits exposure to science learning, why these barriers exist, and how they might be changed.

Understanding connections between important components in the educational system--In trying to affect the science education system, NSF needs to understand how different system components interact. For example, how does testing actually affect the curriculum? How does the process of textbook adoption limit alternatives for effective reform? What is the role of state frameworks in determining what happens in the classroom? What is the relationship of science supervisors to teachers? Answers to such questions have very real implications for both the design of research and the engineering of its application. NSF needs to understand how all of the critical institutional components of the K-12 educational system interact if it is to work effectively with the schools. Various observers have argued for the need for a "systems" or "ecological" view, for example:

> Studies generally are viewed as too narrow in concept and flawed in method to deal realistically with the complexities of human behavior. The physical science model, so widely used in educational research, with its emphasis on experimental control of variables and statistical analysis has limited value for investigating issues raised by the reform movement.... Better would be a model derived from ecology which recognizes complexities and assumes broad patterns of interactive behavior such as would be characteristic of a teacher and students in a learning situation. (Hurd, 1986b)

The interaction of emerging national social needs and the role of science education--The changing demographics, the progressive disenfranchisement of large groups of people from the scientific world, the increasing need for a higher level of public science literacy, and the threat of weakness in the technological/human-resource infrastructure all are issues that will bear on the role that science education must play. Accordingly, research on science education as a system must continually examine the implications for science education. More simply put:

> Science education research ought to explain how [all] students can be attracted to the field, how they can be encouraged to pursue education in science that is appropriate to their needs, and what scientific knowledge they should have.... (Linn, 1986)

NSF (SEE) can maintain support for these kinds of investigations for between $3 million and $5 million a year, depending on the exact nature of its investments (ongoing support for monitoring systems, for example, is likely to be more costly than studies).

More Extensive Documentation and Evaluation of SEE's Investments

Aside from their direct benefits to the target audience and their indirect benefits to the project participants, NSF's projects are potentially valuable investments for a much wider audience. The extent to which this value is realized depends on the degree to which NSF invests in efforts to learn from its own projects and to share what it learns with others. There are two complementary approaches to learning from SEE's own projects. One is to document and evaluate each project (or sets of projects) as a case (or set of related cases) to be learned from. The other is to treat each project (or set of projects) as an arena for research into more basic issues involved in the teaching and learning of science.

Because it has done relatively little to document project activities and evaluate their results, SEE has considerable room for experimentation with more effective approaches. Whatever it does will rest on several premises: (1) evaluation and documentation are central to the ongoing process of learning from interventions in the field, (2) effective evaluative learning will only happen when higher priority is placed on these kinds of activities, and (3) higher priority means a relatively greater allocation of either SEE staff time or funding (e.g., for evaluative activities carried on by outsiders), or both. The allocation of resources to this purposes should not be excessive--perhaps 10% of all resources could be devoted to this purpose (a major national foundation routinely allocates 15% of each project's budget to documentation).

SEE must proceed with caution in this area because evaluation of educational programs is difficult to do well. Blindly or mechanically applied, many evaluation techniques have little value as a way to learn from or about SEE's investments. Under pressure for public accountability, a great deal of money has gone into educational evaluation over the last two decades, and much of it has been wasted. The emphasis must be on *appropriate* evaluation, drawing on the best of recent thinking about evaluation design and techniques. The following kinds of activities deserve consideration:

Building cross-project evaluation (and research) agendas into the proposal solicitation process--Although there are distinct limitations on the capacity (or willingness) of a project team to "study itself," SEE could do more to incorporate better documentation and evaluation into the original thinking behind project design, especially into the design of larger-scale projects solicited for focused purposes. By making evaluation design a clear priority in proposal preparation (and review) and by suggesting in its solicitations to the field elements of a common evaluation agenda to be addressed by all projects and to be carried out by project staff (or others) over the life of the project, SEE stands a better chance of attracting proposals and supporting projects that take the need for evaluation seriously. Other ways might be considered to assist project directors with the task of evaluation, such as support for a Technical Assistance Center, analogous to those funded by the U.S. Department of Education to assist local compensatory education programs meet evaluation requirements. Nonetheless, SEE should not overestimate the yield of evaluative information from project directors who lack expertise in evaluation work.

documentation, it can produce insights into the phenomena being addressed by the projects in question. Project directors could be given the incentive to prepare and present thoughtful critiques of their own work or assessments of key issues confronting their projects by organizing the meetings somewhat like symposia and publishing "proceedings" from the meeting (recorders or transcribers with good substantive and editorial skills would be necessary to accomplish this goal). SEE has already begun to experiment with these meetings and should continue these experiments.

If it invested between $2.5 million and $3 million annually in separate documentation and evaluation activities, SEE would be able to sustain a varied array of systematic learning activities. In addition, a certain portion of many grant awards should be reserved for documentation or evaluation, as discussed above.

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SUPPORT FOR INNOVATION

NSF cannot anticipate all of the interesting developments regarding science education at any one time. Unanticipated opportunities are likely to arise that deserve consideration and the possibility of discretionary support. NSF has an especially important role to play where these situations lead to highly innovative ways of thinking about science education, creative models for approaching problems, or new avenues for NSF (SEE) to exert its influence. We include the following categories of activities:

- *Innovative proposals that do not match current priorities.* Certain unsolicited proposals are exceptionally innovative and creative, but do not correspond to the programmatic emphases of the Foundation at the time. For example, a proposal to do exploratory research on iconic languages and their relationship to visual aspects of science education would not fit with current emphases in any of SEE's programs, yet could deserve serious consideration (assuming the proposal were imaginatively prepared).

- *Cross-cutting proposals.* Some proposals cannot be assigned easily to one program area because they combine elements of several--for example, a proposal for developing instructional materials and associated training approaches derived from recent research on teaching, or a proposal to establish a network among software development firms for the purpose of collaborative exploratory work in a new area of software design.

- *Unanticipated events.* Unanticipated events often present new possibilities for the Foundation that deserve to be explored. For example, the sustained interest shown by the public in the Carnegie Forum report *Teachers for the 21st Century* and the resulting momentum toward fundamental restructuring of the teaching profession was unanticipated by even the Carnegie Forum itself and has created an opportunity for the Foundation to explore the way these reform proposals relate to science and mathematics teaching (SEE has, in fact, taken steps to open a dialogue with leading individuals within this reform movement).

The Role for NSF

In response to these situations, NSF (SEE) needs to maintain, on an ongoing basis, a discretionary reserve of funds that it can draw on when the merits of the unusual proposal or unforeseen opportunity warrant it. Mechanisms need to be in place, as well, that maintain an openness to these possibilities, and even to encourage, within reason, the submission of these kinds of proposals.

Serendipitous discoveries play as important a role in educational improvement as in scientific research, even though the task of improving educational systems generally demands more focused investment than does basic scientific research. NSF (SEE) can enhance the possibility of such discoveries by devoting some portion of its funding to open-ended investigations aimed at highly innovative research or development (not clearly related to targeted priorities), as well as by reserving some discretionary funding for important unanticipated events.

Such possibilities are especially appropriate for the Foundation to consider. NSF is one of the few national-level agencies with sufficient resources to encourage innovation in science education and to take advantage of unanticipated events. Although private foundations are a possible source of support for such things, few specialize in science education issues, and even fewer have discretionary funding to support high-risk or innovative activities. Furthermore, many of the larger foundations that take an interest in science education (e.g., Carnegie, Ford, Sohio, Sloan) have fairly well-defined program emphases that exclude a wide range of proposal possibilities. Other government agencies are an unlikely prospect; their resources for this kind of endeavor are very limited and are often aimed at a particular target. The U.S. Department of Education (ED), for example, has a small amount of funds available for unsolicited grants (under the Secretary's Discretionary Fund, a set-aside percentage of money under Title II of the Education and Economic Security Act, earmarked for the improvement of mathematics and science education), but the bulk of ED's funding for mathematics and science education improvement goes to states and localities in the form of block grants for teacher training programs. The situation is analogous to that facing research, as we described in the previous section: NSF is one of the few agencies with a broad enough focus and sufficient discretionary resources to consider the possibility of maintaining some resources for unsolicited, highly innovative activities.

NSF's (SEE's) Current Approach to Open-Ended Innovation Support

Currently, the Foundation handles these possibilities in two ways. First, as a general policy, SEE will accept any proposal it receives on any topic related to science education. Proposals are assigned for initial consideration to one of the nine programs that are aimed at the K-12 level. Because the program rubrics are comprehensive and because each program operates under a broadly defined program announcement, it is likely that an unusual proposal will come close to at least one of the existing program areas. Second, each program officer is informally allotted a small amount of discretionary resources for special events and opportunities that arise; the Assistant Director exercises comparable discretionary control over funds when the occasion warrants.

There is a third way that the Foundation solicits innovative ideas from the professional community. Some SEE programs place heavy emphasis on innovation or "model building" in program announcements; it is also common knowledge in the professional community that the Foundation favors support for new activities on a "seed-funding" basis. But this kind of invitation to creativity is typically related to a specific set of programmatic priorities. The Applications of Advanced Technology (AAT) program is a case in point. Of all of SEE's current programs, it is most clearly oriented toward high-risk, high-gain investments, through funding meant to develop prototypes of the next generation of instructional technology. The current program announcement, reinforced by the priorities of the program officer, is quite specific (this is, in fact, one of the program's strengths). AAT is concentrating its resources on the following priority areas: symbol manipulation tools, authoring systems, problem solving with computers, and intelligent tutors. Proposals to explore other aspects of advanced instructional technology, which might have considerable merit, are unlikely to get well reviewed.

The example points out a dilemma for SEE, which becomes more acute as it directs its funding toward more specific targets and opportunities: the Foundation may be less sensitive to creative possibilities that don't fit its programmatic priorities. In one sense, that is the cost of becoming more focused, but at the same time the long-term success of NSF (SEE) depends in part on a continual responsiveness to new possibilities.

In principle, SEE's system takes care of this need, but there are several ways in which it falls short of the mark. SEE staff indicate that proposals that do not clearly adhere to the announced priorities within each program or that combine priorities of more than one program are at a disadvantage in the proposal review process; SEE's programs are not a completely open invitation to the field. Highly innovative proposals are at a disadvantage in a different way; such ventures are likely to draw mixed reviews from panels or mail reviewers because of the diversity of viewpoint among the reviewers chosen. Even though follow-up reviews may be arranged to resolve the discrepant reviews, it is still very difficult for innovative proposals to receive consistently high marks and, hence, gain acceptance.

The result is a pattern of mutual caution exercised by both SEE and the professional community. Proposers tend not to submit "wild" ideas, because they understand that these are unlikely to be well reviewed. On its part, SEE relies on a review process that tends to screen out the more innovative ideas.

There are, of course, good reasons to be cautious with public funds. NSF would not want to be in the position of putting *most* of its education-related funds into high-risk, high-gain activities. The expectations of the public and Congress, among others, are too oriented toward shorter-term efforts that achieve visible results. Nonetheless, the problems of K-12 science education call for bold thinking and creativity. NSF (SEE) can help to keep this kind of thinking alive.

Alternative Approaches

There are various ways to improve this situation. The following are some ideas that SEE should consider.

Setting up a "mad money" pot--By reserving a modest amount of money (e.g., half a million to a million dollars) every year for innovative proposals that do not conform very well to the scope of existing programs, the Foundation could formally invite such proposals more directly than it does now. Required preliminary proposals could streamline the screening process and help to nurture promising ideas that are not yet at the full proposal stage. (Other agencies have created precedents for this approach, such as the National Institute of Education's Unsolicited Grants Program or the Fund for the Improvement of Postsecondary Education.)

Creating a cross-program task force of SEE program officers for handling innovative proposals--Such a group would be charged with identifying promising proposals that "fall between the cracks" and setting up an appropriate standing panel for considering them. Special review procedures might be necessary to ensure that the unusual nature of these proposals was not a negative factor. The task force could be allocated a target amount of funding, say $1.0 million and $1.5 million annually, to invest in the most promising cross-cutting proposals that do not fit neatly into any one program category.

Increasing and formalizing the discretionary funds at the level of individual programs, divisions, or even within the Director's office--This activity would simply establish current practices more securely. A total discretionary reserve of approximately $1.5 million annually would provide SEE professional staff with sufficient wherewithal to respond to appropriate opportunities as they arise.

A total annual allocation of $3 million to $4 million would thus be sufficient to cover unanticipated opportunities and support unsolicited, innovative proposals of the kind described here. However, if overall NSF (SEE) strategy were to emphasize advancing the state of the art, as in the "fundamental change" strategy noted earlier and discussed in the *Summary Report*, then a proportionately greater investment in open-ended idea generation might make sense.

PART TWO:

THE BASIS FOR STRATEGIC INVESTMENT

- Designing Initiatives

- The Basis for Overarching Strategies

- Notes on Strategic Capacity in NSF

PART TWO:

THE BASIS FOR STRATEGIC INVESTMENT

In this part, we explore three requirements for the National Science Foundation to invest its funds strategically in K-12 science education. First, NSF must design initiatives aimed at opportunities (such as those described in *Volume 1* and the *Summary Report*) related to the long-term goal (i.e., of broadening the pool of competent and interested science learners up to the age of 18). Second, it must develop an overarching strategy to guide the choice and relationships among initiatives, so that they have the greatest chance of achieving mutually reinforcing effects on the goal. Third, the Foundation must build and maintain its capacity for investing strategically--that is, ensure that it has the staff, procedures, and resources in place to carry out strategic investment in science education over the long term.

As a base for this strategic investment, the Foundation must also invest in core function activities on a continuing basis, as described in Part One of this volume, so that it has the information to design initiatives properly and the professional community is adequately prepared to respond to these initiatives.

Because the business of contributing to K-12 educational improvement is different from the business of supporting scientific and engineering research, the Foundation's approach to investing in science education needs to differ significantly from the arrangements for supporting scientific research. The approach to science education must be proactive, coherent, and targeted. Investments need to be engineered so that systemic changes are likely. In its Education Directorate, NSF has begun to rebuild the capacity to undertake this kind of investment, but the Foundation's strategic capacity requires further development and the support of the Foundation as a whole if strategic investments are to achieve the maximum payoff.

These components of strategic investment in science education, and the relationships among them, are displayed schematically in Figure 2-1. A discussion of each follows.

Designing Initiatives

By "initiative" we mean a programmatic attempt to support projects and other activities aimed at particular targets, using certain funding mechanisms, and embodying a particular philosophy or "theory" of change. In the course of examining each opportunity, we developed a set of initiatives that we believe deserve serious consideration as NSF decides how it will direct its grant programs.* These are not the only sensible initiatives that can be imagined; rather, they are meant to illustrate initiatives that are likely to achieve desired results.

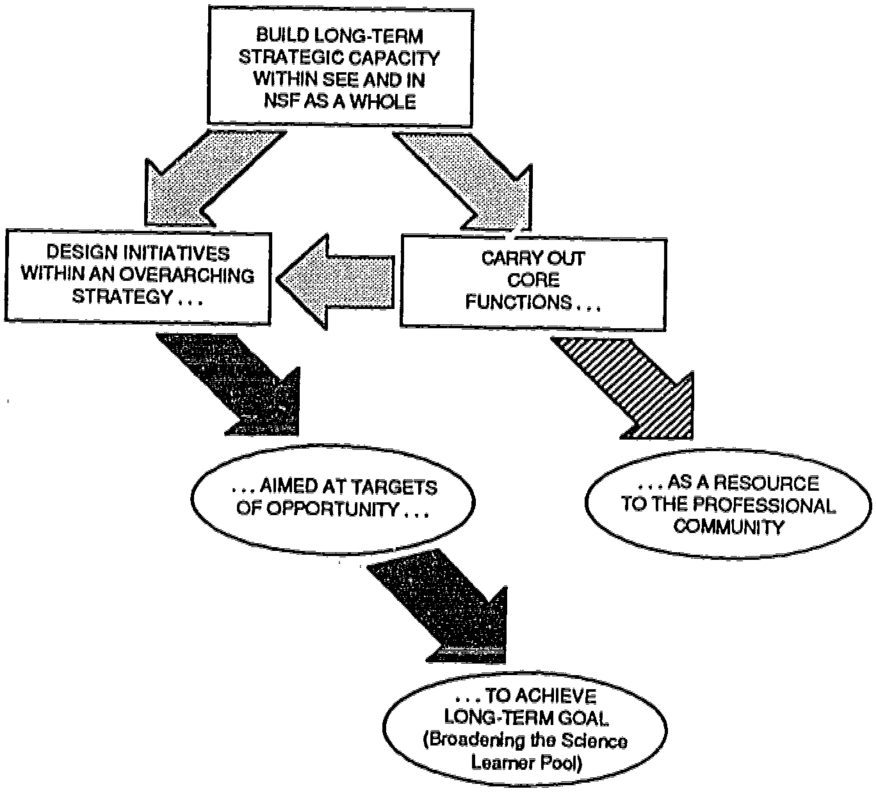

FIGURE 2-1 ELEMENTS OF STRATEGIC INVESTMENT IN K-12 SCIENCE EDUCATION

A Way of Thinking About Initiatives

We think of initiatives as hypotheses--that is, an informed guess about the way the Foundation's actions (a solicitation, the award of funds, etc.) will influence the science education community and, in so doing, affect the quality of instruction and learning in science. As it is implemented over time, an initiative sets in motion a chain of causes and effects that represent a "test" of the original hypothesis.

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* These initiatives are described by the area of opportunity to which they relate, in *Volume 1 - Problems and Opportunities*. A summary listing of initiatives, organized by two overarching strategies, appears in Appendix A of this volume.

In these terms, "initiative" is not synonymous with "program," at least as the concept is used in SEE today, although there is clearly overlap. In most cases, SEE's programs are less focused than our definition of an initiative would imply, but one may still discern a hypothesis of sorts within each program. The Instructional Materials Development (IMD) program thus embodies a hypothesis that might be stated as follows:

> By inviting the science education community to propose projects aimed at developing innovative curricula across the full range of grades and subjects (mathematics, biology, earth science, etc.), SEE will be able to increase the array of creative curricular improvements from which educators and others (e.g., publishers) select their materials. This process, in time, will enhance the curricula to which students are exposed.

Within the IMD program, the "targeted solicitation" aimed at elementary science materials development (initiated in 1986 and still under way) embodies a more complex and focused funding hypothesis. It could be stated as follows:

> By providing long-term (e.g., 4 to 5 years) funding to large-scale collaborative projects--combining the talents of developers, publishers (as intellectual and financial partners), and a school system (as a laboratory for testing and refining developed materials)--SEE can generate a small number of creative and commercially viable alternatives to current elementary science programs. The terms of SEE's solicitation and awards will (1) focus development on science programs that work well for the "average" elementary school and student, and (2) encourage publishers' commitment to widespread dissemination of the materials when they are produced. Ultimately, these materials will reach a substantial proportion of the student population (assuming success in previous steps).

Whether either hypothesis will be borne out by the events of the next 5 years or more is a matter for speculation at present and is not the point of the discussion here.* The examples are meant instead to illustrate some of the components and variables involved in initiative design:

- *Targets*, which can be either broad (curriculum improvement in mathematics or science at any K-12 level) or narrow (innovative elementary science programs).
- *Funding mechanisms*, which includes the funding vehicles (grants, contracts, purchase orders, etc.), size and duration of awards, the specificity of the proposal solicitation mechanism, and the nature of requirements for project completion.

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* Our assessment of current investments undertaken with regard to either hypothesis appears in *Volume 1* in Opportunities 1, 2a, and 7.

- *Intended type(s) of grantee*, which may be relatively unspecified (as in the IMD grants program) or rendered fairly specific (as in the case of developer-publisher-school system collaborative teams).

- *A philosophy of, or approach to, change in educational systems*, for example, emphasizing short-term incremental improvement or longer-term fundamental change.

- *Hypothesized relationships* between (1) NSF's actions and the grantees' response, and (2) grantees' activities (supported or stimulated by NSF) and effects on the target.

Design Considerations

Designing a suitable initiative to address the opportunities described in other volumes of this report parallels the process of identifying the opportunities themselves (see *Volume 1*), only at a more practical and operational level. The central design considerations are: (1) Within the area of opportunity, what intervention targets are most critical and most closely related to the long-term goal of broadening the science learner pool? (2) What approaches to the problem are appropriate to NSF as a federal science funding agency, draw on NSF's unique capabilities, and are likely to maximize the direct and indirect impact of its dollars? (3) What approaches to the problem are most timely, given the activities of others, conditions in the field, the state of knowledge about the problem, etc.? Two other considerations--one philosophical, the other practical--also enter into the process of designing initiatives. First, what philosophy or "theory" of change is most appropriate to the opportunity (and most consistent with overall strategic objectives within the Directorate)? Second, what approaches are most feasible, in terms of both administrative requirements and political exigencies? Responsiveness to key constituencies--in Congress, the scientific establishment (including the NSF hierarchy outside SEE), and the science education community (or segments within it)--is an extremely important consideration in this regard.

Assuming the initiative takes these considerations into account, it must meet the ultimate criterion: does the hypothesized relationship hold? Does the activity set in motion by NSF funding, leadership, communication with the field, etc., contribute to improved conditions for teaching and learning science?

SEE's Current Array of K-12 Initiatives

In the past few years, SEE has demonstrated an increasing ability to design sophisticated initiatives that take into consideration all these factors. A good example is the targeted solicitation, issued 2 years ago (with awards made in 1986), supporting the development of elementary mathematics programs that feature the calculator and the computer. It addressed a central conceptual and programmatic problem in K-6 mathematics (the organization of mathematics to reflect the impact of two key technologies), approached the problem in a way that was particularly appropriate to NSF (by inviting collaborative projects drawing on the mathematics education and mathematical sciences communities), and called for proposals at an opportune time (following a spate of reports calling for the reform of mathematics education, at a time when the two technologies were becoming widely dispersed in schools). Furthermore, the initiative was eminently practical; the implied philosophy of change--aimed at long-term rethinking of the K-6 curricular base--was appropriate to the state of knowledge and general progress toward reform goals.

Not all of SEE's recent initiatives are as well conceived. A recently announced "private sector partnerships" initiative provides a case in point. It calls for "activities by partnerships between business/industry, school systems, and other educational institutions...to demonstrate ways in which community concerns can be translated into positive action to improve the quality of science, mathematics, and technology education" (*Federal Register*, March 17, 1987). Although the initiative is generally responsive to political constituencies and to the apparent interest of many private-sector firms to broaden their support for improving science education, the initiative is likely to spawn a diverse series of demonstrations that may contribute little toward the goal of broadening the science learner pool or to any other strategic goal. The initiative is reactive, not strategic, and is more properly thought of as a mechanism that could be used to address any specific programmatic goal (in fact, the initiative invites proposals that relate to any of the existing K-12 programs).

Other recent initiatives launched by SEE fall on the continuum suggested by these two examples, from carefully conceived, complex solicitations to those with a less sophisticated hypothesis about educational improvement. The elementary science materials development initiative described earlier and a solicitation for projects to develop comprehensive teacher preparation programs for the middle school level (issued in 1986) fall at the more sophisticated end of the continuum. Others, including several less formally declared initiatives, such as investments in intelligent tutors (part of the Applications of Advanced Technology program) or children's science and mathematics television broadcasts (part of the Informal Science Education program) fall in between. The hypotheses represented by these investments are simpler (although no less carefully thought out). Still others--including ones currently under consideration--represent less careful thinking and a still simpler hypothesis about NSF's effects on the field.

The Process of Initiative Design

The current array of initiatives supported by NSF (SEE), and future ones that it may put forward, emerge from a process of initiative design that is often fairly ad hoc and dependent on an individual's grantsmaking skill, although there are clear exceptions such as the elementary science materials development solicitation, which evolved over a period of time with a good deal of consultation among publishers and others in the science education community. More typically, however, the process happens as described by a SEE staff member:

> "I'll tell you how it happens most of the time. I will get word from upstairs that we ought to have an initiative for such and such a reason and that we need it soon, and so I sit down and write it--in an afternoon, pretty much out of my own head. Do I have good information on which to base my judgments about the focus, grant size, stipend level, or whatever? No, I don't; I just go with my intuitions. Then the thing will probably go through several drafts with some of my colleagues commenting and that's it."

It is possible, of course, to develop sound initiatives this way. SEE's staff are capable individuals, and those who have been around the Foundation for a while have a great deal of grantsmaking expertise to draw on. However several characteristics of this process limit its potential to yield strategically potent initiatives. First, the process is heavily driven by political exigencies. The wishes of Congress and of the NSF hierarchy will always be critical factors in anything SEE plans to do, but that doesn't mean that they should be the sole driving force. Strategic planning can anticipate political factors at the same time that it considers the various ingredients for an opportunity described elsewhere in this report (important national needs, appropriateness to NSF's unique capabilities, and timeliness). Second, the time line for initiative development is often very short; some SEE staff describe the process as operating in a "crisis" mode. Understandably, there is little time for refining or revising initial ideas for initiatives. Third, the process allows for little input from the professional community with regard to either the larger question--is this the right target for an NSF initiative?--or the more specific questions about the details of the initiative itself.

Contrast this process with standard operating procedure at a major private foundation engaged in science education improvement, among other investments addressing domestic social issues. Program officers in this foundation develop initiatives over a long period of time--half a year to a year, for example. During that time they put together what amounts to a proposal for an initiative--with a fairly detailed rationale, estimates of costs and likely effects, etc. This proposal is often developed with the help of outsiders, through brief (1-day) initiative design meetings and other forms of consultation. At the end of the year, the proposal is presented to the foundation board; if it accepts the proposal (and assuming money is available), the initiative is launched and given a substantial period of time (e.g., 7 years) to prove itself.

There are important and inescapable differences between private foundations and NSF. Private foundations do not have to answer to the public and its political representatives, for one thing, and have far greater discretion over their funds. Nonetheless, there is no reason in principle why the kind of careful initiative design process described above, or a variation on this theme, could not become standard operating procedure for NSF in matters of educational investment. All initiatives could be developed through a process that included:

- *Scanning*. A careful review of salient issues in the field, conducted on a regular basis through commissioned papers prepared by experts in the field (this is now being done by the Office of Studies and Program Assessment in its planning for the future) and by other devices (agenda-setting meetings, surveys, policy studies, etc.).

- *Selecting.* A process of prioritizing targets for potential initiatives that is referenced to overall strategic objectives of the Education Directorate (and Foundation) and selecting among them a set for more detailed planning and review.

- *Formulating.* Sketching the design of the initiative with diverse input from both SEE staff and outside experts; this should be done iteratively, resulting in an equivalent of the private-foundation initiative proposal described above. The formulating process (and the initial process of scanning) should be done with sufficient outside input to generate awareness of, and interest in, the initiative within the science education community.

- *The go/no-go decision.* The initiative proposal should be reviewed and scrutinized carefully by an appropriate group within SEE (possibly including NSF staff from outside the Directorate)--for example, one that oversees long-range planning for SEE; this group then would recommend action to the Assistant Director of SEE.

Experienced SEE staff would no doubt point out that this kind of process is both time consuming and difficult to fit into staff job assignments as currently conceived, and they are right. But when one considers the consequences of most of SEE's initiative design decisions, which commit millions of dollars in public funds to improvement activities over a long period of time, there is ample justification for taking this activity very seriously. To do so may well involve significant changes in staffing and staff assignments (see discussion below of "strategic capacity").

Implementation of Initiatives

Although the point may seem obvious, the ultimate success of any initiative rests as much with the way it is implemented as with its design. The initial design, often reflected in a program announcement, is only one step toward strategic investment. For the initiative to be effective, SEE staff must implement it proactively, through such activities as: actively communicating with relevant professional audiences, encouraging proposals from highly qualified individuals and groups, "shaping" proposals, monitoring projects once they are under way, evaluating their contribution to strategic objectives, etc.

SEE program staff do much of this routinely, but the limitations on their time preclude active monitoring and evaluation. Mid-course adjustments in project plans are generally left to the project directors' discretion entirely. As is the tradition with most scientific research grants, SEE grants funds to presumably capable individuals and trusts them to accomplish the task they set out to do. That model is probably more applicable to scientific research than to the "social engineering" task that many SEE-funded projects undertake. Accordingly, there is a greater need for attention by NSF (SEE) to the projects it has already funded for several reasons. First, project directors engaged in complex projects are likely to need support, encouragement, technical assistance, and critical feedback. Second, as pointed out in the discussion of documentation and evaluation earlier in this volume, each project is an opportunity for the science education community as a whole to learn about science teaching and learning, as well as interventions in the educational system. Strategic investment implies that the Foundation will do what it can to maximize this sort of support and learning.

Developing Overarching Strategies

An overarching strategy for SEE, as we define it, is an organizing rationale guiding diverse investments in K-12 science education. A strategy has the following components:

- An overall long-term goal, along with 5- to 10-year objectives that represent steps toward the goal.
- A coherent set of initiatives--aimed at improving (1) content and approach, (2) professional capacity, and (3) system functioning--that seem likely to achieve the strategic objectives.
- A clear philosophy of educational change and NSF's relationship to it.

A coherent, clearly articulated strategy to guide NSF's investments in K-12 science education would accomplish several things at once. First, it would increase the likelihood that NSF's (SEE's) initiatives would achieve mutually reinforcing effects on the long-range goal. Given the complexity of the goal we have suggested (broadening the pool of competent and interested science learners up to the age of 18) or, for that matter, almost any educational improvement goal one could imagine, it is important that NSF's limited resources be deployed to achieve maximum effect. An overarching strategy assures some concentration of effort. Second, the existence of the strategy provides a reference point for NSF's (SEE's) own planning. The choice of the next initiative, decisions about which proposals to fund, and communication with the professional community, among other tasks, are all easier given a clear sense of the Directorate's guiding strategy. Third, the existence of a guiding strategy sends clear signals to the professional community about the larger purposes around which talent and energy can mobilize. SEE will always be dealing with a diverse professional community, but if it can energize those elements of the community that have the most to offer to a particular strategy, rather than supporting professional efforts that are moving in all directions at once, it can build momentum toward difficult-to-achieve ends. Finally, NSF (SEE) is in a much better position to explain and justify to Congress and other political bodies its need for, and use of, funds if it can articulate a clear sense of direction to its investments.

In the last few years, a strategy has begun to emerge as the predominant direction for SEE's K-12 funding. On balance, most of SEE's funds are awarded to projects aimed at achieving incremental improvements in the short term, more than at fundamental reconceptualization or restructuring over the long term. Emphasis is shifting to the elementary and middle school levels; the bulk of funding is devoted to improving curriculum and teacher education.

In its present form, SEE's overall strategy is not as well articulated or as coherent as it could be at the Directorate level. Each of the nine current K-12 programs embodies a strategy of its own (and even within some programs the predominant strategy has not been clarified); collectively, the programs are designed to address the major components of the science education system. But because the strategies of different SEE programs diverge considerably and do not relate obviously to one another or to a long-term goal, external audiences are unlikely to know what NSF is trying to accomplish. Within SEE (and NSF as a whole), a statement of K-12 strategy has yet to be articulated clearly enough to aid in the design of new initiatives or other procedural adjustments.

Currently, SEE and the Foundation leadership are taking steps toward developing a clearer mission and strategy for the K-12 level, as part of an approach to science education at all levels. The Foundation has recently submitted to Congress the first annual update of its 5-year strategic plan for science education improvement, part of which deals with plans for K-12 investments. A Foundation-wide Task Group on Education and Human Resources is currently at work on a report that will establish a planning framework to guide NSF's educational investments at all levels over the next few years. But the results of these efforts so far fall short of the clarity or direction that is needed.

We discuss below the basis for developing a clearer and sounder strategy.

Basis for an Overarching Strategy

In the *Summary Report* we sketch two alternative strategy scenarios, which one can discern at work within and across SEE programs but which have yet to be articulated above the level of individual programs. Each presents a fundamentally different philosophy of educational change and NSF's role in the change process*:

- *Incremental improvement strategy*. This strategy emphasizes upgrading current formal and informal educational systems, primarily through investments that achieve widespread impacts in the short term. For example, support for collaborative ventures with publishers to improve science course materials, inservice teacher education, and national children's broadcasts in science and mathematics reflect this strategic approach.

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* These scenarios and the kinds of investments they imply are described more fully in the *Summary Report*. A summary listing of initiatives related to each and our estimate of resources necessary to implement them appears in Appendix A.

- *Fundamental change strategy*. This strategy aims at exploring the possibilities, extending the state of the art, and searching for new approaches that can radically improve education over the long term. Research on science learning environments, exploration of technological innovations, and long-term leadership development illustrate this strategic approach.

We summarize the two strategies schematically in Figures 2-2 and 2-3.

The two strategies have historically contended to be the guiding principle behind the Foundation's educational investments, and an unstated tension between the two continues at present. Programs such as Applications of Advanced Technology and, to some extent, Research on Teaching and Learning aim at long-term change in understanding and technical capability. Others, such as Teacher Enhancement or Presidential Awards for Excellence in Science and Mathematics Teaching, emphasize shorter-term intervention in the current system. Still other programs fall uneasily in between. As noted above, current SEE investments in K-12 science education reflect an emerging emphasis on incremental improvement rather than fundamental change, although the Directorate has not declared this intention in so many words.

The feature that distinguishes these two strategies is the philosophy of change (and NSF's role in the change process) they embody. This is not the only basis on which a strategy could be built. One could, for example, take a particular educational level as the cornerstone for strategic investment by declaring that the biggest need in science education lies at the lowest levels, and therefore investments aimed at the elementary school level would receive the greatest priority. (Some have argued, along similar lines, that the biggest need exists at the middle school/junior high school level.)

In fact, SEE has made a significant gesture in this direction--both by declaring that the elementary level would receive special consideration and by directing at least two initiatives at this level (elementary science and mathematics materials development solicitations). The emphasis on elementary school curriculum improvement, in fact, has been a prominent feature of SEE press releases in the past year, which indicate a long-term NSF commitment to improving curriculum at each level of schooling, starting with the lowest. This strategic thrust is sound, as far as it goes. But there is a conspicuous lack of fit between the curricular thrust, which emphasizes elementary-level activities, and the various teacher support activities, which concentrate on the middle and high school levels, especially the latter. Even the targeted solicitation aimed at middle school teacher preparation is a noticeable departure from the tradition of funding secondary school teacher education activities, serving high school teachers primarily and more often in the sciences than in mathematics (see discussion of Opportunities 4 and 5 in *Volume 1*). If an elementary-level science improvement emphasis were to become the basic building block of SEE strategy, then coordinating investments in curricular improvement and professional capacity building would seem essential, difficult as it might be to do so. Research investments, as well, could be made with greater emphasis on the elementary level.

In considering alternative grounds for a clear overarching strategy, we settled on the philosophy of change, rather than educational level (or other strategic focus), primarily because we were struck over and over again, in interviews with NSF (SEE) staff and outsiders, by the pervasiveness of these two philosophies of change and the clear differences in investment approach they represented. These overarching theories of change present NSF (SEE) with a fundamental choice in the basic direction of its investments.

There are other reasons, as well, why making improvement at the elementary level the cornerstone of the Foundation's K-12 science education investment may not be the wisest course. First, a primary focus on this level would minimize the Foundation's attention (at least for a few years) to large segments of the science education community, the bulk of whom relate to the middle and high school levels. Second, the arguments for concentrating on this level emphasize the intensity of the need more than the fit with NSF's unique capabilities. It is not obvious that the Foundation is well qualified to mount a comprehensive strategic thrust aimed at all facets of elementary science and mathematics education, even though there are particular opportunities for it to make a contribution here--for example, by rethinking elementary mathematics and science education (see Opportunities 1 and 2a in *Volume 1*), training district leadership for change in elementary science (Opportunity 4), and enhancing informal science learning resources, many of which are aimed at young children (Opportunity 10).

Identifying a Primary Strategy

Because NSF (SEE) currently maintains programs that exhibit one or the other of the two strategies (incremental improvement or fundamental change), the challenge before the Directorate is to declare one or the other (or a suitable alternative) as the primary (although not exclusive) direction for NSF (SEE) investments. The choice of a primary focus is not easy. Each of the two strategies represents a different combination of elements, all of which are important to solving the problems facing science education nationwide and all of which are appropriate to NSF in some fashion or other. The trade-offs among them, discussed in the *Summary Report*, reflect the fact that each strategy maximizes different things that are important to the effectiveness of the Foundation.

We summarize here some considerations for choosing among strategies and review the differences between the two we described. To be effective, NSF's strategy for investments in K-12 science education must:

- *Promise significant payoff in improving the state of education in the sciences for children and youth*, in three areas simultaneously: (1) improving the content of, and approach to learning and teaching science and mathematics; (2) strengthening the professional community concerned with education in the sciences at the K-12 level; (3) building good science content into the "infrastructure." If improvement in these areas can be effected by NSF (SEE) programs, then the Foundation stands the best chance of making systemic changes.

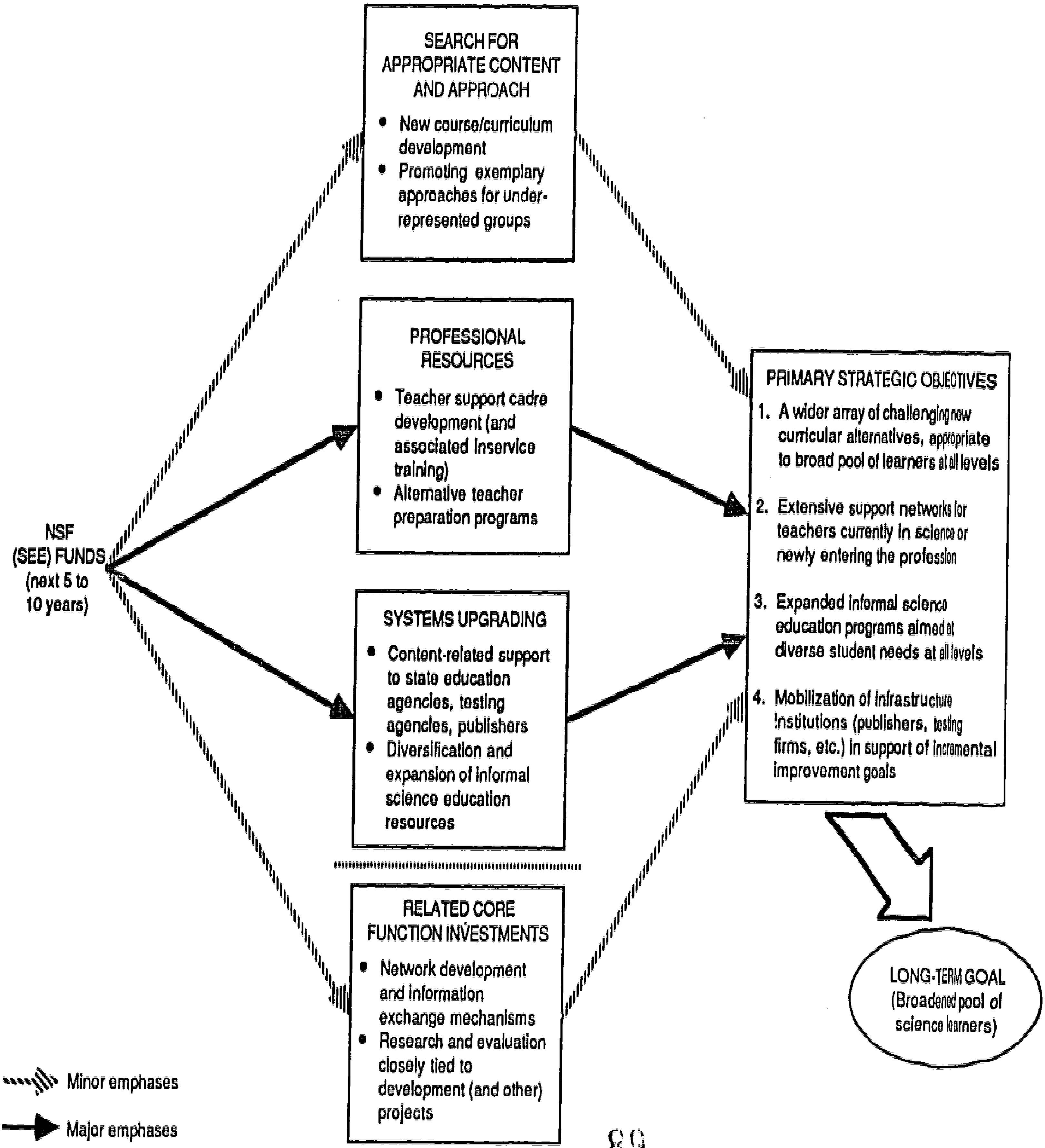

FIGURE 2-2 INCREMENTAL IMPROVEMENT STRATEGY

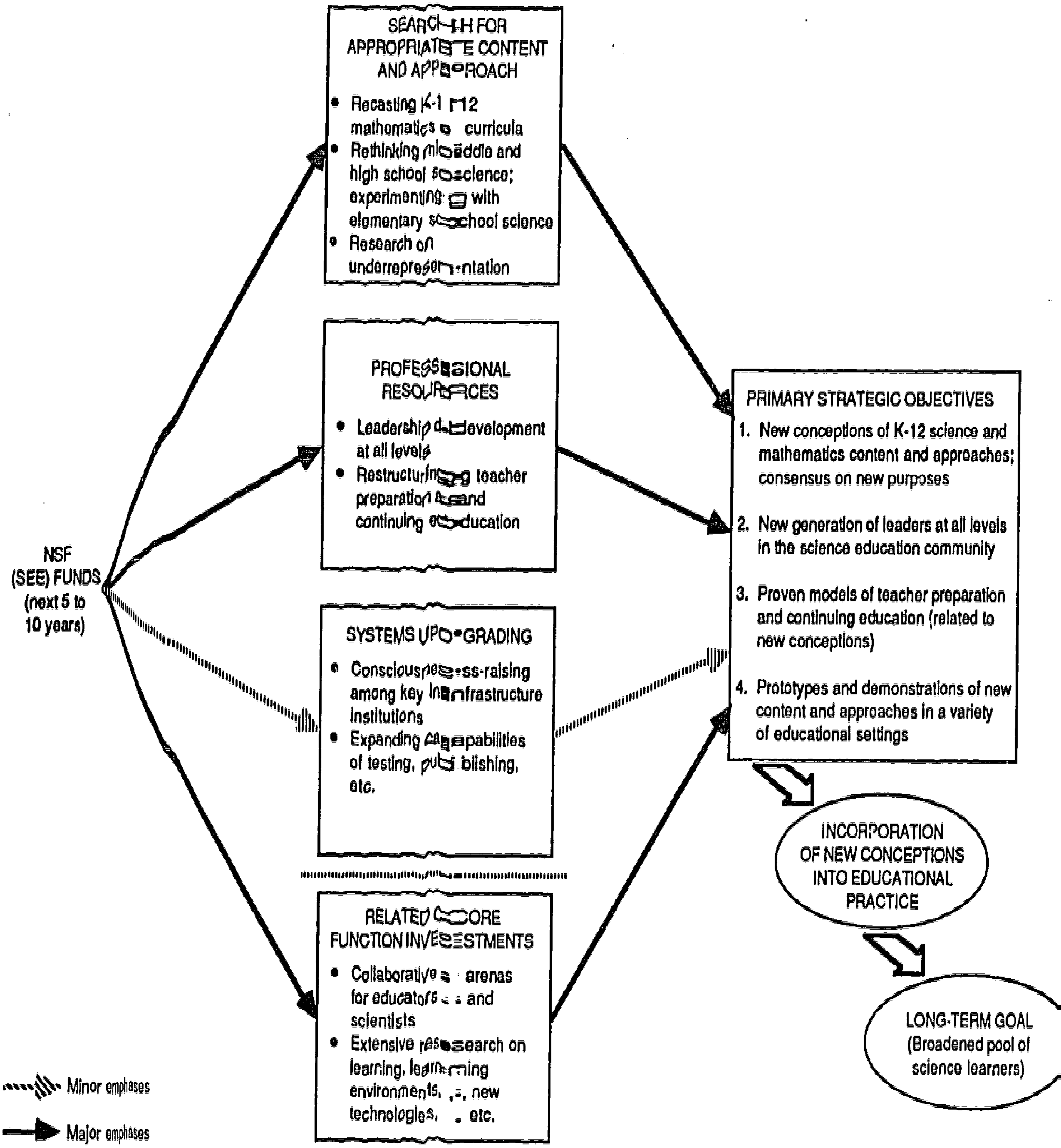

FIGURE 2-3 FUNDAMENTAL CHANGE STRATEGY

- *Balance short-term and long-term investments* — Because science education is under heavy scrutiny, it is essential that some improvements be made that are evident in the short run; short-term results will also help NSF (SEE) modify its future initiatives on the basis of lessons learned. Influencing improvements in science education indirectly by extending the state of the art and knowledge is intrinsically more long term, but equally important, at least in some degree. This too must be understood and explained by NSF (SEE) to its audiences.

- *Be feasible*, both for NSF (SEE) and its grantees (as implementors of the strategy) and in terms of the "market readiness" of practicing educators in and outside of schools (the ultimate implementors of education in the sciences).

- *Appeal to important constituencies of the Foundation*, in particular: (1) the members of the scientific and engineering establishment (including its representatives in the disciplinary directorates of NSF); (2) the public and its representatives (i.e., in Congress); (3) the professional community for education in the sciences (which includes not only practicing educators but also educational researchers, developers, and others).

We summarize in Table 2-1 the way our proposed strategies compare on these dimensions. In so doing, we should point out that the strategies are very similar in other respects. Each, in its own way, addresses the central national problem of broadening the pool of interested and competent science learners, although the nature of NSF's contribution to achieving that goal differs between them. Each features highly leveraged investments, both in the sense that NSF's dollars elicit other resources toward the same ends and in the sense that NSF's investments have the potential for significant impact extending beyond the immediate recipient of funding or target audience. Each strategy features a balance among the types of activities supported, the degree of risk incurred across investments, and the size of projects. Finally, each strategy assumes that NSF will adopt a high-profile stance in pursuit of the ultimate goal.

We do not believe that either of these strategies is clearly superior (nor do we assert that these are the only two that could be imagined). It is also not a question of choosing one strategy to guide all of NSF's educational investments; there will always be a need for a mixture of investments, some aimed at incremental involvement, others at fundamental changes. The important question is one of emphasis, given limited resources. There are not enough resources under any believable scenario for the Foundation to fully implement both strategies (see Appendix A for estimates of the resources required). Declaring one strategy to be the primary direction for the Foundation's educational investments thus concentrates resources in one direction, but it does not preclude investments guided by the other philosophies. Having a primary strategy provides guidance about the way a marginal increase in funding should be spent, as well as a basis for adjusting current programs where their emphases and contribution to strategic objectives are unclear. It also helps to explain and justify current and projected budget allocations for these investments.

Table 2-1

COMPARISON BETWEEN TWO STRATEGIES

Basis of Comparison	Incremental Improvement Strategy	Fundamental Change Strategy
1. Payoff to K-12 science education, in terms of improved:		
- Content and approaches	Moderate	High
- Professional community	High	High
- Infrastructure	Moderate	Low
2. Balance of short- and long-term investments	Primarily short-term	Primarily long-term
3. Feasibility, in terms of:		
- Fit with current SEE programs/policies	High	Low
- "Market readiness" of practicing educators	Moderate	Low
4. Appeal to important constituencies		
- Scientific establishment	Moderate	Higher
- The public and its representatives	Moderate	Low
- Professional community for education in the sciences	High	High

In summary, the best strategy will be one that SEE leaders feel comfortable with and can convince other NSF leaders to support and articulate within and outside the Foundation.

Building Strategic Capacity

To implement strategies of the sort just described requires several things: (1) SEE leaders, in conjunction with SEE staff and NSF leadership, must articulate--within NSF and externally--the strategy that they feel most comfortable with; (2) NSF must request (and be granted) sufficient resources to carry out such a strategy; (3) SEE staff must design and implement appropriate initiatives, along with necessary adjustments in staffing, programs, and procedures; (4) SEE staff, with the support of NSF as a whole, must assume a proactive posture in pursuit of strategic objectives.

These steps require that SEE and the Foundation as a whole build and maintain a "strategic capacity" for investing in educational improvement over the long term. This capacity--an institutional capability to invest funds strategically--includes: a centralized home base within the Foundation, the right staff expertise, continuity of resources, procedures and policies that enable SEE staff to be proactive, and support from the Foundation's top leadership.

Evolution of NSF's Capacity for Educational Investment

In the 1960s and 1970s, the Foundation maintained and developed a significant capacity for investing in science education at the K-12 level. A large staff, many of them with long-term grantsmaking expertise, assembled over the years in the Science Education Directorate; by the late 1970s, this group represented a significant repository of experience and was the hub of many networks within the science education community, which had been built in part as a result of NSF funding. All this capacity for educational grantsmaking was abruptly eliminated in 1981 when Congress abolished the Science Education Directorate and eliminated all of its programs (except graduate fellowships).

The reinstatement of the Education Directorate in 1983 presented NSF with the challenge of rebuilding its capacity for investing in education. That capacity has developed rapidly in the 4 years from then to the present. After an initial period of start-up difficulties, SEE moved quickly to reestablish its program structure, rebuild its staff, and process the flood of proposals that came its way. (Its initial lack of efficiency or direction--a major motivating factor in Congress' call for studies like this one--is entirely understandable, given the circumstances.) SEE's progress to date is remarkable, considering the extent of the disruption--in terms of discontinued relationships, departed staff, and lost records.

Most important, SEE has increasingly assumed a strategic posture in K-12 science education. The movement toward a more strategic approach to investment in science education manifests itself in several ways:

- *Use of targeted solicitations.* SEE has used more "targeted solicitations" within several of the programs and has more clearly defined priorities in others. Four such initiatives have been formalized in separate solicitation announcements; a comparable number are currently on the drawing boards. The result is a clear willingness to adopt more sophisticated funding hypotheses (as described earlier in this part of the report), which appear better matched to the complex task of "engineering" change in science education systems.

- *A more proactive posture.* Accompanying the movement toward focused investment, SEE has become increasingly proactive, in both overt and subtle ways. Many program officers routinely encourage appropriate proposers. Staff have made overtures to a number of the important groups in the professional community to explore possibilities for mutual collaboration (for example, a recent meeting of foundations and scientific societies involved in supporting professional networks).

- *Collaborative planning activities.* Some program and divisional staff involve a wide range of professionals in planning and have hosted initiative design conferences to help chart future directions for investment. One unit within SEE is currently engaged in an elaborate strategic planning exercise, drawing on commissioned papers from experts and on internal staff projections. These practices represent an excellent beginning in the direction of strategic investment.

Further Development in Strategic Capacity

But SEE's strategic capacity must develop further in this direction. The evolution to date and the need for further improvement are briefly summarized below with respect to each aspect of capacity.

Organizational home base--SEE provides a suitable home base within NSF for staff with K-12 educational expertise. The centralization of such staff in a single directorate is a prerequisite for coordinated strategic investments and should continue. Although this point may seem obvious, the matter has been debated over the years and remains an issue, especially in light of the Foundation's plans to disperse budgetary control over undergraduate-level educational investments among all research directorates.

Specifically, the Foundation's plans for FY 1988--which represent a quantum increase in overall NSF funding for education--feature several new programs that will be dispersed throughout the Foundation, although SEE will act in a coordinating role. A career access program (aimed at colleges and universities with high percentages of minorities and other underrepresented groups), undergraduate-level curriculum development, and an expanded program of research experience opportunities for talented undergraduates have been proposed. To date, K-12 education programs appear unaffected, although during the debate, sentiment within some research directorates favored various kinds of precollege investments organized along similar lines (especially for talented high school students who seem most likely to enter the scientific "pipeline").

An unspoken tension over control of educational investments is likely to exist in the Foundation for a long time, reflecting deep-seated ambivalence in some quarters within NSF (and in the larger national policy community) over the value and efficacy of educational investments, their effects on funding for scientific research, and their legitimacy as a central part of the Foundation's mandate. The gradually declining percentage of Foundation resources allocated to education from the mid-1960s until recently (before the FY 1988 budget submission) is one indication of the power of this ambivalence. It is likely that this ambivalence will continue to express itself periodically in calls for the absorption of SEE functions into other parts of the Foundation.

Staff expertise--SEE has assembled a diverse professional staff with many of the competencies necessary for dealing effectively with K-12 science education systems. At present, the Directorate's staff includes nearly 40 professionals devoting most or all of their time to K-12 science education investment. The staff includes individuals with backgrounds in most major disciplinary traditions in the sciences (including mathematics, although this disciplinary area is not represented in proportion to its importance in the structure of K-12 education), familiarity with educational systems (elementary, secondary, and informal education institutions), some grounding in key infrastructure institutions (teacher education institutions, state education agencies, and publishing), and some expertise in research related to science education (social science measurement, educational research, evaluation).

For reasons that are understandable (the loss of permanent staff in the early 1980s, the need to gear up quickly, the difficulty of luring good people away from their current employment), SEE has yet to attract a sufficient cadre of permanent staff with grantmaking expertise, good substantive backgrounds, and familiarity with educational systems: approximately two-thirds of SEE's professional staff who deal with K-12 issues are rotators, which contrasts sharply with the 1-in-3 average across other directorates in the Foundation. Rotators bring enthusiasm and recent connections with the field, but they lack grantmaking expertise; their rapid turnover also makes it more difficult to ensure continuity over time. In one division, 5 new rotating staff (out of 11 professional staff) will be assuming their duties this fall; the division is about to receive several permanent staff appointments for the first time. There are good reasons for this kind of staffing pattern, and it will take time to identify and secure the right kind of permanent staff (mistakes in according staff permanent status are extremely costly). But until the right mix of staff is in place, this division will find it difficult (although not impossible) to develop and maintain a consistent strategic thrust along the lines discussed earlier.

If SEE is to undertake and maintain a more strategic presence in K-12 science education, further adjustments and additions to the staff will have to be made. Under either the incremental improvement or the fundamental change strategy, for example, additional staff members with mathematics education expertise would be required to address opportunities such as revamping the K-12 mathematics curricula and to match the heavy emphasis on mathematics education at the elementary and secondary school levels.

In many respects, additions or changes in SEE staffing depend on the kinds of opportunities that it chooses to address. Staffing in the following areas is currently thin, and this fact would be a detriment if SEE were to undertake ambitious initiatives related to each area of expertise:

- *Elementary science education* (both science and mathematics)--needed to undertake extensive investments in rethinking mathematics and science content and approaches at the elementary level (see Opportunities 1 and 2a in *Volume 1*), the improvement of support systems and preparation programs for elementary teachers (see Opportunities 4 and 5), and more extensive investments in informal science learning resources aimed at young children (see Opportunity 10).

- *Educational and social science research*--necessary for more extensive investments in core functions as described earlier in this volume (see discussion of buiding the base of information and knowledge in science education).

- *Science and mathematics testing*--necessary for initiatives aimed at improving science and mathematics testing and assessment (Opportunity 8).

- *State educational policymaking*--necessary for initiatives aimed at support for state science and mathematics education reform (Opportunity 9).

- *Underrepresented groups of learners in science education, especially minorities*--necessary for a more effective strategic approach to serving underrepresented groups (see Opportunity 3). Staff would need to have great familiarity with these issues, intimate contact with the networks of science educators most involved with these issues; staff from underrepresented groups themselves would be preferred.

The number of new staff required depends in part on the amount of funds to be disbursed, but it is also possible that SEE has too few staff (even at current funding levels) for the proactive activity implied by either strategy. Even with no change in current SEE programs to address opportunities we have described, any significant increase in SEE's funding implies a need for more staff to process the additional proposals that would result, as well as to undertake the proactive investment activities we have described.

Continuity of resources--The success of any overarching strategy in K-12 science education depends, in part, on the amount of resources allotted to it. For strategic investment to succeed, NSF will need to maintain a level of funding over a period of years (e.g., 5 to 10) that corresponds with plans and objectives for K-12 education improvement. This is admittedly a difficult thing to manage in an era of concern over budget deficits; however, vehicles for securing long-term funding do exist (such as the Foundation's current request for a 5-year appropriation) and should be vigorously pursued.

The amount and continuity of funding for K-12 science education reflects the relative priority placed on support for different levels of education. Because this report deals only with investments at the K-12 level, it has little to say about relative priorities between this and higher levels of education. However, it should be pointed out that the pattern of budget requests for K-12 activities from the Foundation since 1983 suggests a reluctance on the Foundation's part to increase its investments in this level (even the current budget request, which reflects sizable increases for scientific research and for education as a whole--mostly undergraduate activities to be lodged outside SEE--has little real increase for K-12 activities).

Procedures and policies affecting proactivity--Both within SEE and in the Foundation as a whole, procedures and policies that bear on the proactivity of staff (and the Foundation as a whole) deserve careful examination, in recognition of the differences between support for education and support for scientific or engineering research (there are some parallels between education and engineering that should be examined). Although this study concentrated on an analysis of opportunities, alternative initiatives, and strategies, it became obvious that there were important operational implications of the alternatives under consideration. In particular:

(1) *Merit review procedures*. The application of merit review procedures in various areas of educational investment may be different from those used by other parts of the Foundation. The problem becomes especially difficult for reviewing educational investments because many, if not most, proposals to SEE are thoroughly interdisciplinary, and the relevant "disciplines" are as diverse as elementary education, cognitive psychology, and molecular biology.

Alternative arrangements (such as standing review panels, which can provide not only expert external review but some continuity of vision in project funding decisions over time) should be actively considered and applied wherever they make sense. The thinking represented in the Foundation's recent Advisory Committee on Merit Review (which completed a report in September 1986)--for example, involving the use of multistage review processes for large and complex proposals--should be applied to SEE review processes wherever feasible. Small planning grants issued to larger numbers of potential bidders on large-scale multiyear projects (for which only a few awards can be made) have important advantages as a way to assess more accurately the capabilities of a prospective project team, in addition to allowing the team to assemble and refine its thinking.

(2) *Staffing policies set by the Foundation*. Policies governing staff ceilings, which are set by NSF outside of SEE, should be carefully reviewed to determine whether they permit SEE enough staff to engage in the kinds of proactive outreach that are implied by the initiatives and strategies we have

been discussing. For example, total staffing ceilings include those staff paid out of NSF's administrative line item as well as staff brought on for temporary assignments (e.g., under IPA mobility assignments) paid for out of program funds.

It may well make sense to allow SEE the flexibility to augment its staff for critical strategic purposes above the formal staff ceiling levels, through more extensive use of program funds for staffing (adding a few staff in this way would not seriously reduce funds available for projects).

(3) *Expectations for the use of staff time within SEE.* The balance of time devoted to paperwork and proposal review--as opposed to monitoring ongoing projects, designing new initiatives, cultivating potential collaborators, etc.--needs to be adjusted if K-12 educational investments are to become more strategic. This is not to ignore the real time pressures placed on SEE staff by the large numbers and complexity of proposals they receive. In addition, the numbers of staff currently available may preclude or inhibit strategic investment activities to some extent, as suggested above.

But there are ways to streamline the proposal review process (e.g., through more vigorous use of preliminary proposals and even by forms of "batch" processing of proposals in areas where the projects to be funded conform to a uniform mold) and to augment staff capacity (e.g., by use of third parties for project monitoring and initiative design activities). New rotating staff can be brought in with a clearer set of expectations about other responsibilities besides proposal review. SEE should experiment more actively with these kinds of activities. These expectations might be formalized in divisional budgets, for example, by allocating a certain percentage of staff time to planning activities or designating staff with major assignments for strategic planning activities.

Support from Foundation leadership--Although they are coordinated and implemented by SEE, strategic investments in K-12 science education are more likely to succeed if they receive the active support of the Foundation as a whole, especially its leadership. Clearly articulated support for educational investments or certain strategic directions in educational improvement coming from the Foundation's leaders or the National Science Board carry great weight within national policy circles and the scientific community, not to mention the influence such pronouncements may have on the private sector or public perceptions. On the other hand, silence by these leaders conveys an opposite message: K-12 science education is unimportant, at least in relation to the other priorities of the Foundation.

During the first half of the 1980s, NSF's top leadership paid relatively little attention to science education. This attitude may have reflected the hostile political climate at the national level (in which a sustained effort by the new administration to downgrade and even eliminate the federal role in education was under way), as much as the preferences of the Foundation's leaders. Nonetheless, with the exception of the activities of the National Science Board's Commission on

Precollege Education in Mathematics, Science and Technology, there was little public support for an effective presence in K-12 science education of any kind. The catalyst for a rebirth of NSF's educational programs at this level came from outside the Foundation (the Congress) rather than from within.

NSF's leadership has recently taken more interest in educational matters, especially those related to undergraduate and doctoral or postgraduate study. Simultaneously, the political climate has grown more supportive, both of educational activities undertaken by NSF and of NSF's scientific and engineering research functions. A Foundation-wide task force on education and human resources (a theme within the Foundation's FY 1988 budget request, as well) is currently at work attempting to clarify the Foundation's role in all areas of science education; NSF has issued discussion papers on the development of human resources in relation to the nation's drive to improve its economic competitiveness. Also, strategic planning exercises related to education have been conducted within SEE and other parts of the Foundation.

But despite these signs of renewed interest in its educational mandate, the Foundation as a whole is sending mixed signals regarding K-12 science education. If NSF's top leadership is committed to developing an effective strategic capacity in K-12 science education, it should move quickly, in conjunction with SEE, to develop more effective and consistent statements of mission and strategy and to build them into Foundation-wide policy on educational investments. The following indications can be construed as mixed signals regarding K-12 science education:

- Virtually all of the significant increases in funding for science education proposed by the Foundation for FY 1988 are at the undergraduate level and above. This fact has a reasonable explanation: the virtual absence of Foundation support for this level of education in the 1980s is considered by many to be the most serious flaw in NSF's approach to education, so that higher education deserves the lion's share of new science education monies. Nonetheless, the fact that most K-12 activities appear in the Foundation's budget without increases, even minimal ones, sends a message to the outside world, and in particular to the political bodies that scrutinize the Foundation's budget requests, that K-12 education is not important.

- At present, the statements of educational mission developed inside and outside of SEE do not agree; updated 5-year plans recently forwarded to Congress have lacked a clear statement of strategic approach along the lines described earlier in this report. The lack of agreement may be, in part, an artifact of the dynamic situation that exists at the time this report is being completed: discussions are still under way, and attempts are being made to evolve a more coherent framework for educational planning. But our interviews with individuals inside and outside SEE suggest that resolution of the disagreements is not a foregone conclusion and may require more vigorous intervention by the Foundation's leaders.

- Within the strategic plan most recently submitted to Congress, the Foundation is most specific about graduate-level educational activities (target numbers of fellowships are mentioned, for example); by contrast, K-12 educational activities are described in much more general terms. If the plan were equally specific about, say, the target numbers of elementary school science teachers to be served as the number of graduate fellowships to be granted, then the plan would appear to address science education at the K-12 level with a comparable degree of care.

NSF's top leadership and the National Science Board (NSB) have a role in helping to articulate the strategy for K-12 science education, and they should exercise that role more vigorously. The absence of public commentary by the NSB on K-12 science education issues since its report *Educating Americans for the 21st Century* (1983) is notable. By helping to enunciate the Foundation's strategies to political and professional groups, as well as to the public, these bodies may obviate congressional pressures on the one hand; on the other, they may help to mobilize the relevant professional communities behind the Foundation's educational mission.

NSF as a whole, not SEE alone, will need to exercise leadership in the scientific community on behalf of K-12 science education if it wishes to establish a more effective strategic presence in this area. Many of the Foundation's primary constituencies (in the scientific community) do not necessarily recognize the importance of science education investments, least of all at the K-12 level. The reasons for this state of affairs go deep into the history and tradition of the Foundation, and deeper still into the society at large. Assuming the Foundation wants to contribute to broadening the pool of young science learners, it will require the concerted effort of committed individuals at all levels in the Foundation to educate the scientific community to accord K-12 science education the prominence it deserves.

PART THREE:

NSF'S INVESTMENT HISTORY IN K-12 SCIENCE EDUCATION

- NSF/SEE Precollege Science Education, 1952-1986: Program Chronology
- Program Funding History, 1952-1986
- Program Descriptions: Formal and Informal Science Education, Primarily at the K-12 Level

NSF/SEE
PRECOLLEGE SCIENCE EDUCATION
1952-1986

PROGRAM CHRONOLOGY

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June 1986

FOREWORD

The following tables show the duration and level of funding of the various programs of the Science and Engineering Education Directorate (SEE) of the National Science Foundation from 1952 to the present. Programs are organized by level as follows: precollege, informal (all levels), college, and graduate/postgraduate. Within levels, they are generally broken down by type, such as teacher/faculty development, materials/curricular development, research, equipment, etc.

Information used in formulating this table through 1983 is from the National Science Board, "Discussion Issues, 1983: Precollege Mathematics and Science Education," NSB 83-128, June 1983. Information for more recent years is being provided by SEE.

Cross checks of the data derived from the NSB publication with data contained in NSF Annual Reports has revealed some discrepancies in program durations and levels of funding.

NSF/SEE
SCIENCE EDUCATION PROGRAMS
1952-1986

I. PRECOLLEGE

A. Teacher Training

18. SISST Summer Institutes for Secondary School Teachers (1954-73)

19. AYISST Academic Year Institutes for Secondary School Teachers (1956-73)

20. ISISST In-Service Institutes for Secondary School Teachers (1956-73)

21. SIEST Summer Institutes for Elementary School Teachers (1959-66)

22. ISIEST In-Service Institutes for Elementary School Teachers (1959-66)

23. SSTSF Secondary School Teacher Summer Fellowships (1959-65)

25. RPHST Research Participation for High School Teachers (1959-68)

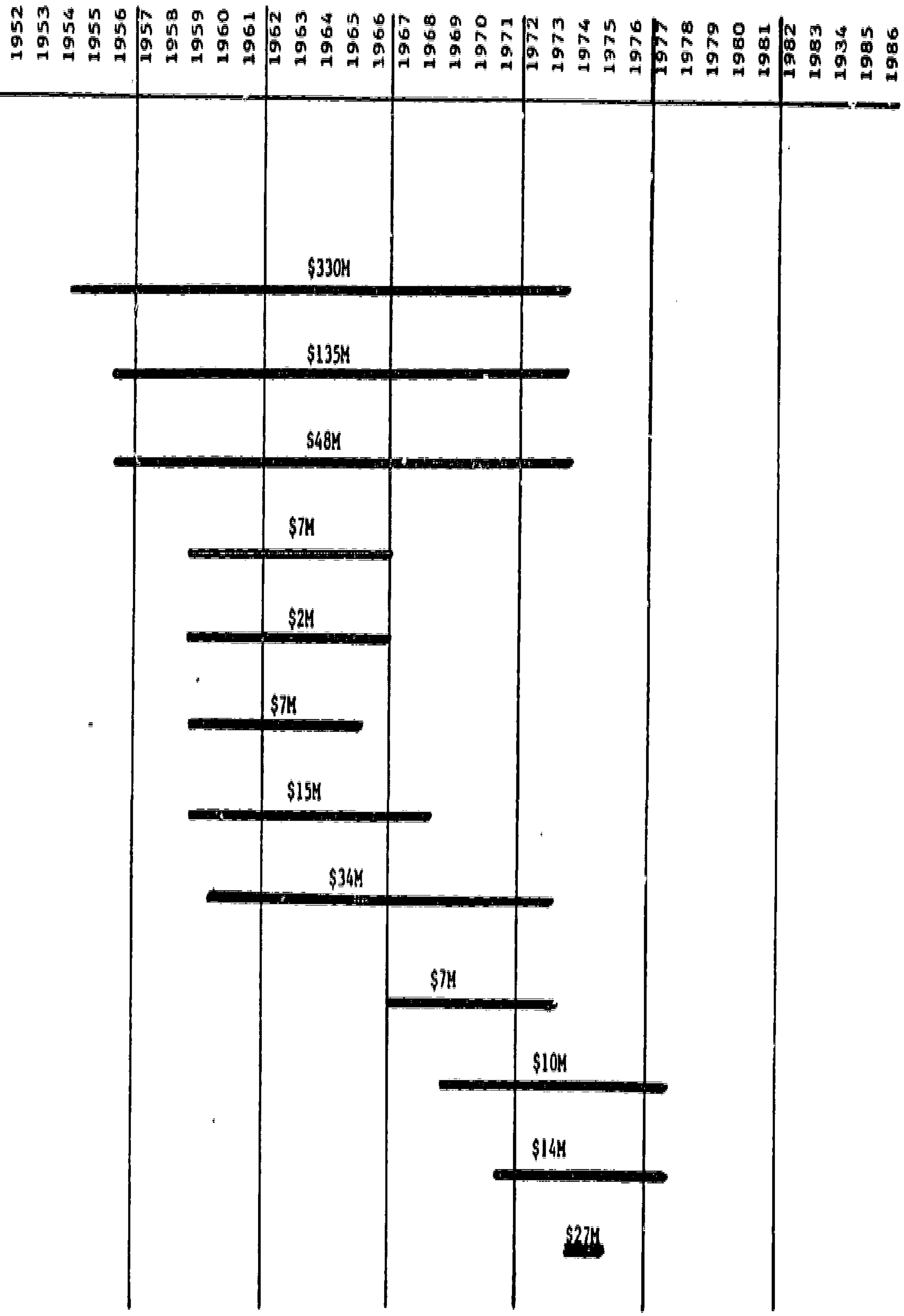
24. CCSS Cooperative College - School Science (1960-73)

26. RPW Resource Personnel Workshops (1967-73)

27. PSTEP Pre-service Science Education (1969-77)

56. CSTC Comprehensive Systems Teacher Centers (1971-77)

28. PIII Precollege Instructional Improvement and Implementation (1974-75)



29. PCTD Precollege Teacher Development in Science (1977-82)

XX. TEP Teacher Enhancement and Preparation (1984-present)

B. Materials Development

54. CCI Course Content Improvement (1957-71)

55. PMID Precollege Materials and Instructional Development (1972-76)

*60. CIE Computing Activities in Education (1972-73)

*61. TIE Technological Innovation in Education (1974-76)

63. DISE Development in Science Education (1977-82)

67. MDPMUC Materials Development in Precollege Mathematics Using Computers (1979-81)

XX. IMD Instructional Materials Development (1984-present)

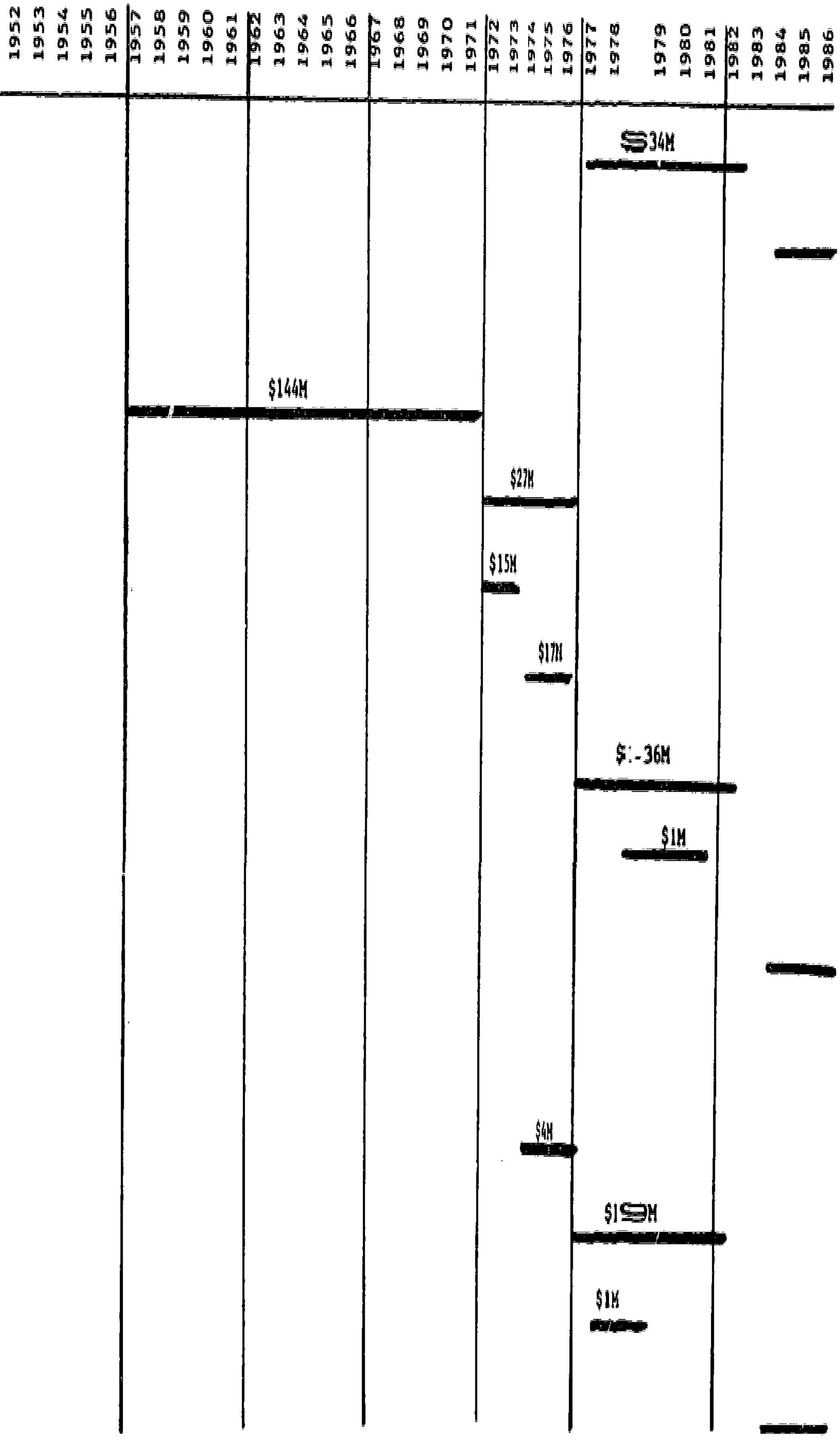
C. Research

*62. PAEP Problem Assessment and Experimental Projects (1974-76)

*64. RISE Research in Science Education (1977-82)

66. RCPSK Research on Cognitive Processes and the Structure of Knowledge (1978-79)

XX. SPA Studies and Program Assessment (1984-present)



* The program appears in this list in more than one category because the program covers more than one level.

XX. RTL Research in Teaching and Learning (1984-present)

D. Other

*72. PDE Program Development and Evaluation (1958-61)

12. SST Student Science Training (1959-81)

*73. ISA International Science Activities (1962)

36. SA Specialized Activities (1962-65)

*68. WIS Women in Science (1974-76, 1979-81)

*69. MWH Minorities, Women and the Handicapped (1977-78)

48. IDSE Information Dissemination for Science Education (1977-81)

*50. RCSE Resource Centers for Science and Engineering (1978-81)

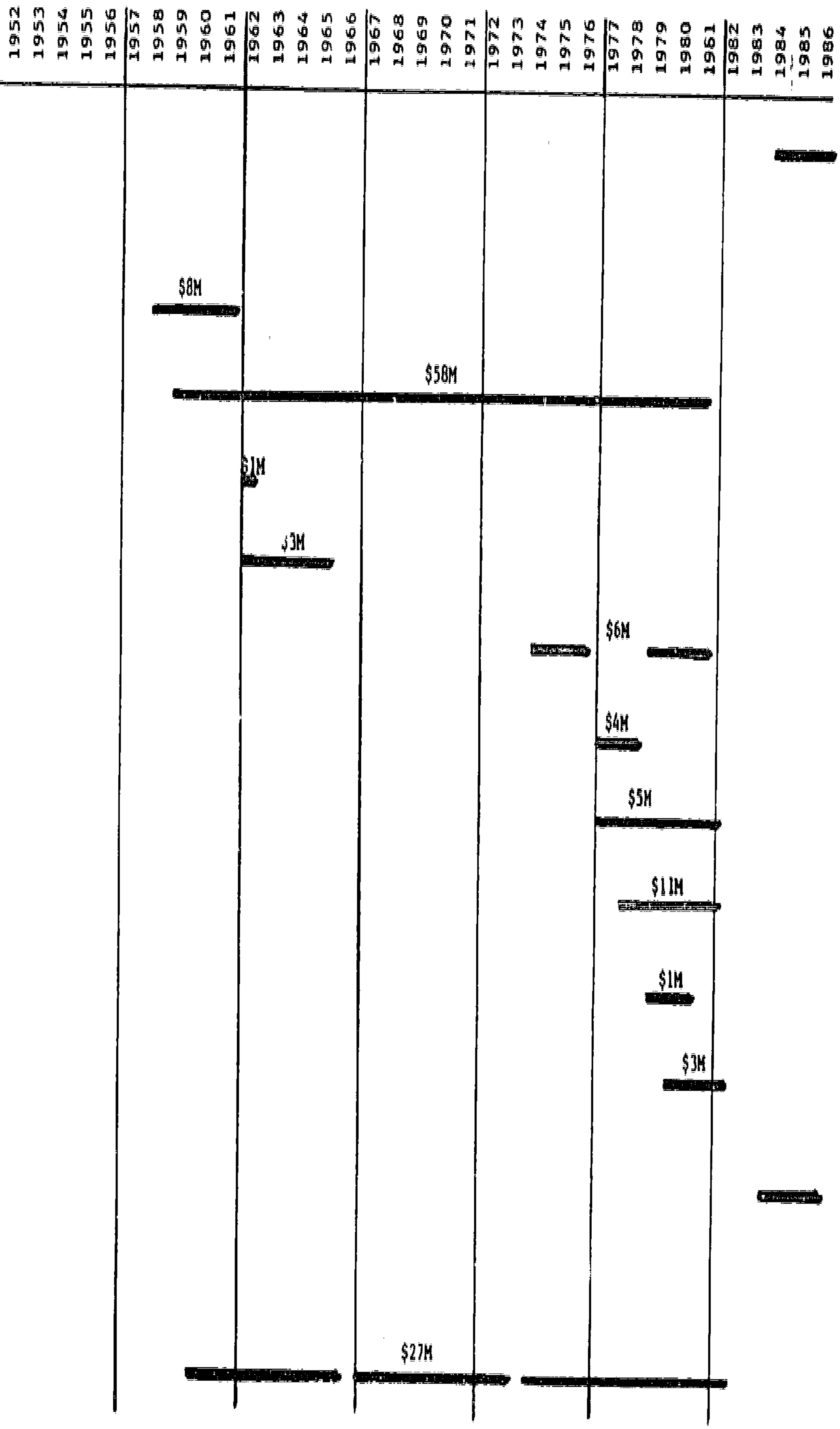
70. PHIS Physically Handicapped in Science (1979-80)

16. RAMHSS Research Apprenticeships for Minority High School Students (1980-82)

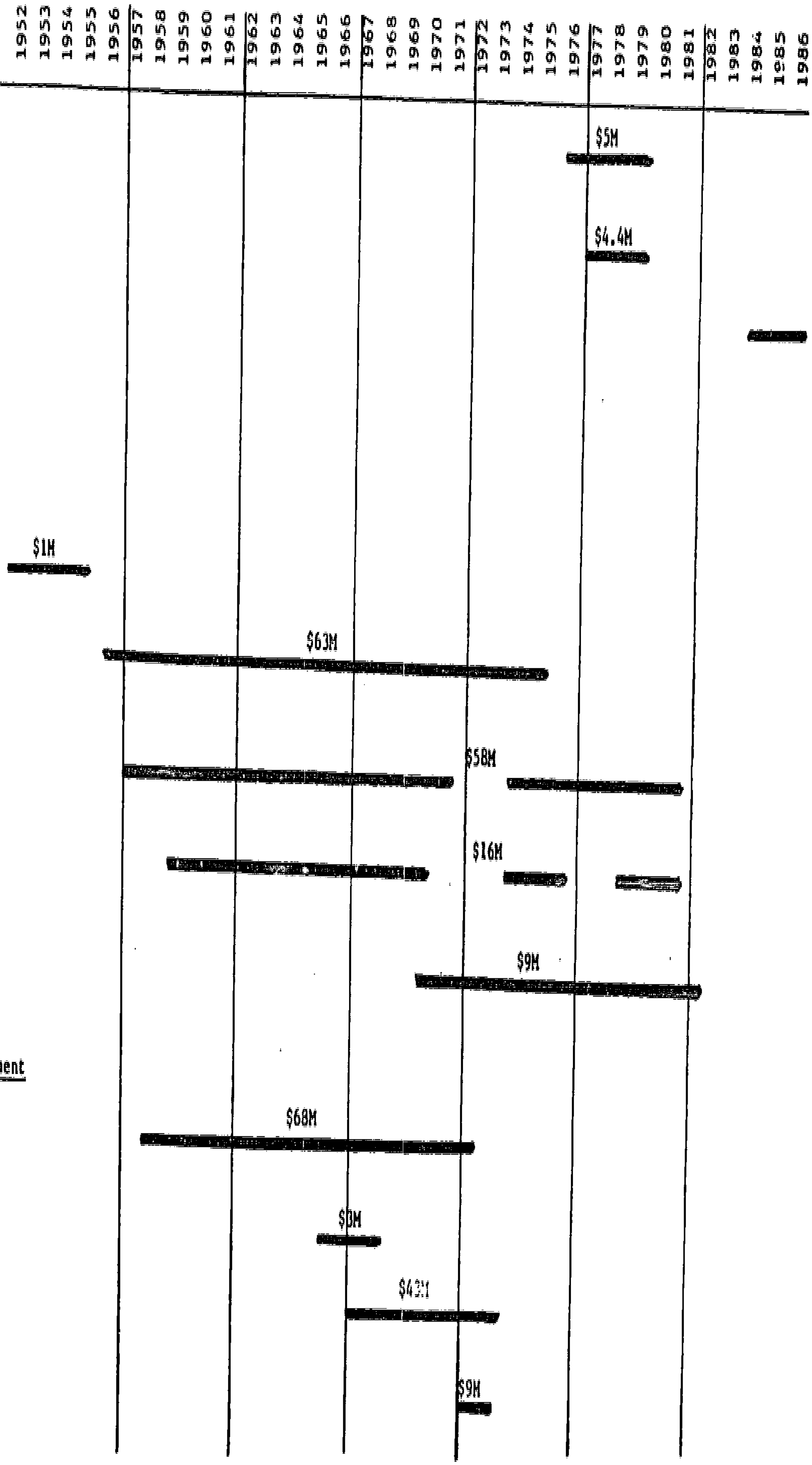
XX. AAT Advanced Technologies (1984-present)

II. INFORMAL EDUCATION (all levels)

51. PUOS Public Understanding of Science (1960-66, 1967-73, 1974-82)



* The program appears in this list in more than one category because the program covers more than one level.



74. EVIST	Ethics and Values in Science and Technology (1976-79)	$5M
75. SFC	Science for Citizens (1977-79)	$4.4M
XX. ISE	Informal Science Education (1984-present)	

III. COLLEGE

A. Faculty Development

30. EIS	Education in the Sciences (1952-55)	$1M
32. CTW	College Teacher Workshops and Seminars (1956-75)	$63M
*31. SFPD	Science Faculty Fellowships (1957-71) and Professional Development Grants (1974-81)	$58M
33. RPCT	Research Participation for College Teachers (1959-70, 1974-76, 1979-81)	$16M
34. CNSF	Chautauqua NSF Type Short Courses (1970-82)	$9M

B. Materials and Curriculum Development

39. SCIP	Science Curriculum Improvement (1958-72)	$68M
53. SPUE	Special Projects in Undergraduate Education (1966-68)	$8M
40. COSIP	College Science Improvement (1967-73)	$42M
41. COSIP-D	College Science Improvement Program - Part D (1972-73)	$9M

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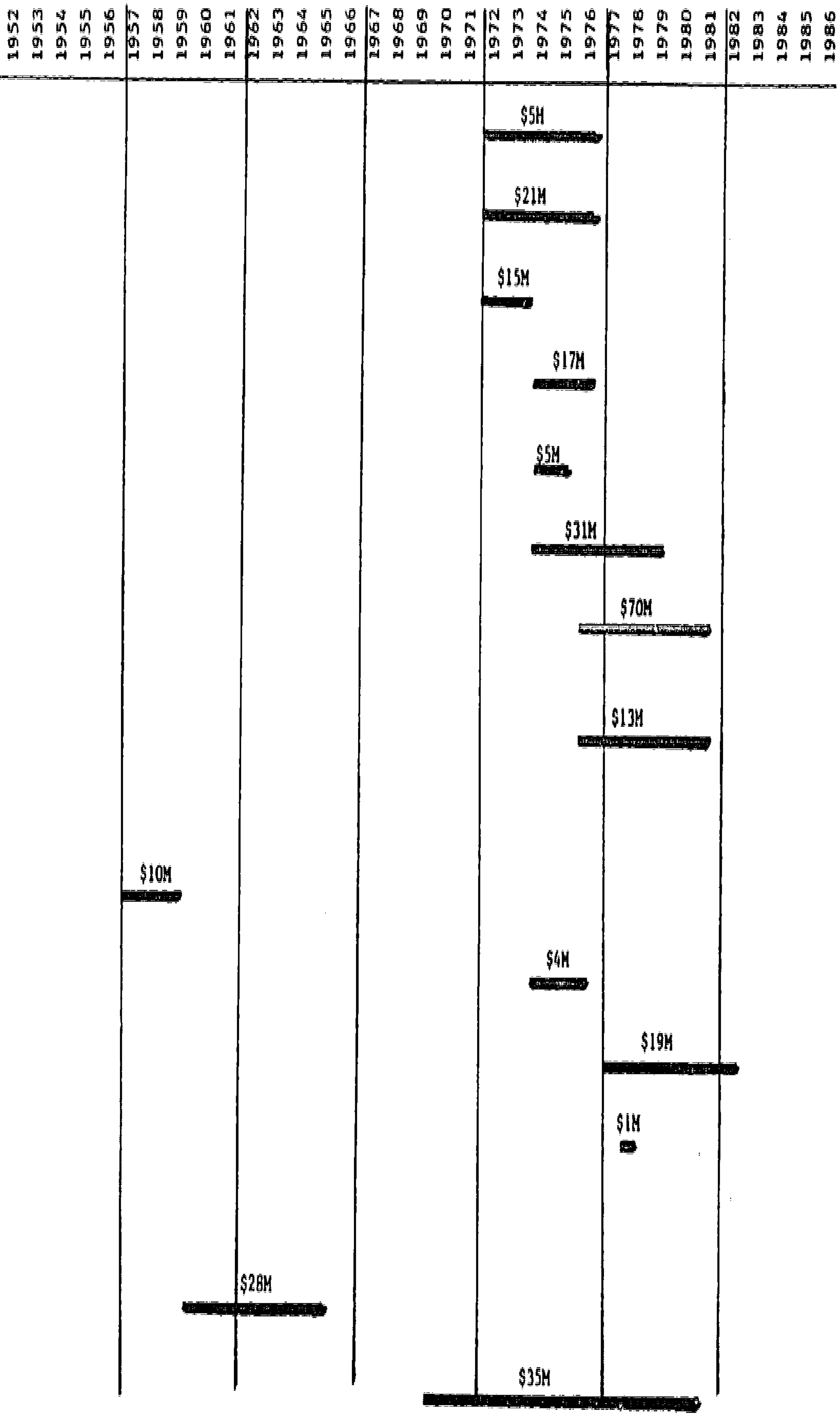
* The program appears in this list in more than one category because the program covers more than one level.



57. SETE — Science and Engineering Technician Education (1972-76)

59. UMID — Undergraduate Materials and Instructional Development (1972-76)

*60. CIE — Computing Activities in Education (1972-73)

*61. TIE — Technological Innovation in Education (1974-76)

42. RULE — Restructuring the Undergraduate Learning Environment (1974-75)

43. MISIP — Minority Institutions Science Improvement (1974-79)

45. CAUSE — Comprehensive Assistance to Undergraduate Science Education (1976-81)

46. LOCI — Local Course Improvement (1976-81)

C. Research

52. SPISE — Special Projects in Science Education (1957-59)

*62. PAEP — Problem Assessment and Experimental Projects (1974-76)

*64. RISE — Research in Science Education (1977-82)

65. TYCLASE — Two-Year College Assessment Program (1978)

D. Students (Career Training)

13. SEUS — Science Education for Undergraduate Students (1960-65)

14. URP — Undergraduate Research Participation (1970-81)

* The program appears in this list in more than one category because the program covers more than one level.

15. SOS — Student-Originated Studies (1972-80)

E. Equipment/Instrumentation

35. ISEP — Instructional Scientific Equipment (1961-70, 1972-81)

XX. CSIP — College Science Instrumentation Program (1985-present)

F. Other

*72. PDE — Program Development and Evaluation (1958-61)

*73. ISA — International Science Activities (1962)

*68. WIS — Women in Science (1974-76, 1979-81)

*69. MWH — Minorities, Women and the Handicapped (1977-78)

IV. GRADUATE AND POST-GRADUATE

A. Fellowships/Traineeships

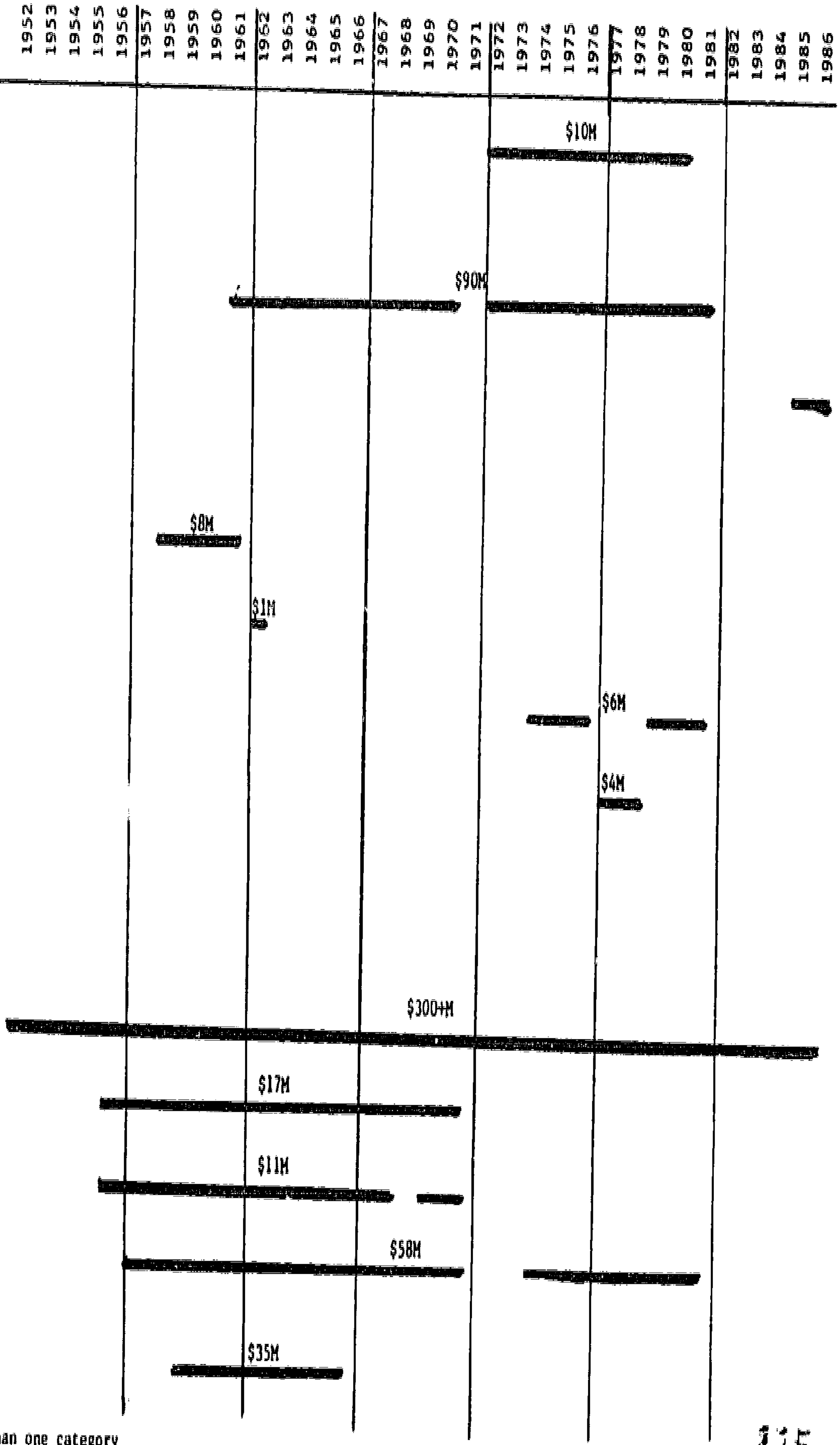
1. GFP — Graduate Fellowships (1952-present)

2. POST — Postdoctoral Fellowships (1956-71)

3. SPOST — Senior Postdoctoral Fellowships (1956-68, 1970-71)

*31. SFPD — Science Faculty Fellowships (1957-71), later Professional Development Grants (1974-81)

4. CGF — Cooperative Graduate Fellowships (1959-66)



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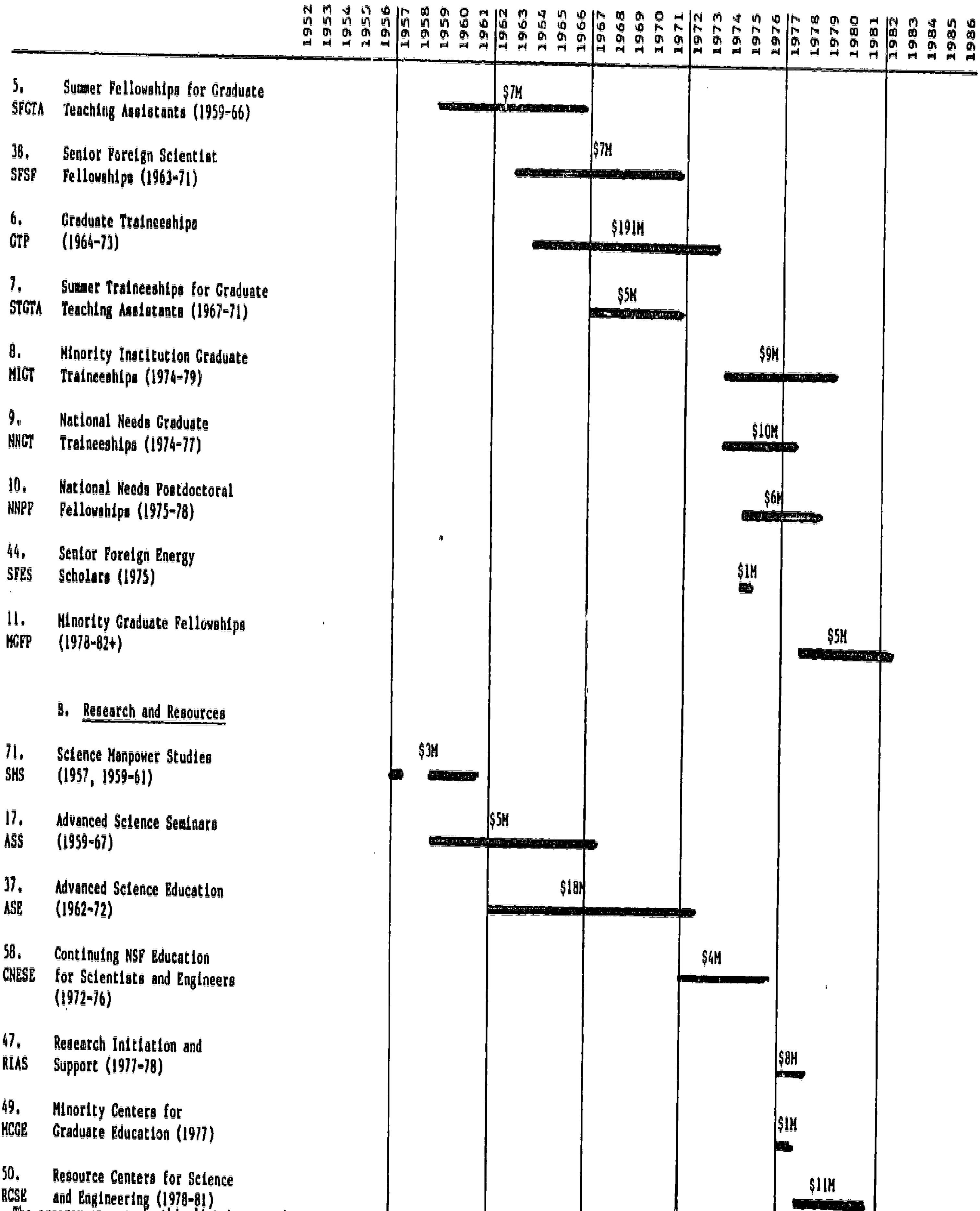

* The program appears in this list in more than one category because the program covers more than one level.

PROGRAM FUNDING HISTORY:
1952-1986

SCIENCE AND ENGINEERING EDUCATION DIRECTORATE
NATIONAL SCIENCE FOUNDATION

JUNE 1986

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June 1986

SOURCES:

Data for 1952 to 1969 and 1971 are from "The National Science Foundation and Precollege Science Education: 1950-1975," Report Prepared for the Subcommittee on Science, Research and Technology of the Committee on Science and Technology, U.S. House of Representatives, (Washington, DC: U.S. Government Printing Office), January 1976.

Data for 1970 and 1972 to 1982 are from the Annual Reports of the National Science Foundation, various years.

Data for 1974 and 1975 were provided by the Science and Engineering Education Directorate of the National Science Foundation.

All figures are in Thousands of Dollars.

I. A. TEACHER TRAINING - PRECOLLEGE

YEARS	SISST	AYISST	ISISST	SIEST	ISIEST	RPHST[1]	SST-SF	CCSS	RPW	PSTEP	CSTC	PIII	PCTD	LRTD	SMEN	LA/HW	PA	TPE	TOTALS
1952																			0
1953																			0
1954	NA[2]																		0
1955	NA[2]																		0
1956	615[3]	505																	1,120
1957	4,939[4]	4,251	162																9,352
1958	6,399	4,907	621																11,927
1959	19,618	8,800	1,861	470	81	NA	1,475												32,305
1960	19,405	9,013	2,068	514	71	NA	1,268												32,339
1961	18,553	9,118	2,571	642	192	NA	800	NA[6]											31,877
1962	23,019	10,361	3,327	695	196	NA	810	521											38,929
1963	23,080	10,504	3,193	1,045	293	NA	861	751											39,727
1964	23,093	10,482	3,108	1,240	451	NA	855	721											39,950
1965	22,950	10,596	3,218	1,251	439	NA	826	848											40,128
1966	22,498	10,019	2,917	743	458	1,602		1,957											40,193
1967	21,316	9,184	2,954			1,218		2,213	NA[7]										36,865
1968	22,122	8,449	3,654			1,235		3,387	NA[7]	370									39,217
1969	19,200	8,301	3,279					4,824	NA[7]	679									36,28
1970	23,300	8,421	5,215					4,654	NA[7]	NA									41,590
1971		23,828[5]						4,730	1,703	2,635	1,956								34,852
1972		18,330[5]						4,355	1,359	1,511	6,037[9]								31,592
1973		12,455[5]						2,020	822	367	1,849[9]								17,517
1974										1,570	2,463	14,679							18,711
1975										1,458	958	12,311							14,727
1976										1,435[8]	[8]								1,435
TQ										285[8]	[8]								285
1977										1,100	280		4,840						6,220
1978													6,760						6,760
1979													NA[10]						0
1980													NA[10]						0
1981													NA[10]						0
1982													NA						0
1983																			0
1984														1,790	89	7,370	635	3,990	13,874
1985														10,266	1,341	5,285	919	7,204	25,015
TOTALS	270,106	177,523	38,147	6,600	2,182	4,055	6,895	30,981	3,884	11,409	13,543	26,990	11,600	12,056	1,430	12,655	1,554	11,194	642,803

[1] Includes "Supplemental Projects." Numbers shown are for precollege teachers only. For other years, data are not available separately, but instead included as part of the total for "Research Participation for College Teachers."

[2] Not available separately, included in total for "Education in the Sciences."

[3] Includes "College Teacher Institutes" in this year only.

[4] Precollege level only for 1957 and subsequent years.

[5] Separate breakdown not available; number for "Institutes" (precollege only) as a whole; also includes "Leadership Specialist Projects."

[6] Not available separately; included in "Science Education for Sunday School Students."

[7] Seems to be included in totals for "Course Content Improvement."

[8] Comprehensive Systems/Teachers Centers included in total for Pre-service Science Education.

[9] Includes "Comprehensive In-Service Teacher Education" and "State and Urban Systems."

[10] Included in total for "Faculty Improvement Programs," which consists of Precollege Teacher Development, Chatauqua-NSF, Science Faculty/Professional Development Fellowships, and Research Participation for College Teachers.

I. B. Materials Development

Years	CCI	PMID	CIE	TIE	DISE	NSF-NIE MD	IMD	TOTALS
1952								0
1953								0
1954								0
1955								0
1956								0
1957	630[1]							630
1958	779[2]							779
1959	5,819							5,819
1960	4,522							4,522
1961	5,082							5,082
1962	7,721							7,721
1963	9,623							9,623
1964	12,071							12,071
1965	9,271							9,271
1966	9,917							9,917
1967	11,690							11,690
1968	13,307							13,307
1969	7,711							7,711
1970	6,507							6,507
1971	4,359							4,359
1972		3,469	8,372					11,841
1973		3,312	6,216					9,528
1974		8,261		7,432				15,693
1975		7,380		5,997				13,377
1976		4,294		2,926				7,219
TQ		1,328		684				2,012
1977					8,720			8,720
1978					5,550			5,550
1979					8,180	NA		8,180
1980					8,110	NA		8,110
1981					6,160	NA		6,160
1982					NA			0
1983								0
1984							14,032	14,032
1985							5,530	5,530
TOTALS	109,009	28,044	14,589	17,038	36,720	0	19,562	224,961

[1] Figure for 1957 includes undergraduate level as well as precollege.

[2] Figures for 1958-1971 are for precollege level only; "Supplementary Teaching Aids" are included.

I. C. Research

Years	PAEP	RISE	NSF-NIE R	SPA	RTL	TOTALS
1952						0
1953						0
1954						0
1955						0
1956						0
1957						0
1958						0
1959						0
1960						0
1961						0
1962						0
1963						0
1964						0
1965						0
1966						0
1967						0
1968						0
1969						0
1970						0
1971						0
1972						0
1973						0
1974	1,464					1,464
1975	1,240					1,240
1976	716					716
TQ	256					256
1977		2,350				2,350
1978		2,350	500			2,850
1979		3,830	NA			3,830
1980		5,680				5,680
1981		4,710				4,710
1982		NA				0
1983						0
1984				1,809	1,227[1]	3,036
1985				1,748	2,908	4,656
TOTALS	3,677	18,920	500	3,557	4,135	30,789

[1] Does not include approximately $3 M for Research in T
Program administered by the Directorate for Biologica
Sciences but appropriated to SEE.

I. D. OTHER

YEARS	PDE	SSTP	ISA	SA	WIS	MWH/PHIS	IDSE	RCSE	RAMHSS	AAT	SPEC PROJ	PRE-COLLEGE[5]	TOTALS
1952													0
1953													0
1954													0
1955													0
1956													0
1957													0
1958	985										389		1,374
1959	2,285	6,535[1]											8,821
1960	2,274	4,458[2]											6,731
1961	2,364	3,050[2]											5,413
1962		1,810[3]	343	1,088									3,241
1963		2,181		751									2,932
1964		2,305		893									3,198
1965		2,131		424									2,555
1966		1,973											1,973
1967		2,070									591		2,661
1968		2,067									433		2,500
1969		1,873									311		2,184
1970		1,931											1,931
1971		2,051											2,051
1972		1,938											1,938
1973		1,955											1,955
1974		1,375			605								1,980
1975		1,747			392								2,139
1976		1,945			1,003								2,948
TQ		6			1								7
1977		1,930				2,000	390						4,320
1978		2,200				2,310	720	2,790					8,020
1979		NA[4]				2,360	1,030	2,740					6,130
1980		NA[4]				2,230	1,270	2,750					6,250
1981		NA[4]				3,480	1,220	2,770					7,470
1982												4,150[5]	4,150
1983												1,110[5]	1,110
1984										1,210			1,210
1985										6,485			6,485
TOTALS	7,907	47,529	343	3,156	2,002	12,380	4,630	11,050	0	7,695	1,725	5,260	103,676

[1] 1959 figure includes undergraduate as well as precollege.

[2] Referred to as "Science Education for Secondary Students."

[3] In 1961 and subsequent years, broken out separately as "Summer Programs for High School Students" or "Student Science Training."

[4] Included in total for "Student Oriented Programs," which consists of "Undergraduate Research Participation," "Stu Oriented Studies," and "Student Science Training Program."

[5] This Precollege category includes all SEE awards for 1981-82 other than fellowships and traineeships;

II. INFORMAL EDUCATION

YEARS	PUOS	EVST	SFC	ISE	TOTALS
1952					0
1953					0
1954					0
1955					0
1956					0
1957					0
1958					0
1959	25				25
1960	317				317
1961	327				327
1962	294				294
1963	369				369
1964	396				396
1965	NA				0
1966	NA				0
1967	(472)				0
1968	(295)				0
1969	(185)				0
1970	NA				0
1971	(436)				0
1972	(794)				0
1973	(805)				0
1974	2,212				2,212
1975	1,689				1,689
1976	1,671	671			2,342
TQ	28	172			200
1977	1,970	1,210	910		4,090
1978	2,400	1,290	1,670		5,360
1979	3,440	1,260	1,590		6,290
1980	3,910	1,290	2,050		7,250
1981	4,300	3,070			7,370
1982	NA				0
1983					0
1984				1,952	1,952
1985				7,168	7,168
TOTALS	23,348	8,963	6,220	9,120	47,651

1 Data for 1967 to 1973 are from the texts of the NSF Annual Reports. This program was not part of SEE during the 1967 to 1973 period, and accordingly these figures are not included in either the program total or the total funding for SEE as a whole.

III. A. FACULTY DEVELOPMENT

YEARS	EIS	SFPD	CTW	CTI	RPCT[3]	CNSF	COL.TEACH PROGRAMS	FAC.IMPRO PROGRAMS[5]	TOTALS
1952	7								7
1953	41								41
1954	161								161
1955	316								316
1956	314		NA						314
1957		675	NA	278					953
1958		1,580	NA	285					1,865
1959		2,328	260	2,159[1]	2,380				7,127
1960		2,259	265	2,217[1]	2,413				7,153
1961		2,323	342	2,305	2,647				7,618
1962		3,086	428	2,850	2,375				8,738
1963		3,799	640	3,049	2,559				10,047
1964		3,839	628	4,245	3,715				12,427
1965		4,098	NA	4,094	4,004				12,195
1966		4,160	NA	3,896	1,381				9,437
1967		3,330	NA	4,475	1,519				9,324
1968		2,865	NA	4,103	1,613				8,581
1969		2,510	NA	3,171	797				6,477
1970		3,034	NA	NA[2]	NA[2]	NA[2]	4,161[2]		7,195
1971		3,000	NA	NA	NA	NA			3,000
1972			NA	NA[2]	NA[2]	NA[2]	3,182[2]		3,182
1973			NA	NA[2]	NA[2]	NA[2]	3,823[2]		3,823
1974		1,484	NA[4]		919	1,308[4]			3,712
1975		1,556	NA[4]		972	1,194[4]			3,722
1976		1,300			1,263	895			3,457
TQ		0			0	0			
1977		2,220				980			3,200
1978		2,320				1,060			3,380
1979		NA[5]			NA[5]	NA[5]		10,030[5]	10,030
1980		NA[5]			NA[5]	NA[5]		11,790[5]	11,790
1981		NA[5]			NA[5]	NA[5]		10,180[5]	10,180
1982						NA			0
1983									0
1984									0
1985									0
TOTALS	839	51,764	2,563	37,126	28,556	5,436	11,166	32,000	169,450

[1] Also includes "Technical Teachers Institutes."

[2] "College Teacher Program" category includes College Teacher Institutes, Research Participation for College Teachers, and Chataugua-NSF Short Courses.

[3] Data for 1959 to 1965 include "Research Participation for High School Teachers" as well as college teachers.

[4] Data on Chataugua-NSF Short Courses for 1974 and 1975 include College Teacher Workshops.

[5] The category "Faculty Improvement Programs" include Chataugua-NSF. Research participation for College Teachers, Precollege Teacher Development, and Science Faculty Professional Development.

NOTE: Data for College Teacher Workshops for 1965 through 1973 may be included with data on Advanced Science Seminars.

III. B. MATERIALS AND CURRICULUM DEVELOPMENT

YEARS	SCIP	SPUE	COSIP	COSIP-D	SETE	RULE	UMID	MISIP	CAUSE	LOCI	UNDERGRAD INSTRUCT	TOTALS
1952												0
1953												0
1954												0
1955												0
1956												0
1957												0
1958	56											56
1959	211											211
1960	1,897											1,897
1961	1,329											1,329
1962	1,269											1,269
1963	3,010											3,010
1964	1,904											1,904
1965	5,281											5,281
1966	5,647	1,406										7,054
1967	6,666	686	2,464									9,816
1968	6,045	906	9,624									16,574
1969	5,004	716	8,764									14,484
1970	9,806		6,829									16,635
1971	5,166		3,675		77							8,918
1972	4,618		3,027	5,047	1,251							13,943
1973			848	4,281	144		1,955					7,228
1974					1,002	2,471	6,564	6,002				16,039
1975					1,989	2,091	4,882	4,958				13,921
1976					289		2,487	4,743	10,112	1,033		18,662
TQ					0		333	2	34	0		369
1977								5,140	10,880	2,210		18,230
1978								4,690	13,470	2,520		20,680
1979								4,910	13,520	NA[1]	6,400[1]	24,830
1980								80	13,280	NA[1]	5,680[1]	19,040
1981									8,890	NA[1]	6,170[1]	15,060
1982												0
1983												0
1984												0
1985												0
TOTALS	57,909	3,714	35,231	9,328	4,752	4,562	16,221	30,525	70,186	5,763	18,250	256,439

[1] "Undergraduate Instructional Improvement" consists of "Local Course Improvement" and "Instructional Scientific Equipment" together. No separate breakdowns are available for these programs for 1979 to 1981.

III. C. RESEARCH

YEARS	SPISE	TYCLASE	TOTALS
1952			0
1953			0
1954			0
1955			0
1956			0
1957	688		688
1958	166		166
1959			0
1960			0
1961			0
1962			0
1963			0
1964			0
1965			0
1966			0
1967			0
1968			0
1969			0
1970			0
1971			0
1972			0
1973			0
1974			0
1975			0
1976			0
TQ			
1977			0
1978		460	460
1979			0
1980			0
1981			0
1982			0
1983			0
1984			0
1985			0
TOTALS	854	460	1,314

III. D. STUDENTS

YEARS	SEUS	URP	SOS	STUDENT ORIENT.	TOTALS
1952					0
1953					0
1954					0
1955					0
1956					0
1957					0
1958					0
1959					0
1960	2,872				2,872
1961	3,388				3,388
1962	4,373				4,373
1963	5,878				5,878
1964	6,052				6,052
1965	5,479				5,479
1966	6,583				6,583
1967	4,734				4,734
1968	4,142				4,142
1969		3,716			3,716
1970		3,817			3,817
1971		3,926	1,491		5,417
1972		3,861	1,896		5,757
1973		2,133	1,095		3,229
1974		2,022	1,733		3,755
1975		2,874	1,150		4,024
1976		2,544	982		3,526
TQ		0	0		0
1977		2,650	960		3,610
1978		1,980	920		2,900
1979		NA[1]	NA[1]	5,420[1]	5,420
1980		NA[1]	NA[1]	5,110[1]	5,110
1981		NA[1]		5,680[1]	5,680
1982					0
1983					0
1984					0
1985					0
TOTALS	43,499	29,523	10,228	16,210	99,461

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[1] Data on "Student Oriented Programs" for 1979 through 1981 consists of "Undergraduate Research Participation", "Student-Originated Studies", and "Student Science Training Program." Separate breakdowns for these three programs for these years are not available.

III. E. EQUIPMENT

YEARS	ISEP	CSIP	TOTALS
1952			0
1953			0
1954			0
1955			0
1956			0
1957			0
1958			0
1959			0
1960			0
1961	NA		0
1962	NA		0
1963	NA		0
1964	NA		0
1965	8,205		8,205
1966	7,736		7,736
1967	4,906		4,906
1968	4,336		4,336
1969	4,615		4,615
1970			0
1971	5,230		5,230
1972	2,881		2,881
1973	1,578		1,578
1974	3,141		3,141
1975	4,458		4,458
1976	2,994		2,994
TQ	0		0
1977	2,970		2,970
1978	3,740		3,740
1979	NA[1]		0
1980	NA[1]		0
1981	NA[1]		0
1982			0
1983			0
1984			0
1985		4,838	4,838
TOTALS	56,788	4,838	61,626

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[1] Data on "Instructional Scientific Equipment" for 1979 through 1981 are included in "Undergraduate Instructional Improvement", which includes "Local Course Improvement" as well. No separate breakdowns are available for these years.

IV. A. FELLOWSHIPS

YEARS	GFP	POST	SPOST	CGF	SFGTA	SFSF	GTP	STGTA	NIGT	NNGT	NNPF	SFES	MGF	FEL.SHP TRAIN.	TOTALS
1952	1,533														1,533
1953	1,366														1,366
1954	1,727														1,727
1955	1,784														1,784
1956	1,579	348	150												2,077
1957	1,867	424	388												2,679
1958	2,602	725	696												4,022
1959	3,186	1,116	768	3,685	514										9,268
1960	3,386	1,061	738	4,121	560										9,865
1961	4,111	1,095	706	3,485	599										9,996
1962	5,533	1,404	945	4,177	846										12,905
1963	7,600	1,471	964	5,356	950	677									17,018
1964	9,036	1,632	1,029	6,135	961	619	6,000								25,411
1965	9,617	1,626	1,061	6,296	979	661	15,061								35,300
1966	12,181	1,580	1,083	1,471	990	673	22,348								40,325
1967	11,895	1,204	774			644	26,971	1,060							42,547
1968	9,912	664	538			786	30,229	1,063							43,193
1969	9,155	702				729	25,905	811							37,302
1970	10,375	1,000	686			780	26,240	1,029							40,110
1971	9,418	1,300	689			914	18,046	1,041							31,409
1972	9,897						10,443								20,340
1973	10,483						4,826								15,309
1974	9,776								NA	3,222					12,999
1975	9,502								NA	1,296	2,400	428			13,627
1976	11,373								NA	2,164	1,414				14,951
TQ	528								NA	0	0				528
1977	10,800								1,000	2,160	1,370				15,330
1978	11,040								1,360		1,760		NA		14,160
1979	NA[1]								NA				NA[1]	15,260[1]	15,260
1980	NA[1]												NA[1]	13,960[1]	13,960
1981	NA[1]												NA[1]	14,030[1]	14,030
1982	16,750														16,750
1983	14,980														14,980
1984	20,322														20,322
1985	27,298														27,298
TOTALS	270,611	17,351	11,213	34,727	6,399	6,482	186,069	5,004	2,360	8,842	6,944	428	NA	43,250	599,679

[1] Graduate fellowships and Graduate traineeships are not reported separately for 1979 through 1981.

IV. B. RESEARCH AND RESOURCES

YEARS	SMS	ASS	ASE	CNESE	RIAS	MCGE	TOTALS
1952							0
1953							0
1954							0
1955							0
1956							0
1957	397						397
1958							0
1959	780						780
1960	891	321					1,212
1961	1,019	777					1,795
1962		1,000	112				1,112
1963		1,502	882				2,384
1964			1,172				1,172
1965		649	1,353				2,002
1966		1,088					1,088
1967		1,153	2,112				3,265
1968		1,138	1,470				2,608
1969			2,468				2,468
1970			2,393				2,393
1971			3,574				3,574
1972			2,255				2,255
1973				2,072			2,072
1974				1,004			1,004
1975				1,109			1,109
1976				221	4,009		4,230
TQ				0	0		0
1977					4,430	790	5,220
1978							0
1979							0
1980							0
1981							0
1982							0
1983							0
1984							0
1985							0
TOTALS	3,087	7,627	17,791	4,406	8,439	790	42,140

GRAND TOTALS

YEARS	IA	IB	IC	ID	II	IIIA	IIIB	IIIC	IIID	IIIE	IVA	IVB	TOTALS
1952	0	0	0	0	0	7	0	0	0	0	1,533	0	1,540
1953	0	0	0	0	0	41	0	0	0	0	1,366	0	1,407
1954	0	0	0	0	0	161	0	0	0	0	1,727	0	1,888
1955	0	0	0	0	0	316	0	0	0	0	1,784	0	2,100
1956	1,120	0	0	0	0	314	0	0	0	0	2,077	0	3,511
1957	9,352	630	0	0	0	953	0	688	0	0	2,679	397	14,698
1958	11,927	779	0	1,374	0	1,865	56	166	0	0	4,022	0	20,190
1959	32,305	5,819	0	8,821	25	7,127	211	0	0	0	9,268	780	64,355
1960	32,339	4,522	0	6,731	317	7,153	1,897	0	2,872	0	9,865	1,212	66,908
1961	31,877	5,082	0	5,413	327	7,618	1,329	0	3,388	0	9,996	1,795	66,824
1962	38,929	7,721	0	3,241	294	8,738	1,269	0	4,373	0	12,905	1,112	78,581
1963	39,727	9,623	0	2,932	369	10,047	3,010	0	5,878	0	17,018	2,384	90,987
1964	39,950	12,071	0	3,199	396	12,427	1,904	0	6,052	0	25,411	1,172	102,580
1965	40,128	9,271	0	2,555	0	12,195	5,281	0	5,479	8,205	35,300	2,002	120,415
1966	40,193	9,917	0	1,973	0	9,437	7,054	0	6,583	7,736	40,325	1,088	124,305
1967	36,885	11,690	0	2,661	0	9,324	9,816	0	4,734	4,906	42,547	3,265	125,828
1968	39,217	13,307	0	2,500	0	8,581	16,574	0	4,142	4,336	43,193	2,608	134,456
1969	36,281	7,711	0	2,184	0	6,477	14,484	0	3,716	4,615	37,302	2,468	115,238
1970	41,590	6,507	0	1,931	0	7,195	16,635	0	3,817	0	40,110	2,393	120,177
1971	34,852	4,359	0	2,051	0	3,000	8,918	0	5,417	5,230	31,409	3,574	98,810
1972	31,592	11,841	0	1,938	0	3,182	13,943	0	5,757	2,881	20,340	2,255	93,729
1973	17,513	9,528	0	1,955	0	3,823	7,228	0	3,229	1,578	15,309	2,072	62,234
1974	18,711	15,693	1,464	1,980	2,212	3,712	16,039	0	3,755	3,141	12,999	1,004	80,709
1975	14,727	13,377	1,240	2,139	1,689	3,722	13,921	0	4,024	4,458	13,627	1,109	74,033
1976	1,435	7,219	716	2,948	2,342	3,457	18,662	0	3,526	2,994	14,951	4,230	62,481
TQ	285	2,012	256	7	200		369		0	0	528	0	3,657
1977	6,220	8,720	2,350	4,320	4,090	3,200	18,230	0	3,610	2,970	15,330	5,220	74,260
1978	6,760	5,550	2,850	8,020	5,360	3,380	20,680	460	2,900	3,740	14,160	0	73,860
1979	0	8,180	3,830	6,130	6,290	10,030	24,830	0	5,420	0	15,260	0	79,970
1980	0	8,110	5,680	6,250	7,250	11,790	19,040	0	5,110	0	13,960	0	77,190
1981	0	6,160	4,710	7,470	7,370	10,180	15,060	0	5,680	0	14,030	0	70,660
1982	0	0	0	4,150	0	0	0	0	0	0	16,750	0	20,900
1983	0	0	0	1,110	0	0	0	0	0	0	14,980	0	16,090
1984	13,874	14,032	3,036	1,210	1,952	0	0	0	0	0	20,322	0	54,426[1]
1985	25,015	5,530	4,656	6,485	7,168	0	0	0	0	4,838	27,298	0	80,990[2]
TOTALS	642,803	224,961	30,789	103,676	47,651	169,450	256,439	1,314	99,461	61,626	599,679	42,140	2,279,989

1 Does not include approximately $3 M for Research in Teaching and Learning Program administered by the Directorate for Biological and Behavioral Sciences but appropriated to SEE.

2 This figure is approximately $1 M less than the total SEE FY 85 expenditures shown in other sources.

NSF EDUCATION OBLIGATIONS
1952-1986

Source:

Directorate for Science and
Engineering Education
National Science Foundation

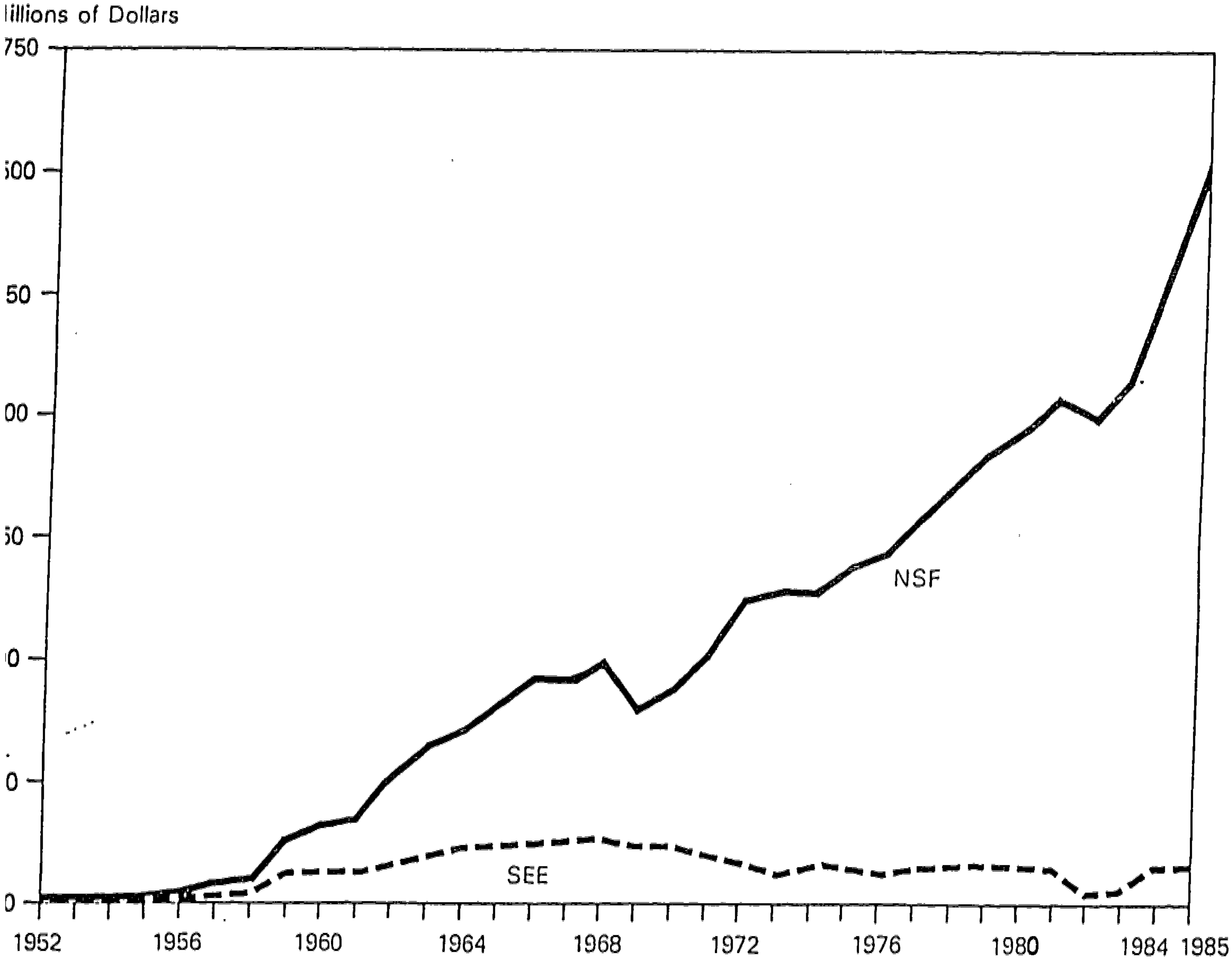
National Science Foundation Education Obligations by Level of Education (in millions of dollars)

Fiscal Year	Total NSF Dollars	Total SEE Dollars	Percent SEE of Total	LEVEL							
				Precollege		Undergraduate		Graduate		Informal	
				%	$	%	$	%	$	%	$
1952	3.47	1.54	44.4	0	0	0.3	.005	99.7	1.54	0	0
1953	4.42	1.41	31.9	0.7	0.01	2	.03	97	1.37	0	0
1954	7.96	1.89	23.7	2	0.04	5	.09	93	1.76	0	0
1955	12.49	2.10	16.8	6	0.13	9	.19	85	1.79	0	0
1956	15.99	3.52	22.0	24	0.85	16	.56	59	2.08	0	0
1957	38.63	14.30	37.0	71	10.15	8	1.14	21	3.00	0	0
1958	49.97	19.20	38.4	66	12.67	13	2.50	22	4.22	0	0
1959	132.94	61.29	46.1	67	41.06	17	10.42	16	9.81	0.03	0.02
1960	158.60	63.74	40.2	65	41.43	18	11.47	16	10.20	0.5	0.32
1961	174.99	63.44	36.3	61	38.70	22	13.96	17	10.78	0.5	0.32
1962	260.82	83.60	32.1	63	52.67	19	15.88	17	14.21	0.4	0.33
1963	320 75	98.72	30.8	57	56.27	23	22.71	19	18.76	0.4	0.39
1964	354.58	111.23	31.4	54	60.06	21	23.36	24	26.70	0.4	0.44
1965	415.97	120.41	28.9	44	52.98	26	31.31	30	36.12	0.3	0.36
1966	466.43	124.30	26.7	42	52.21	26	32.32	32	39.78	0.1	0.12
1967	465.10	125.82	27.1	40	50.33	24	30.20	36	45.30	0.3	0.38
1968	495.00	134.46	27.2	40	53.78	26	34.96	33	44.37	0.2	0.27
1969	400.00	115.30	28.8	39	44.97	26	29.98	35	40.36	0.2	0.23
1970	440.00	120.18	27.3	42	50.48	23	27.64	35	42.06	0.2	0.24
1971	513.00	98.81	19.3	37	36.56	22	21.74	40	39.52	0.4	0.39
1972	622.00	86.10	13.8	41	35.30	32	27.55	27	23.25	0.8	0.69
1973	645.74	62.23	9.6	39	24.29	28	17.42	31	19.29	1.0	0.62
1974	645.67	80.71	12.5	38	30.67	36	29.06	24	19.37	3	2.42
1975	693.20	74.03	10.7	38	28.13	29	21.47	30	22.21	2	1.48
1976	724.40	62.50	8.6	12	7.50	56	35.00	28	17.50	4	2.50
1977	791.77	74.30	9.4	13	9.69	58	43.10	24	17.83	5	3.72
1978	857.25	73.96	8.6	19	14.05	48	35.50	25	18.49	7	5.18
1979	926 93	80.00	8.6	20	16.00	46	36.80	26	20.80	8	6.40
1980	975.13	77.19	7.9	22	16.93	42	32.30	26	20.33	9	7.62
1981	1,041.78	70.66	6.8	37	26.08	37	26.00	21	14.83	5	3.75
1982	999.14	20 90	2.1	18	3.82	0	–	72	15.00	10	2.08
1983	1,085.79	30.00•	2.8	43	12.81	0	–	50	15.00	7	2.19
1984	1,306.91	75.00•	5.7	70	52.50	0	–	27	20.30	3	2.20
1985	1,502.89	81.96•	5.5	52	42.46	6	5.00	33	27.30	9	7.20
1986**	1,555.35	87.00*	5.6	53	46.0	6	5.50	31	27.30	9	8.20

Source: National Science Foundation

(Detail data may not add to totals because of rounding)

NSF Obligations for Science & Engineering Education



Source: Directorate for Science and Engineering Education. National Science Foundation.

NATIONAL SCIENCE FOUNDATION

SCIENCE AND ENGINEERING EDUCATION DIRECTORATE

Program Descriptions

FORMAL AND INFORMAL SCIENCE EDUCATION, PRIMARILY AT THE K-12 LEVEL

Prepared by

SRI INTERNATIONAL

June 1986

FOREWORD

This section includes descriptions of formal and informal science education programs, primarily aimed at the K-12 level, that have been supported by the National Science Foundation since 1952. Most of these descriptions were taken from the annual reports of the Foundation. The year of the report is shown just below the program title. If the description did not come from an annual report, the source is shown on the individual program page.

Although most programs extended over several years, we selected the description, regardless of year, that seemed to best represent the objectives and activities of the program. The reader should remember, however, that the character and activities of programs tended to change over time. To get a complete picture of any program, it would be necessary to review the annual reports for all years of program operation.

The program descriptions appear in the same categories and order as the Program Funding History, 1952-1986.

TABLE OF CONTENTS

TEACHER TRAINING

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* Arranged in time-line order, within group.

MATERIALS DEVELOPMENT

RESEARCH

OTHER

OTHER (Continued)

INFORMAL EDUCATION

18. SUMMER INSTITUTES FOR SECONDARY SCHOOL TEACHERS (SISST)

1959

1. *Summer Institutes for Secondary School and College Teachers.*—The summer institutes for high school and college teachers have increased from 2 in 1953 to 348 during the summer of 1959. They are designed to improve the competence of the participating teachers by providing courses that are specially aimed at overcoming deficiencies in their knowledge of the subject matter of science and mathematics. Most of the participants have completed their formal coursework a number of years ago, and others must teach courses in science and mathematics for which they have not had adequate academic preparation.

The institutes vary in length from 4 to 12 weeks. The average in 1959 was 7 weeks. The number of participants in each institute in 1959 varied from 10 to 150.

Of the 348 summer institutes in 1959, 30 were for college teachers only; 19 were for both secondary school and college teachers; and the remaining 299 were for secondary school teachers only.

Adequate balance in geographic distribution was maintained; for example, 57 percent of the institutes were held east of the Mississippi and 43 percent were held west of the Mississippi. There were 51 summer institutes in New England and New York, 86 in the other Eastern States and the District of Columbia, 53 in the Southeastern States, 52 in the Midwest, 61 in the Southwest and Hawaii, 41 in the Rocky Mountain and Northwest region (including Alaska), and 4 in the Commonwealth of Puerto Rico.

The National Science Foundation grants provided funds for participant support. The maximum amount awarded a participant was set by the Foundation at $75 per week for stipend, plus allowance for dependents and travel. While most institutes followed this schedule and granted the maximum allowable amounts to each awardee, a few distributed their available funds in smaller amounts to more participants. Many of the institutes accepted a few registrants beyond those who received stipends.

The National Science Foundation in addition awarded each host institution sufficient funds to pay necessary tuition and fees for the stipend holders. The Foundation grant also covered direct costs occasioned by the institute to the extent that they exceeded the amount already allowed for tuition and fees.

One of the essential features of this program is that the institutes are managed so that the participants are treated as a special group and their identity maintained. They are usually housed together, and often spend scheduled out-of-class time together in company with their instructors.

19. ACADEMIC YEAR INSTITUTES FOR SECONDARY SCHOOL TEACHERS (AYISST) 1959

Academic Year Institutes

Academic year institutes are full-time, year-long programs of study in science and mathematics designed especially for secondary school teachers in these fields. Financial support for the teacher and for the host institution is provided by a grant from the Foundation. The courses of study are planned by the colleges and universities which sponsor them; each institution supplies the facilities and administers its own program.

For the 1959-60 Academic Year Institute program, 32 colleges and universities received awards. The 32 institutes represent 32 different institutions in 29 States. Seven of these institutes are in the field of mathematics only, while the other 25 give training in the principal sciences, as well as in mathematics. Twenty-two of the institutes will continue through the summer of 1960; 10 are for the academic year only. Supplementary experimental grants were made to three institutes for support of eight college teachers—"teachers of science"—in each institute. It is estimated that the 1959-60 program will give support to over 1,500 teachers from all 50 States.

During this year, supplementary grants were also made to 19 of the 1958-59 institutes to enable them to extend their programs through the summer of 1959 for about 450 teachers.

Foundation grants to sponsoring institutions provide a maximum stipend of $3,000 per academic year, plus additional allowances for dependents, travel, and books. Institutions receive support for the operational costs, so that teachers do not have to pay tuition or fees.

20. IN-SERVICE INSTITUTES FOR SECONDARY SCHOOL TEACHERS (ISISST) 1961

IN-SERVICE INSTITUTES

In-Service Institutes for Secondary School Teachers

In-Service Institutes offer instruction for teachers of science and mathematics during the academic year at times so chosen that the participants may attend while still teaching full time—e.g., late afternoons, evenings, or Saturdays. These institutes provide an excellent opportunity for the sponsoring colleges and universities to help secondary school teachers who live within commuting distance.

During academic year 1960–61 a total of 191 In-Service Institutes for Secondary School Teachers, offering instruction for approximately 8,900 participants, received support from the Foundation. In the 1961–62 school year, approximately 11,500 secondary school teachers will participate in 253 In-Service Institutes. This expanded program provides support for promising new projects as well as substantial support for the continuation of institutes which have already established working relationships with the teachers and schools in their areas. The program reaches many teachers who are not able, for various reasons, to attend summer or academic year institutes.

Approximately half of the course work offered in these institutes during the past year was in the field of mathematics, while the remainder covered the range of the biological, physical, and earth sciences.

In the 1961–62 In-Service Institutes program, about one-fourth of the grants are for sequential-type programs. Noteworthy among these sequential institutes are four located in large metropolitan areas which offer teachers the opportunity to complete, on a part-time basis, master's degree programs essentially equivalent to those developed in academic year and summer institutes.

About two-fifths of the institutes are directed toward subject matter which closely relates to new course content developments in the fields of mathematics, biology, chemistry, and physics. Three institutes in radiation biology will receive joint support from the Atomic Energy Commission and the National Science Foundation.

21. SUMMER INSTITUTES FOR ELEMENTARY SCHOOL TEACHERS (SIEST) 1964

Elementary School Personnel

A major consideration in providing supplementary training in science and mathematics for elementary school teachers is the fact that very few of the approximately 1,100,000 elementary school teachers in the United States (kindergarten through grade 6) have any appreciable training in these subjects and are qualified to teach them. Consequently, the Foundation has chosen necessarily to concentrate on training leaders who may, in turn, influence and instruct their colleagues. This training is conducted in summer institutes for which participants are selected on a national scale and in the more numerous in-service institutes, which are oriented to local needs.

The institutes for elementary school teachers are directed toward improving the subject-matter background in science and mathematics of those individuals holding key positions in (1) introducing the teaching of science and (2) improving the teaching of mathematics in the elementary grades. This group of individuals include specialist teachers, subject-matter supervisors, principals, and regular classroom teachers who are leaders in science instruction in their schools. Most of these individuals have had minimal training in either science or mathematics, yet they are being called upon to lead their schools in adjusting to new curricular ideas which introduce science, the scientific method, and an understanding of fundamental mathematical concepts. As a result of grants made in fiscal year 1964, about 3,350 elementary school personnel in the categories mentioned will receive training next year. This represents a 37 percent increase in the number of individuals as compared with last year's participants.

Although funds for institutes for elementary school personnel were increased this year, the Foundation continues to receive many more meritorious proposals for these institutes than it can support and, at the same time, the number of applications received by the grantee institutions is about fifteen times the number of places available. The Foundation is considering means of assisting more teachers. One plan is to encourage local instructional programs supervised by university scientist-educators, but staffed by local secondary or elementary school teachers who have received special training for the purpose. This arrangement should materially reduce the operating costs as well as the manpower demand on colleges and universities.

22. IN-SERVICE INSTITUTES FOR ELEMENTARY SCHOOL TEACHERS (ISIEST) 1961

In-Service Institutes for Elementary School Personnel

In-Service Institutes for Elementary School Supervisors and Teachers provide part-time study in the sciences and mathematics during the academic year. Courses offered have been especially designed by colleges and universities to meet the need for informed instruction and supervision in the sciences and mathematics at the elementary school level.

In academic year 1960–61 the Foundation supported 13 institutes of this type, with approximately 400 teachers, supervisors, and principals participating. The 1961–62 program has been increased to 35 institutes, with training opportunities for approximately 1,030 elementary school personnel. Need for expanding this program was more than adequately demonstrated by the many local studies cited in the proposals received and by the lack of formal science instruction in the training of the majority of elementary school teachers.

Because of the very small number of participants who receive training as compared with the number of elementary teachers who need it, the institutes usually emphasize work with "key" teachers, specialists, or supervisors who may in turn help other teachers. Many institutes also serve as active centers for developing new materials and lesson plans for elementary schools. Several institute programs correlate their instruction with newly developed curriculum materials in mathematics.

23. SECONDARY SCHOOL TEACHER SUMMER FELLOWSHIPS (SSTSF)

1959

Summer Fellowships for Secondary School Teachers of Science and Mathematics

New in fiscal year 1959, the program of *Summer Fellowships for Secondary School Teachers of Science and Mathematics* permits secondary school teachers of high ability to undertake individually planned programs of summer study to improve their subject matter competence, and thus enhance their effectiveness as teachers.

Tenures from one summer of 6 weeks to three full summers are available. Stipends total $75 for each week of tenure. In addition, the Foundation awards cover the cost of tuition, plus limited travel and dependency allowances. The selection of 628 awardees was made from 1,578 applicants during 1959, the first year of the program, at a cost of approximately $1.5 million.

Supplemental Training for Teachers

While many factors combine in the "effective" science teacher, the fundamental one is knowledge of his field. For a number of years, an increasing amount of support has been provided for programs which supplement the subject-matter knowledge of teachers—particularly at the secondary school level. This support, in the past, has been concentrated largely in the now well-known summer institutes. Growing programs of Academic Year and In-Service Institutes have extended the opportunities of secondary school teachers to obtain supplemental subject-matter training. That the same problem exists at the college and university levels has been recognized and is being dealt with through Summer Institutes and Summer Conferences for College Teachers and Science Faculty Fellowships.

A number of new programs in the area of supplemental teacher training inaugurated in 1959 have been designed to bolster weak spots in the area of teacher qualifications; these programs now span the entire spectrum from the elementary and junior high schools through the graduate levels.

Secondary school teachers of science and mathematics differ widely in the extent and quality of their subject-matter training. Many are trying to provide adequate instruction to their students when they themselves have had little or no formal training in the subjects which they are teaching. Others are bona fide graduate students who need the opportunity to progress in their fields of specialization. In the past, efforts have been made to reach both groups—and those between the extremes—through the institutes programs. Many summer institutes have been designed to reach teachers at particular levels within this range.

These institutes have not been adequate, however, to serve the needs of the best qualified of the secondary school teachers of science and mathematics—those whose primary need is to pursue graduate study toward advanced degrees in their fields of specialization. For this reason, the new program of Summer Fellowships for Secondary School Teachers was designed and introduced during fiscal year 1959. The mechanism of this program is very similar to that used in the Graduate Fellowship programs, and in the summer of 1959 the first awardees—selected by the Foundation through a national competition and studying in their individually designed programs of study at the institutions of their choice—began receiving stipends for durations of one to three summers.

The Research Participation for Teacher Training Program provided another method of improving the professional competence of the best qualified science and mathematics teachers in secondary schools and colleges. This program made it possible for teachers with an adequate subject-matter background to participate in ongoing research programs at institutions with established research traditions. This experience provided the participating teacher an insight into science not gained by course work.

Three important new activities designed for groups of science teachers not previously included or to meet other special needs were launched within the institutes framework. These programs were directed toward groups of teachers of science, mathematics, and engineering whose needs had not been met through other programs.

Growing recognition of the importance of science education as a part of the general education program at the elementary school level led to the first tentative and experimental approach by the Foundation in this area—to help determine the responsibilities of the Foundation and ways in which it might best meet these responsibilities. A small program of 12 Summer Institutes for Elementary School Teachers and Supervisors was supported.

24. COOPERATIVE COLLEGE-SCHOOL SCIENCE (CCSS)

1966

Cooperation in School System Improvement

Curricular reform must ultimately be carried out in the classroom. Vastly improved materials, whether supported by NSF or other sources, are of vital importance. How well they are used, however, depends primarily on the local school system. Responsibility for the education of students rests with local school boards and school superintendents, and their understanding of the requirements imposed by improved curricula and the competence of their teachers governs the successful adoption of the new materials.

The Cooperative College-School Science Program provides a means for NSF assistance in the complex task faced by a school system when adopting improved materials and in other ways improving its instructional program. This activity encourages collaborative efforts between school systems and neighboring colleges or universities, including consultation with experts who are well-versed in modern course content in science and mathematics.

Grants are made only to the cooperating colleges or universities, but the active participation of the school system is required for such activities as designating the schools and teachers who will be using such materials, sharing some of the costs, and arranging for teachers to undertake necessary retraining.

Each project supported under this program can be individually tailored to the needs of the school system benefiting from the activity. Thus, detailed planning may culminate in intensive training sessions for teachers, followed by a flexible arrangement for additional help in adapting the new materials after the teacher returns to the classroom.

Until 1966 the program had been directed primarily toward the secondary school level but it has now been expanded to include some elementary school science and mathematics. A total of 2,016 secondary school teachers, 2,465 elementary school teachers, and 1,544 secondary school students participated in 57 projects at 50 institutions. Program expenditures in 1966 were approximately $2 million.

Concentration on the needs of a particular school system permits a high degree of involvement by that system and ultimately should satisfy the training needs within that system for a reasonable period of time. Many schools should then be able to undertake their own teacher improvement programs, using the models and contacts already established by the Cooperative College-School Science Program grant. Some examples of programs supported in this area will illustrate the possibilities.

Physics Teaching in the State of Missouri—Several physicists from college faculties in Missouri, with the cooperation of the Missouri State Department of Education, surveyed the academic qualifications of the State's physics teachers, and found very few teachers who could be considered qualified according to minimal standards of course preparation. Four institutions, therefore, collaborated in proposing to the National Science Foundation a massive upgrading of the physics teachers throughout the State.

The program began with a series of spring meetings and visits to schools, designed to interest the teachers in the program of self-improvement. Then, during the summer of 1966, approximately 25 teachers attended each of the 4 institutions. Those who had the lowest level of academic preparation were given introductory background course work, while those at the highest level renewed their familiarity with mathematics and advanced concepts of physics.

The summer sessions were followed by periodic meetings concerned with the introduction of better physics materials and experiments into the classroom, with the State department of education retaining a strong interest in this aspect.

The program is expected to continue for 1 or 2 more years, involving additional teachers and giving more advanced training in physics to the teachers at the lower levels in 1966.

This coordinated approach toward upgrading the teachers in a single discipline within a limited geographical area has already stimulated interest on the part of other disciplines and other States.

Elementary School Mathematics in Large Urban School Systems—The Madison Project, now based at Webster College, Webster Groves, Mo., has developed a coordinated set of materials designed to enrich the elementary mathematics program rather than to supplant it. As a result of this experience several large cities have decided to start their elementary mathematics reform by introducing Madison Project materials. A grant was made to Webster College, which conducted intensive familiarization sessions during the summer in Chicago, New York City, and San Diego, followed by frequent contact during the 1966–67 academic year.

At least 1,800 teachers were involved in these sessions. They form a nucleus of resource teachers in their own schools. Leaders from among them will conduct training for their own school systems with a minimum of guidance from the Webster College staff. At that stage the project will become self-supporting, with the school systems assuming full responsibility for introduction of the program and training of teachers.

25. RESEARCH PARTICIPATION FOR HIGH SCHOOL TEACHERS (RPHST)

1961

Research Participation for High School Teachers

This program provides opportunities for high school and junior college teachers of science and mathematics to obtain research experience with outstanding research scientists at colleges, universities, and nonprofit research organizations. Teachers participate in research by actually working on an individual basis in the laboratory or in the field. This experience should improve the teacher's understanding of science and of the scientific method and thus contribute to raising the level of his classroom instruction. The closer relationships between colleges and high schools resulting from this program should lead to better preparation of high school students for college.

In general, a teacher applying for this program is required to have a master's degree in the scientific subject matter, or an academic background including sufficient advanced science courses to qualify him for admission to candidacy for such a degree, although actual candidacy for the degree is not a requirement. "Graduates" of institute programs are a prime target group. As in the college-level program, some participants will continue in the academic year.

The 51 grants made in this program in 1961 provide support for 367 summer participants and 102 academic-year participants in a variety of disciplines in the mathematical, biological, physical, and engineering sciences, and in psychology.

26. RESOURCE PERSONNEL WORKSHOPS (RPW)

1972

Resource Personnel Workshops and Conferences

Resource personnel projects are designed to inform pre-college supervisory and teaching personnel about prospective new curricula. Supervisor Projects include short courses which provide the information necessary for educational decision-makers — principals, directors of education, and other school administrators — to conclude whether or not to adopt specific curricula changes for their school systems. They also give these supervisors the necessary background to support their teachers should these new curricula be implemented. Other precollege resource personnel projects include a course of 3 to 4 weeks' duration, with some follow-up in the Academic Year Institutes Program discussed later. A major focus of these projects is to provide leadership training for implementing new curricula. Such projects typically bring together a team consisting of a science educator, a school administrator, and a teacher to take the course, after which they assist their home school district in adopting the curriculum improvements.

In addition to funding the distribution of information about newly developed courses and curriculum materials and providing courses on them, NSF supports conferences directed toward planning the cooperative development of new courses. At these conferences, scientists, educators, and educational technology experts plan concise materials and curricula that can be fully developed in appropriate teacher-training institutions. Students in pre-service teacher education programs at these institutions help with the design, development, and testing of these materials. Together, the 20 grants for these administrators' conferences and the 26 grants for the resource personnel projects provide various degrees of background or training for nearly 2,700 participants in fiscal year 1972.

27. PRE-SERVICE TEACHER EDUCATION (PSTEP)

1969

PRE-SERVICE TEACHER EDUCATION

The Pre-service Teacher Education program, established in fiscal year 1969, aims at improving the preparation of prospective teachers of precollege science. It encourages universities and 4-year colleges to develop a closer working relationship between their science departments and education departments in providing training that will offer undergraduate students both increased knowledge of subject matter in science and mathematics and greater skill in organizing and presenting course materials. The Foundation believes that such an approach to pre-service education should help to alleviate the need for early supplementary or remedial training of new teachers.

The program does not prescribe the curricula through which universities and colleges will achieve these goals, but emphasizes certain curricular elements or characteristics that the Foundation views as highly desirable.

Prior to the formal announcement of this new program in March 1969, the Foundation had supported several pilot projects to experiment with approaches to improving the pre-servive education of science teachers. Among these were efforts conducted by the University of Georgia and five other units of the State of Georgia system, the Illinois State University, the State University of New York College at Plattsburg, and the Nebraska Board of Education of State Normal Schools.

The six grants, totaling $678,600, made in this program in fiscal year 1969 provide funds for the continuation of some of the earlier efforts and for three new projects (a summer project concerned with practical methods in science teaching—East Carolina University; a 3-year project for preservice teachers with double majors in any two of the following: physics, chemistry, mathematics—University of Pittsburgh, Pennsylvania; and a 4-year physics project that includes opportunities for undergraduate participants to construct and test their own instructional units—Austin Peay State University, Tennessee).

Emphasis in the early years of the Pre-service Teacher Education Program will be on the education of prospective secondary school teachers, but some attention will also be directed to projects for improving the preparation of elementary school teachers.

56. COMPREHENSIVE SYSTEMS TEACHER CENTERS (CSTC)

1971

NEW PATTERNS IN TEACHER EDUCATION

The two top layers of the figure on p. 74 represent new ways to organize teacher education, both initiated in fiscal year 1971. Activities include both pre-service and in-service teacher education components and place strong emphasis on interaction with schools in the region of the host institution to help meet their needs. Five Comprehensive Grants were awarded in fiscal year 1971 to the University of Mississippi, University of Notre Dame, San Jose State College, the University of South Dakota, and the University of Wyoming.

The Comprehensive Project at the University of Wyoming is a good example of this new program. The University of Wyoming has been continuously engaged in teacher education activities since 1954. These activities have increased the university's interest in the education of secondary school teachers of science and developed a close working relationship between the university and the high schools of the State. Through the Comprehensive Project, a system of "portal schools" will be developed throughout the State to serve as centers where teachers will be trained in the use of newly developed curricula and materials. Conducting these in-service programs will be teachers who will have been trained in summer and academic year programs at the university. The "portal schools" will also provide prospective science teachers with the opportunity to work under the guidance of a master teacher. An associated intern program for post-baccalaureate certificated teachers will permit both the interns and the experienced teachers whom they will in part replace to acquire appropriate advanced training. Also part of the program are a distinguished professional chair in science education, extension of activities to neighboring States, and a science teaching center to serve as library, research center, and coordinator of project activities.

The systems approach, represented at the top of the tetrahedron on page 74, attempts to focus the now more or less independent educational efforts of Federal, State, and local government, and of private agencies on regional science education needs. In this context, a system is defined as an integrated group of interacting agencies, designed to carry out a predetermined function. The agencies in question may include institutions involved in the education of science teachers; a State department of education, other State and Federal agencies; cooperating school districts; private foundations, and industrial and business organizations. The function to be performed is to be expressed in terms of objectives and related to the overall plans for science education in the region.

The first experimental grant for this approach was awarded in fiscal year 1971 for the Del Mod System, a State-wide coordinated project in Delaware planned cooperatively by the University of Delaware, Delaware State College, Delaware Technical and Community College, the Delaware State Department of Public Instruction, the school systems of

Delaware, the DuPont Company and the National Science Foundation. It is organized around two concepts: Science Resource Centers and Science Education Field Agents. The four Science Resource Centers will serve as focus for various aspects of in-service and pre-service teacher education, as sources of materials, and as bases of operation for Science Education Field Agents. The Science Education Field Agents will provide liaison between the institutions of higher education and the school systems in roles somewhat similar to County Agricultural Agents, having major responsibility for in-service education and for implementation in the schools. Around these key concepts will be built a comprehensive mix of activities for in-service and pre-service teacher education, including the development of curricular materials in marine science and population studies, with related curricular changes and new teaching strategies in the classrooms of the schools in the State. The implementation phase has been planned in close consultation with the 26 school systems in Delaware whose cooperative involvement will increase as the project develops. Attention will also be devoted to technical education, initially through the development of a science education technician program at Delaware Technical and Community College. In the first phase of the project, the major thrust will be science in the middle schools, with expansion to include the role of mathematics in science (a pilot mathematics project is included in the first year), and eventually science and mathematics, kindergarten through 12th grade. A continuing and substantive program of testing and evaluation, starting with the collection of base-line data and designed to measure changes in both achievement and attitude, will be an integral part of the project.

28. PRECOLLEGE INSTRUCTIONAL IMPROVEMENT AND IMPLEMENTATION (PIII) 1974

Instructional Improvement Implementation

A major restructuring of implementation activities at the precollege level was accomplished in fiscal year 1974. Attention is now focused principally on bringing innovative curriculum materials into the classroom and orienting the educational staff of schools and school districts in the appropriate use of the materials they have chosen. Implementation grants are categorized as: (1) *orientation of educational leaders*—involving teams from selected regions to become thoroughly familiar with one or two of the major curriculum projects supported by NSF so that local training can be handled by members of these teams, and familiarizing education system decisionmakers with new curriculum developments to increase their understanding of their options for improvement of instruction in the sciences and in mathematics; (2) *school system-centered projects*—for school systems committed to full implementation of one of the new curricula in their classrooms, in collaboration with local colleges to strengthen the quality of teacher training; and (3) *teacher-centered projects*—to permit individual teachers who have leadership roles in their own schools or school systems to gain thorough background in one or two curricula so that they may try out the materials in their local situations prior to a commitment for widespread adoption.

This year grants were awarded costing $5.9 million for elementary school implementation activities. A total of 17,587 teachers, supervisors, and other resource personnel in science and mathematics participated in 157 projects.

29. PRECOLLEGE TEACHER DEVELOPMENT IN SCIENCE (PCTD)
1979

Pre-College Teacher Development in Science

In its third year of operation, this program continues to stress the improvement of the teacher's knowledge of the subject matter of science and to improve communication and cooperation between elementary or secondary school teachers and college or university scientists. Projects are designed either for summer or for academic-year activities. Of the 13,000 participants in the 1979 program, 18 percent were teachers from elementary school, 50 percent from middle and junior high school, and 32 percent from senior high.

In one academic-year project at San Francisco State University 70 middle and high school teachers used earthquake awareness to develop insights into fundamental principles of science and as a theme around which to teach science. The seminar drew on the expertise of research scientists in the Bay area.

In another project the University of Arizona conducted a four-credit, four-week summer course, "Mineral Resource Technology and the Environment," for middle and high school physical science teachers. The course demonstrated the role of the physcial sciences in mineral resource technology and in the mineral resource engineering disciplines and provided a comprehensive overview of the social, environmental, and economic impacts on Arizona of mineral resource development.

LEADERSHIP ACTIVITIES FOR PRECOLLEGE TEACHERS

Objectives of the Program

- Identify a cadre of well-trained and highly skilled elementary and secondary school master teachers.
- Provide teachers experience with up-to-date content, developments in educational technology, teaching methods, and research in teaching and learning they can use to enrich and improve instruction.
- Provide effective opportunities for in-service, peer teaching supported and encouraged by school administrations and community resources in the region from which the teachers are drawn.
- Provide the teaching community with people trained to implement improved education in mathematics, science, and technology effectively and widely.
- Recognize and honor precollege teaching professionals and provide role models, including women, minority, and physically-handicapped master teachers.
- Provide an incentive to establish cooperative and collaborative regional partnerships among schools, colleges and universities, the private sector, and others that will continue to use the human resources developed and that will build upon projects initially funded in part by the NSF.
- Develop leadership programs that serve as a magnet for attracting the most talented individuals into education.

Scope of the Program

Appropriate project activities may include, but are not limited to, seminars, conferences, research participation opportunities, and workshops designed to expand the scientific and/or mathematical knowledge base of teachers who have a solid foundation in these areas. Projects should provide the training for participant teachers to take leadership roles in in-service training of their peers in their home schools and communities.

Projects should be designed to engage teachers, school administrations, and the community as meaningful collaborators with a commitment to extend the impact of the master teachers when they return to their home schools. It is expected that support and encouragement will be forthcoming from the home school and project staff and be part of the project plan as the master teachers conduct training sessions for their colleagues.

Characteristics of Leadership Activities

Effective project planning and development will usually involve precollege teachers with appropriate expertise and background to help guide program design.

Projects should provide for intensive, hands-on sessions for teachers to learn in depth about one or more recent developments in their fields of specialization, including the results of research on teaching and learning that might have an impact on their instruction. Teachers should have the opportunity to work with the best instructional materials, educational technology, and teaching methods related to the content of the knowledge-intensive sessions and time to adapt these materials and methods for use both in their own classrooms and laboratories and for the instruction of their peers. Adequate time should be scheduled to allow teachers to interact in a meaningful way, professionally, with the other teacher participants and project staff. Several weeks of sustained effort will probably be required to provide adequate time for these activities.

The outcomes of these projects should include:

- teachers of science and mathematics who are confident of their grasp of the new knowledge and methods obtained;
- teachers prepared to carry what they have learned back into their own teaching and to conduct staff development and in-service continuing education for their colleagues. Such cadres of master teachers, as they are developed, should play significant roles in local and regional teacher development projects; and
- improved materials and methods, collected and adapted by the participants, for use in their classes and in presentations in their home schools.

Source: NSF/SEE, Program Announcement: Teacher Enhancement and Informal Science Education, NSF 85-9, April 1985.

LOCAL AND REGIONAL TEACHER DEVELOPMENT

Objectives of the Program

- Assist local and regional communities in their efforts to provide appropriate continuing education and professional development opportunities for elementary and secondary teachers who lack mathematics and science background for the courses they teach.
- Assist in identifying and developing creative approaches, including telecommunication and computer networks, to improve the science and mathematics knowledge base of elementary school teachers and non-certified secondary school teachers.
- Provide teachers experience with developments in educational technology, teaching methods, and research in teaching and learning they can use to enrich and improve instruction.
- Provide an incentive to establish cooperative and collaborative partnerships among schools, colleges and universities, the private sector, and others that will continue and build upon the projects initially supported in part by the NSF.
- Provide an incentive to examine the roles that women, minorities, and the physically-handicapped are playing in the local and regional educational setting and to develop ways to increase their access to activities and careers in mathematics, science, and technology.

Scope of the Program

Appropriate project activities include, but are not limited to, part-time and full-time courses, seminars, and workshops dealing with:

- content in mathematics, science, and technology;
- application of education technology, such as computers and telecommunications, to the teaching and learning process;
- new or improved instructional activities, delivery systems, or teaching practices in mathematics and science; and
- procedures to increase teacher effectiveness with various groups of students, including women, minorities, and the physically-handicapped.

In addition to classroom-oriented approaches, activities might include, for example, delivery via electronic media, using museums and science centers, or research experiences in a college, university, industrial, or national laboratory in carefully designed programs to provide effective education and professional development.

Characteristics of Local and Regional Teacher Development

Effective project planning and development will usually involve precollege teachers with appropriate expertise and background to help guide program design.

Projects should be designed to address local and regional problems or needs, and evidence for such need should be included. The proposal should explain why this project is particularly appropriate to these needs. Proposed solutions should draw upon the best available approaches, adapted to local circumstances, and all available resources, including local and regional cadres of master teachers, as appropriate. Projects designed to increase teachers' knowledge of content and/or methods new to them should provide intensive, hands-on practice.

Activities may vary in length according to their scope and the type of participants. They may be conducted during the academic year, the summer, or both. At least several weeks of sustained effort will probably be required at some point to provide adequate depth for lasting professional development. There should be a plan for the instructional staff and/or local master teachers to support, encourage, and advise the teachers as they begin to use their new knowledge in the classroom and laboratory. Methods for assessing how well the development and teaching improvement goals of a project are met should be an integral part of the project plan.

Activities may take place at a college or university, a local or state educational facility, an academic or industrial laboratory, a museum or nature center, or in other appropriate settings. Academic credit, or the equivalent, for teacher participation is encouraged, where appropriate. The activities in which the teachers participate should be designed to be appropriate for their needs. Where standard undergraduate or graduate courses are part of a project, their inclusion should be justified on the basis of the assessed needs of the target audience and the local problem(s) to be addressed.

In some cases the projects may run over two or more years, perhaps even continuing indefinitely. In all cases, local and regional support from partnerships of colleges and universities, local and state education agencies, business and industry, cultural institutions, and others is expected to be combined with NSF support for the projects. For longer term projects, proposals should contain an explicit plan for decreasing NSF support and increasing local and regional support—toward the goal of full and sustaining local and regional support.

Source: NSF/SEE, Program Announcement: Teacher Enhancement and Informal Science Education, NSF 85-9, April 1985.

PRESIDENTIAL AWARDS FOR EXCELLENCE IN SCIENCE AND MATHEMATICS TEACHING*

This is a Presidential initiative to provide national recognition for distinguished secondary school teachers of science and mathematics. Teachers whose primary responsibility is classroom teaching of science or mathematics at grades 7 through 12 in an accredited school in any of the fifty states, Puerto Rico, or the District of Columbia are eligible for this award. In addition, a minimum of five years' teaching experience in science or mathematics is required. Awardees receive national recognition and their schools receive $5,000 to be used under the awardees' directions for instructional purposes in their school districts.

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*This description is provided for information purposes only. No applications or proposals are sought for Presidential awards via this announcement.

Source: NSF/SEE, Program Announcement: Teacher Enhancement and Informal Science Education, NSF 85-9, April 1985.

SCIENCE AND MATHEMATICS EDUCATION NETWORKS

SCIENCE AND MATHEMATICS EDUCATION NETWORKS

Objectives of the Program

- Encourage the development of substantial local and regional resource-sharing networks and collaborations that may include, among others, teachers, schools, local and state education agencies, colleges and universities, business and industry, and cultural and professional organizations, designed to accomplish the objectives of this activity. Collaborations that take advantage of available curricula and materials, methods, and human resources and expertise and, as necessary, appropriate communications technology for dissemination are encouraged, and an information brokering role is assumed by the NSF in helping them develop.
- Provide opportunities for teachers, school administrators, educational decision-makers, and local and state educational agencies to learn about new and alternative instructional materials, classroom teaching techniques, and recent research findings that may have meaningful classroom applications for teaching mathematics and science at the precollege level.
- Provide professional support to local mathematics and science teachers by introducing them to new materials and teaching techniques—and by providing a continuing source of information and advice on how these innovations may be put to practical classroom use.
- Build bridges between educational product developers and distributors and users, including teachers and local and state education agencies responsible for product selection, to help producers better meet the needs for effective mathematics and science instructional materials.
- Establish mechanisms for disseminating information about resource materials for efficient and effective classroom instruction.
- Initiate collaborative, coherent, and constructive programs to help teachers, school administrators, and school board members translate the results of research on teaching and learning into classroom practice.
- Develop resource-sharing networks augmented by effective and appropriate use of telecommunications and computer networks, that will serve the scientific and instructional needs of local school districts and will continue after NSF support has terminated.

Characteristics of the Program

Resource-sharing networks for dissemination of information on the successful curricula, methods, materials, and human resources available in well-defined geographical regions of the country are encouraged. The planning, execution, and support of these networking activities will involve collaboration and cooperation among many people (precollege and college teachers, administrators, parents, businesspersons, etc.) and institutions (local and state education agencies, colleges and universities, business and industry, professional societies, and cultural institutions). Cooperative efforts will be based on sharing and using identified strengths found in the region to meet needs and improve mathematics and science education throughout the region. Networking projects developed in this way are likely to consist of a substantial number of individual, correlated but independent activities that, together, meet the overall needs of a particular region. Discrete projects that focus more narrowly on a particular need and consist of relatively few activities are also supported by this program.

Whether in discrete projects or as part of a collaborative network, this program encourages sharply focused individual project activities designed to engage the participants actively with the information presented. The individual activities in an information project will often be of relatively short duration, a few days to a week or so, and concentrated on a specific topic to insure depth of coverage can be accomplished in a short period of time. Projects might embody a coherent collection of such activities that provides broad coverage of a topic but extended over a longer period of time, for example, a series of weekend workshops each focusing on a different problem solving technique. The timing, extent of coverage of topic, and rate of engagement of participants should be a function of the project's stated needs.

Other characteristics of networking projects include, but are not limited to:

- helping to define and respond to the educational needs of specific geographic regions;
- providing a continuing source of information and advice to the teachers, principals, and others as training is put into practice in the classroom;
- exchanging information about demonstrated collaborative efforts among teachers, schools, local and state education agencies, professional societies, colleges and universities, business and industry, cultural institutions, and others in the planning, execution and support of the project;
- helping educators and planners develop long and short term priorities for gaining and using information; and
- demonstrating alternative solutions, increasing the participants' awareness to possible alternatives, and helping them to develop their strategies for choice among them.

Source: NSF/SEE, Program Announcement: Teacher Enhancement and Informal Science Education, NSF 85-9, April 1985.

MATERIALS AND METHODS FOR TEACHER PREPARATION

Objective of the Program

This program supports:

- the development of creative new materials and model programs that are designed to improve the preparation of undergraduate students to become elementary or secondary school teachers of mathematics, science, and technology;
- the development of creative new materials and model programs that are designed to provide effective continuing education to teachers of mathematics, science, and technology throughout their careers;
- the development of creative new materials and model programs that are designed to enable individuals of high ability in mathematics, science, and engineering to enter teaching at the precollege level.

Scope of the Program

Appropriate project activities include, but are not limited to, the following:

- the development of specialized materials, courses and software designed for current or future teachers to provide them with the basic knowledge in science, mathematics and technology necessary to become and remain effective precollege teachers;
- the development of materials or model programs to acquaint current or future teachers with the results of research in the cognitive sciences on effective methods for teaching and learning mathematics, science and technology;
- the development of materials or programs that demonstrate effective science teaching strategies for reaching students with special needs such as those who are gifted and talented, women, minorities, and/or physically handicapped.
- the development of materials or model programs to strengthen the mathematics, science, and technology knowledge of teachers who are currently not certified to teach in these subject areas, or to strengthen the teaching skills of scientists, mathematicians or engineers who wish to become precollege teachers.
- the development of model programs that test, demonstrate, and evaluate innovative approaches to the undergraduate preparation and continuing education of precollege teachers of science and mathematics. The design of prototypes suitable for widespread adoption and use by local education agencies is especially encouraged.

Characteristics of the Program

In addition to the general characteristics described above for all materials development and research programs, the following points are pertinent.

The anticipated outcomes from projects funded under this program are materials and model programs that are likely to:

- provide teachers entering the profession with a strong grounding in mathematics, science, and technology;
- assure that teachers are cognizant of techniques that are effective for the teaching of science, mathematics, and technology, as well as techniques appropriate to different learning styles and student needs;
- provide teachers with appropriate mechanisms and materials to assure that their teaching skills and expertise are maintained throughout their careers.

Proposals should address not only the rationale and specific plan for developing materials and model programs, but also the methods that will be used for evaluation and dissemination of the products.

Note: For other NSF programs that relate to teacher development, consult the Program Announcement for *Teacher Enhancement and Informal Science Education* (NSF 85-9).

Source: NSF/SEE, Program Announcement: Materials Development and Research, NSF 85-10, April 1985.

54. COURSE CONTENT IMPROVEMENT (CCI)

1960

Curriculum Improvement

A second major Foundation policy move in the field of science education came with the inauguration of projects designed specifically to improve science curricula within the Nation's schools. It was recognized early in the Foundation's history that, too often, science courses were being taught on the basis of outmoded textbooks and obsolete theories. Although teachers and school administrations had tried to keep up with rapidly evolving scientific disciplines, there existed no systematic channels through which they could learn of these changes in a manner designed to enable them to incorporate the knowledge into their classroom situations.

The Foundation also recognized that it was in the national interest to involve broadly based groups in action programs to remedy this problem. The problem had been identified; further discussion would not contribute to a solution unless the groups concerned were committed to produce specific materials useful to the classrooms at various levels.

Similarly, the NSF has scrupulously maintained the principle that, although classroom materials might be produced with the aid of the Federal Government, the Government has no control whatsoever over the content of these materials nor over their distribution. This remains in the hands of the scientists. The Government has no mechanism to "sell" the materials produced; the aim is merely to make available classroom materials that, if they are indeed better, will sell themselves to the schools needing them.

Course Content Improvement Programs

Modernizing the content of science and mathematics curricula and courses, as well as all types of aids to learning and teaching, is essential to upgrading education for today's age of science. Content, adapted to the learner's level, must continuously reflect science as on-going inquiry and science at the level of understanding achieved by current knowledge. The purpose of the Foundation's Course Content Improvement Programs is to provide support for projects which engage the Nation's best talent in the difficult and urgent task of achieving these goals.

These programs have evolved steadily since 1954. The complexity of problems in this domain, together with their far-reaching implications, led to an initially cautious approach through relatively small grants for a variety of exploratory studies. Support was increased considerably in fiscal years 1957 and 1958, when the first major effort was launched—the development of a new high school physics course. The results and success of pilot projects, along with growing realization among first-rank scientists that such efforts merit high priority among their responsibilities, justified a further substantial increase to about $6 million annually in fiscal years 1959 and 1960.

First priority has thus far been given to new course and materials for secondary schools, nearly 85% of program funds being allocated to this educational level during the period 1954–1960. In addition to continuing substantial support for high school projects, major effort must be focused upon the improvement of college and university programs, both through undertakings involving nationwide teams of scientists, mathematicians, and engineers and through modernization of curricula and courses within the great diversity of higher educational institutions and scientific and engineering fields. Also, recognition of the vital importance of elementary and junior high school experience in developing proper attitudes and laying the groundwork for subsequent schooling makes imperative a thorough study of science and mathematics curriculum improvement at this level.

Evaluation of projects supported by these programs points up two important aspects of course content improvement: first, assurance of excellence in content, for which perhaps the best guarantee is development and constant improvement of materials by top-level scientists, working with outstanding teachers and other experts; second, determining pedagogical feasibility through school trial, careful study of results, and revision of materials based thereon—an integral element in most projects. The widespread interest in course content developments is reflected in the great number of requests for information received by the projects, the Foundation, and other organizations. Substantial interest is also emerging in Europe, Asia, South America, and other parts of the world.

Course Content Studies and Development

Elementary-Junior High School

Foundation support for course content studies and development for elementary and junior high schools continued to be quite limited in fiscal year 1960 because further study of the problems involved and clarification of the Foundation's responsibilities are still required. These studies are now underway.

Another important need is an effort by scientists to identify significant content and to experiment with materials for pupils and teachers. The University of California received a grant to continue its interdisciplinary project on science for the first six grades; the University of Illinois, a grant for experimental work on instruction in principles of physical science focused on astronomy. The basic importance of mathematics content throughout the elementary and secondary curriculum is conceded by all; the School Mathematics Study Group is continuing its highly promising work on sample courses for grades 7 and 8, and beginning the preparation of material for grades 4 through 6.

High School

Educational Services Incorporated received a grant to complete the first phase of work on a new high school course prepared by the Physical Science Study Committee. As the result of a 4-year effort by some of the Nation's most notable physicists, most materials for this course are now available to all interested schools. Some 30,000 students in 650 schools have already taken the course.

The School Mathematics Study Group received further support through Yale University for revision of sample textbooks and teacher's commentaries for grades 7 through 12, materials for teacher education, special materials for gifted students, and further evaluative studies. The American Institute of Biological Sciences was granted additional funds for efforts by the Biological Sciences Curriculum Study to devise and test textbooks, laboratory and field studies, teacher education materials, and other aids for high school biology. In chemistry support was given to two projects. Grants were made to Earlham College for the Chemical Bond Approach Project to prepare a second version of a text and laboratory guide for trial in some 50 schools during 1960–61, followed by a definitive edition to be published for general use. The University of California received funds for the Chemical Education Materials Study, which is beginning to devise and test text, laboratory, film, monograph and other materials for another type of high school chemistry course.

A related and difficult problem is that of helping teachers and school administrators learn more about new curriculum developments sponsored by various foundations and organizations. One approach will be tried by the National Council of Teachers of Mathematics through a grant for a series of eight regional conferences of mathematics supervisors.

College and University

Projects at colleges and universities follow three general patterns. One pattern involves a conference, series of conferences, or committee study to examine a field and define broad guidelines for curriculum reform. Support was provided for such studies on: introductory physics courses; chemistry for non-majors; and the undergraduate curriculum for chemistry, civil engineering, chemical engineering, sanitary engineering, experimental mechanical engineering, and anthropology.

A second type of activity, which may evolve from a project of the first sort, is the formation of a continuing body to conduct basic studies, provide liaison among specific course-content projects, supply information about developments, and stimulate efforts on the part of individual institutions or groups of colleges. The Mathematical Association of America received a grant to enable its Committee on the Undergraduate Program in Mathematics to assume this responsibility for that field, and comparable commissions concerned with college physics and experimental mechanical engineering have been recommended by the conferences in those fields.

The third kind of undertaking in the college and university studies category is the development of a specific new course which promises to be of wide interest and which includes elements of a truly novel nature. In this area grants were made to Harvard University for a new introductory biology course, to Ohio State University for work on a new laboratory program in organic chemistry, to Lehigh University and North Carolina State College for coordinated projects in experimental mechanical engineering, and to the Massachusetts Institute of Technology for a laboratory course on the principles of instrumentation.

Supplementary Teaching Aids

The objective of the Supplementary Teaching Aids program is to support the development of such aids to learning as new laboratory apparatus, motion pictures, and television presentations which have been designed to extend the range and scope of science, mathematics and engineering courses in significant ways.

For the design and development of prototypes of new laboratory equipment, 32 grants were made in 1960. Projects include an educational wind tunnel using smoke to visualize air flow, a small hypersonic wind tunnel, stereophotomicrography for submacroscopic anatomy, demonstrations for use with overhead projectors, equipment for instrumental chemical analysis, design of inexpensive computers, and a low-cost mass spectrophotometer.

Two educational television projects were granted support. A series of eight half-hour programs produced under a grant to the University of California at Berkeley will enable Nobel Laureate Wendell M. Stanley and his colleagues in the Virus Laboratory to bring the story of modern virus research and its implications for basic biology to large audiences. The use of television in providing teachers of mathematics with background knowledge and a detailed understanding of new curricula is the subject of a project sponsored by the Minnesota Academy of Science.

Educational film projects in a variety of fields were supported. Anthropology films, sensitively edited, can give the student an understanding of unfamiliar cultures; with this purpose in mind, a grant was made to Harvard University for the completion of a series of documentary films on !Kung Bushmen of South Africa. Under grants to the State University of Iowa and the University of Minnesota, films on principles of fluid mechanics will be produced. Iowa also received a grant for films on the biology of slime molds and the use of these organisms in teaching. Yeshiva University was awarded support to begin a series of films for high school and college biology courses which endeavor to put the viewer in the position of an original observer of plants and animals as an attempt is made to uncover fundamental principles through close observation of organisms in their natural environments. Yale University has received support for a series of short films for advanced high school and college courses in chemistry. A grant to the University of Illinois provides for experimentation with the use of films in presenting demonstration classes on new approaches to the teaching of elementary school mathematics.

60. COMPUTING ACTIVITIES IN EDUCATION (CIE)

1969

In fiscal year 1969, the second year of its existence, the Office of Computing Activities administered a variety of programs and studies in support of the computing requirements of education and research, and continued to coordinate other programs of support for computing activities throughout the Foundation.

During the year ending June 30, 1969, the Office of Computing Activities considered 489 proposals requesting a total of $105,453,138. In response, the Foundation made 194 awards obligating $17 million for an award-to-request ratio of approximately 1 to 6. For those proposals resulting in awards, the amount awarded averaged approximately 50 percent of funds requested.

Awards were made to 153 institutions in 39 States and the District of Columbia. Fifteen awards were made to support studies or conferences concerning the use of computers in education and research. Seventeen were made for projects involving precollege education. Of the $17 million granted 96 percent was awarded to educational institutions or consortia, and 4 percent was awarded to nonacademic institutions.

Prior to the establishment of the office, the Foundation had provided support to university computing facilities and to research projects in computer science for over 10 years.

COMPUTING SERVICES

Perhaps the most striking feature of computing activities at academic institutions today is the growth of demand for sophisticated computing services in instruction. This phenomenon appears in the utilization statistics reported by university and college computing centers. It is reflected in changes of course offerings, and frequently in requirements for a programing course in the freshman or sophomore year of college. It also appears in the increased investment institutions have made from their own funds to provide academic computing services.

Institutional Computing Services

The Foundation institutional computing services program is the only Federal program offering institutional support, as distinct from individual project support, for the cost of academic computing services. In fiscal year 1969, $6.5 million was awarded to 23 institutions to assist with necessary expansion or initial installation of computing services. The grants ranged in size from $14,000 to $1.2 million.

An example of the importance of the institutional computing services program can be noted at Michigan State University, an institution with approximately 31,000 undergraduates and 8,000 graduate students. The university operated a computing center which contained a large second-generation computer at an annual operating cost of about $1 million per year, as well as nine smaller special-purpose computers with annual costs ranging from $11,000 to $250,000 each. However, the demand for computing services for undergraduate instruction and for members of the university community who had not previously used computers was growing explosively. In 1 month in 1967–68, the computer center was used by 77 departments and institutes to process nearly 30,000 tasks, almost 60 percent of them for students in connection with course work. Also, financial support for computing from State appropriations, tuition, and income from sponsored research lagged behind the expenditures required.

To overcome these problems the university proposed to purchase a large third-generation computer and sought a grant from the Foundation to help provide financial stability while it developed other sources of support. A grant of $1.2 million for 3 years was made in fiscal year 1969. The figure below shows the history of support for computing at Michigan State.

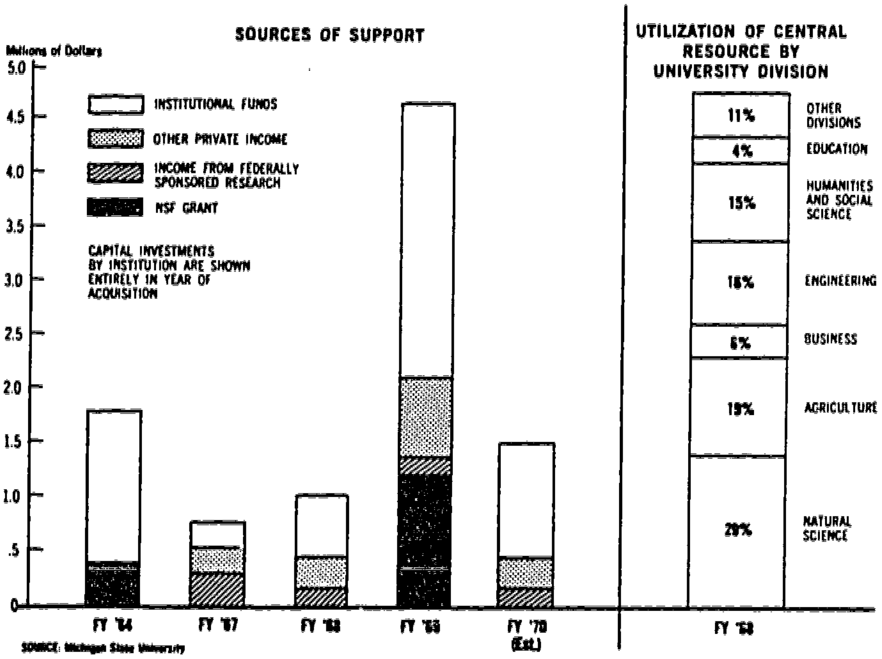
The Catholic University illustrates a different situation—one in which the existing machine had never been able to service more than a limited subset of campus requirements. Although there had been a computing center for several years, the primary equipment lacked the capability to handle major research problems, so faculty members had employed various expedients to secure service from Federal laboratories and other universities. Motivated by desires to eliminate this inconvenience to faculty and to expand computer use in undergraduate instruction, the university requested partial support for the purchase of a medium-scale modern computer. Final action on this proposal was a grant of $275,000 in partial support of a 3-year program.

Regional Computing Activities

Another interesting development in institutional support for computers is the formation of cooperatives, consortia, and other regional arrangements to help provide computing services for educational institutions. The Foundation, through its regional computing pilot projects, has been exploring the merits of these arrangements.

In fiscal year 1968, a major effort involved the inauguration of 10 regional computing activities. Typically, each was centered about a major university which provided computer services to a cluster of nearby colleges. These projects were

MICHIGAN STATE UNIVERSITY COMPUTER CENTER



SOURCE: Michigan State University

designed to make effective use of the experience and equipment at universities to help colleges and a few secondary schools introduce educational computing to their students and faculty.

In fiscal year 1969, five additional regional experiments were established, to enlarge the range of models available for study and evaluation, with total awards of slightly over $2.1 million. Altogether, the regional centers now include 12 major universities, 116 participating colleges, and 27 secondary schools located in 21 States. The figure illustrates a project centered about the Illinois Institute of Technology (IIT), which serves nine participating institutions in Illinois and Wisconsin, and also shows the location of all of these Foundation-supported regional activities. In each of these activities there is a good deal of concern with faculty training, cooperation in the use of instructional materials, and sharing the results of experience with educational use of a computer.

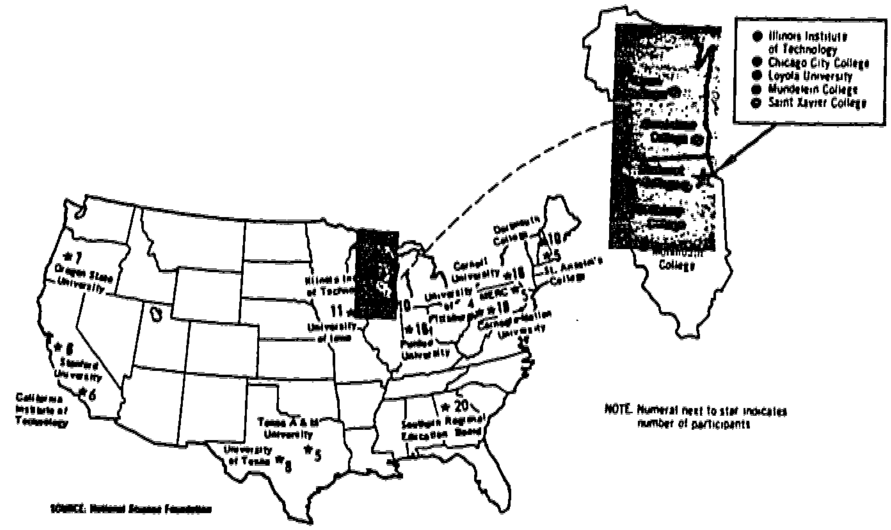
EDUCATION AND TRAINING ACTIVITIES

Curriculum Development

The full impact of computers on education will not be felt until the modes of thought characteristic of computing are incorporated into curricula. Concepts such as the logic of programming procedures, the use of models, the interrelationship of complex events, and the uses of data are emphasized in computing and must inevitably affect the educational process.

A systematic approach to an exploration of the benefits of the computer in undergraduate study in chemistry has led to the support of a carefully selected set of projects. Donald Secrest of the University of Illinois is developing a number of experiments for an undergraduate physical chemistry laboratory in which a time-shared computer is an integral part. Samuel Perone of Purdue University, who has directed two summer faculty workshops in the use of computers linked to instruments for

LOCATION OF REGIONAL COMPUTING ACTIVITIES SUPPORTED IN FY 1968-FY 1969 AND SCHEMATIC OF ONE CENTER



NOTE. Numeral next to star indicates number of participants

SOURCE: National Science Foundation

chemical measurements, is also concerned with uses in undergraduate chemistry laboratories. Since the computer is essential to the solution of theoretical as well as experimental problems, David P. Shoemaker of MIT is exploring ways to give the student access to computational services which include capabilities that result from applied numerical analysis.

A project designed to explore fundamental curriculum [illegible] at the elementary school level [illegible] directed by Wallace Feurzeig of Bolt, Beranek & Newman in Cambridge, Mass. The goal is to demonstrate through classroom presentations that the teaching of the set of concepts related to programing can be used to provide a natural foundation for the teaching of mathematics, and indeed for logical thinking in general. A new programing language permits the expression of mathematically rich algorithms, both numerical and nonnumerical, but is so simple that it can be taught to second graders. Although it is premature to evaluate the significance of this experiment, initial results are encouraging.

Training

The intimate relationship between curriculum development and training activities in many computer projects is well illustrated by the following example in statistics.

A grant to the University of North Carolina in fiscal year 1968 supported the cooperative efforts of the departments of statistics, psychology, and biostatistics in the development of data sets, collections of problems, and programs for use in teaching elementary statistics.

Programs were developed for several types of computing services including commercial time-sharing, a large university computing center, and a small stand-alone computer. In the summer of 1969, the university organized a workshop for 32 teachers from colleges and universities to explain and demonstrate the results of the project. Foundation support will enable these teachers to use the materials developed at the university to integrate computer use in the teaching of statistics at their home institutions. This group of teachers will reassemble at the University of North Carolina in the summer of 1970 to evaluate their experience.

A different type of training project was conducted in the summer of 1969 in the Los Angeles area. Richard Bellman of the University of Southern California directed an experimental program in computing for underprivileged secondary school students that had an enrollment of 80 for a 4-week course. The curriculum included a mathematics class, a programing class, a programing laboratory, and instruction in the use of equipment. Another phase of the project involved 20 additional students, with nonscientific backgrounds, who received an 8-week course in data processing applications typical of hospitals and medical centers.

Computer Science Education

Many universities and colleges are initiating academic programs in computer science, a trend which first started in the last half of the 1950's and which has been gaining momentum rapidly. In some instances these take the form of formal departments, in some they constitute areas of concentration within existing departments, and in other cases they may be interdisciplinary programs focused on the use of computers. In fiscal year 1969, grants were made to six institutions, the University of California at

Berkeley, Purdue University, University of Southern California, Washington University, University of Rhode Island, and State University of New York at Stony Brook, all primarily for graduate education. These grants ranged in size from $80,000 to $344,000 and totaled $1,028,600. Four of these awards will help initiate graduate programs in computer science and two will help strengthen programs that have existed for a few years.

RESEARCH ACTIVITIES

The Foundation supports research in three major areas, computer science, computer-based instructional technology, and computer applications.

Computer Science

The emergence of computer science as an academic discipline has been given impetus by the increasing complexity of computer systems. Although early workers in this field were trained in other areas, the growth of information about computers has been so great that the definition of computer science as a discipline and research area has been a natural consequence.

Today research workers in computer science are concerned with the basic understanding of the potential and limitations of computers; with improved design and more versatile components—in both hardware and software; and with the discovery of better ways of utilizing equipment. Among the research projects being supported are investigations of the properties of algorithms, languages for expressing these algorithms, computing systems for processing them, and techniques for improving means of communication between man and machine. One area of research that is vital to long-range development of this field is that of the theoretical foundations of computer science. Support has been provided to groups at Cornell, Purdue, and the University of California at Berkeley to conduct basic research in this area. Using abstract mathematical models of computational processes, these groups are studying the characteristics of classes of problems which cannot be solved algorithmically. On the other hand, for classes of problems which, theoretically, can be solved, it is extremely interesting to obtain lower bounds for computational time and for storage requirements, and such bounds are being investigated.

Electronics technology appears to be approaching a point where the speed of computers of conventional design is limited by the speed of light. Thus, significant increases in computing power are likely to depend upon new highly complex machine architecture. Jacob T. Schwartz, at the Courant Institute of Mathematical Sciences, New York University, is studying highly parallel machine structures, where several tasks of a large computation are performed simultaneously. He is learning how the parallel units must communicate with each other and coordinate their actions. He is also measuring how much inherent parallelism there is in various computations and thus how much computational power is added by this type of design.

Instructional Technology

A popular impression of the computer's primary use in education is as a teaching machine. Experiments in the use of the computer to present flexibly controlled instructional material—often referred to as computer-assisted instruction (CAI)—or to provide the teacher with more direct information about student progress have shown exciting promise in certain applications. However, these experiments have also pointed to inadequacies in the current state of technology and to more fundamental inadequacies in our understanding of basic areas of learning.

An understanding of both the benefits and the limitations of CAI will depend on its being tested at different educational levels in a variety of circumstances. As part of a limited program of testing and evaluation, grants were made to Patrick Suppes of Stanford University in fiscal years 1968 and 1969 to study the effect of CAI on teaching programing and data processing concepts to 80 innercity secondary school students. This project will serve both to test the effectiveness of this technique in a difficult learning situation, and to collect data about the learning patterns of these students.

In this case, the students are located in San Francisco, Calif., and the instructional material is stored in a computer at Stanford University in Palo Alto, Calif. The choice of remote terminals was dictated by transmission costs: less expensive teletypewriters were used, although visual display terminals might have been superior from an educational viewpoint.

Careful evaluation of the obstacles inhibiting developments in this field led the Foundation to try a different approach in addition to specific project activities. This approach is to strengthen a few major centers to promote longer range basic research in instructional technology. The three centers supported in fiscal year 1969 are located at the University of Pittsburgh, Stanford University, and the University of Texas. Altogether six grants in computer-based instructional technology were made in fiscal year 1969 with total support exceeding $1.2 million.

Computer Applications

Although computers were first developed to assist with complex numerical calculations, it was soon realized that nonnumerical information could be coded and stored in the computer memory equally well and subsequently analyzed or altered by programed procedures. During fiscal year 1969, the Foundation made several grants for study of computer techniques for handling nonnumerical information. A grant will enable William H. Huggins of Johns Hopkins University to conduct research in computer graphic symbols. Another to John L. Clough of Oberlin College will support work on the synthesis of sound by computer. Still another to David L. Bonsteel of the University of Washington will aid the development of techniques for simulating visual experience in architectural space using computer graphics.

55. PRECOLLEGE MATERIALS AND INSTRUCTIONAL DEVELOPMENT (PMID)

1973

Curriculum and Instruction Development

During the year the Curriculum and Instruction Development Program of the Division of Pre-College Education in Science was transformed into the Materials and Instructional Development Section. This change reflects the fact that for some years support has been given not just for the development of complete curricula but for the preparation of specific units of modules, which may fit into existing courses, and for instructional aids which may be addressed to teacher preparation, to special types of students, or to specific learning situations.

Among the grants of special interest was one to Florida State University for the initiation of a major curriculum development, the Individualized Science Instructional System, which will be based on roughly 125 modules in various areas of science addressed to students in grades 10 through 12. Conferences on curriculum development supported by NSF included: the Social Science Education Consortium conference considering the process of dissemination as related to curriculum developments; the Education Development Center's conference on unified mathematics and science at the secondary school level; a series of three study sessions held by the University of Indiana, the University of Maine at Orono, and Newton College of the Sacred Heart to consider the optimal characteristics of mathematics curricula in the K-12 range; and one by the Education Development Center for a summer study of new mathematics materials in the third to fifth grade range. These last four grants may well establish the main parameters of major developments over a period of the next several years in pre-college mathematics education.

61. TECHNOLOGICAL INNOVATION IN EDUCATION (TIE)
1973

TECHNOLOGICAL INNOVATION IN EDUCATION

The U.S. system of education is placing ever increasing demands on the Nation's resources. The fraction of the GNP devoted to all educational expenditures (public and private, from kindergarten through graduate school) has risen steadily since the end of World War II—from about 3 percent to about 8 percent in 1971-72. Nonetheless, the educational needs of certain elements of our population continue to go unmet, and the quality of instruction throughout the system is very uneven. Technological Innovation in Education has as its goals improving the quality of instruction (with special emphasis on science education), improving the efficiency of instruction, and improving access to specialized educational needs through the application of modern computer and communication technologies. In fiscal year 1973, approximately $6.3 million was awarded toward these ends to academic and other nonprofit organizations.

Development of the PLATO IV system of computer-assisted instruction (CAI) continued in preparation for a 2-year, large-scale field test and evaluation. This system is designed to provide highly appealing CAI simultaneously to thousands of widely scattered students, using a single large computer system and graphic terminals invented and perfected at the University of Illinois. The first 250 (plasma panel) terminals have been delivered and installed at locations throughout the country.

Concurrently, the Foundation is sponsoring the development and field testing of the TICCIT (Time-Shared Interactive Computer Controlled Information Television) system of CAI developed and designed by the MITRE Corporation and Brigham Young University to provide highly efficient instruction in community colleges for such introductory courses as English and mathematics. Efficiency will be obtained by exploiting mini-computer and television technology (to serve over 100 student TV terminals simultaneously), and through learner-controlled courseware which simplifies system design, courseware authoring, and student/computer interaction.

Development and field test of the PLANIT (Programming Language for Interactive Teaching) machine-independent system of CAI was completed during fiscal year 1973. The design objectives—to produce a sophisticated system capable of being installed and operated effectively on a very wide variety of existing computing equipment—has been achieved, based upon preliminary results from a field test conducted at Purdue University. A conference will be held early in fiscal year 1974 during which the system will be explained, demonstrated, and distributed.

Research and development continued into computer-based techniques for optimizing student performance. Investigators at Stanford University believe that they can not only improve student performance (by 50 to 100 percent) for elementary reading and mathematics, but also predict such improvements for each student on the basis of the student's performance without CAI during the previous year and his performance after testing with only an hour or two using CAI. A modest experiment was begun to provide CAI of this sort to American Indians at a pueblo in New Mexico. Data are incomplete, but results indicate significant improvements in student performance and attitude, and thus have generated considerable enthusiasm for the project from officials of the school and the community who are taking steps to continue it at local expense after fiscal year 1974. The project could serve as a valuable model for other widely scattered communities of Indians.

All major universities and many colleges now provide computing services for faculty and students. While major computer-based curriculum efforts are only just beginning, one major obstacle in sharing instructional programs is the complexity of the new technology. Since universities use different machines and computer language and operate their services in a variety of formats (batch versus interactive), it is difficult to directly exchange instructional programs. Further, the variety of the disciplinary content creates numerous documentation problems. In order to increase the potential for widespread use of materials and at the same time reduce the time and costs related to program exchange, several universities have initiated a major cooperative effort to study and overcome this problem.

CONDUIT (computers at Oregon State University, North Carolina Educational Computing Service, Dartmouth College, and the Universities of Iowa and Texas at Austin) is a consortium of five regional networks involving 100 colleges and universities with an enrollment of approximately 300,000 students, and is organized to study and evaluate the transportability and dissemination of computer-related curricular materials for use in undergraduate instruction. The goals and procedures of CONDUIT are determined by a Policy Board, which consists of the director of each regional computer network. CONDUIT Central, located at Duke University, coordinates network activities and maintains the CONDUIT library. It also creates and distributes videotaped seminars and self-instructional computer-related materials.

In fiscal year 1973, 12 grants were awarded to establish a regional educational computer network for colleges in Central Mississippi under the leadership of Jackson State College. Five of the participating institutions are private 4-year institutions; three are State-supported senior institutions; and four are 2-year colleges. The Regional Cooperative Computing Activities Program under which the above awards were made was phased out in this fiscal year. An analysis of the impact and cost of regional computer networks on undergraduate instruction is contained in a report published by the University of Iowa entitled "A Study of Regional Computer Networks."

Other supported studies included the examination of various communication technologies such as broadband two-way cable systems, specialized common carriers, stationary satellite, and optical communication links, with a view to assessing their potential for various nonconventional educational telecommunication services.

63. DEVELOPMENT IN SCIENCE EDUCATION (DISE)

1979

Development in Science Education

The development in science education (DISE) program supports the design, field testing, and dissemination of innovative teaching and learning models and materials for science instruction at any level of education. In addition to continued support of several major projects, the DISE program emphasized five special areas: science for the early adolescent; improving access to careers in science; science technology and society; new knowledge and new skills—education for productivity; and technology as applied to learning. This last area included a special solicitation for proposals and support of two projects to design, build, and demonstrate an interactive computer-controlled videodisc system for science education. Following are brief descriptions of these areas and examples of projects supported.

It is disturbing to note that most U.S. citizens receive very little formal science instruction after their junior high school or early adolescent years. Because this is a time often ignored in terms of special emphasis in science instruction, NSF supports projects dealing with pre-service and in-service education of teachers of middle and junior high science. Projects designed to provide junior high school students with information about various fields within science and the related careers are also supported.

By way of illustration, a project at Central Michigan University is designed to produce, evaluate, and disseminate a set of audio-tutorial units in science for the inner city student. Another project, at the National Wildlife Federation, involves preparing high-quality environmental science curriculum materials for middle and junior high schools to develop knowledge of relationships in the natural environment. Also included among the awards this year are efforts in outdoor/informal education such as the Lawrence Hall of Science project on physical science activities in out-of-school settings for early adolescents and their families.

Eight projects in improving access to careers in science were aimed at students ranging from middle school to college. The projects encompass a variety of educational activities for both in-school and out-of-school settings. Two projects are addressed to the special needs of women, three to the special needs of minorities, and three to the needs of both groups. These projects focus on such themes as relating science and mathematics subject matter to scientific careers, providing appropriate role models, and developing general problem-solving and reasoning skills. Three projects will develop material for in-service training of junior high and high school teachers.

In one project aimed at increasing access to careers, Lillian C. McDermott at the University of Washington, working to increase the ability of minorities to participate in mainstream college science courses, has developed a set of instructional materials for lower division undergraduates. These materials, useful in physics, chemistry, and the physical sciences, emphasize both concept formation and reasoning development. They are designed to provide flexibility in length, choice of subject matter, and options for sequencing in courses in which they are used.

The connections between science and society are seldom emphasized in education at any level. For the most part, the education of scientists and engineers fails to deal in any depth with the humanistic aspect of their work or to raise the difficult issue of the social responsibilities of science. Conversely, education in the nonscientific professions is deficient in its neglect of science, and the general education of most citizens prepares them poorly to deal with the science-related social issues and the value problems of the day.

Barry Hyman, working through the American Society for Engineering Education, is using a case study strategy to convey an understanding of public policy to undergraduate engineering students. For four summers, engineering students chosen through a nationwide competition will participate in a public policy internship program in Washington, D.C. Based on their work, case studies will be developed and disseminated widely for use in undergraduate engineering curricula. By the fourth summer, support of the program will be taken over by engineering societies and industry.

In another award, older people, who are rarely exposed to science courses, will participate in a special education program in science and society. The program, at the University of Colorado at Colorado Springs and Colorado College, has the long-term goal of developing a model to encourage older people to attend regular college science courses for credit. This project extends and complements the informal education project supported at the same institution by NSF's public understanding of science program.

The NSF focus, new knowledge and new skills—education for productivity, supports the revision of curricula so that scientifically trained personnel can better contribute to appropriate technological development and, through increased productivity, to the country's economic strength and quality of life. The curricula may be for undergraduate, graduate, and continuing education; the projects, usually based in universities or professional groups, are encouraged to collaborate strongly with industry and with non-academic laboratories.

A project with David M. Himmelblau at the University of Texas at Austin is producing modules for 2,000 topics which give explanations, references to best practice, or study guides that will be formulated for electronic transmission and retrieval by computer. The system of materials will be structured so that specialists can contribute short pieces for teaching new developments without having to rewrite the equivalent of a whole text. Fulfillment of these objectives will be tested in about a dozen industrial and university programs.

The increased use of computers, particularly microcomputers, has increased the demand for people trained in digital systems engineering, which is a combination of electrical engineering and computer science and engineering. Thomas A. Brubaker at Colorado State University is studying ten leading research institutions, both industrial and academic, to identify and develop prototypes of useful materials for teaching digital systems engineering. The goal of the project is to reformulate and combine traditional principles around several thousand generalized engineering techniques which can be retrieved and learned for specific applications.

Projects concerned with the use and technology for science education include the exploration of innovative applications of technology for instruction, the development of materials on using technology as a tool of science, or the development of materials to study the technology itself. Most projects are based on the use of computers, sometimes in conjunction with other devices. For example, several projects supported incorporate the use of graphics to improve instruction. To explore the education potential of the new videodisc technology, Robert Fuller and his colleagues at the Univesity of Nebraska at Lincoln are developing a low-cost approach for the videodisc in physics instruction.

Techniques used by meteorologists in analyzing and reporting the weather are based on the computer analysis and graphical display of weather data collected by satellite. Atmospheric sciences education will begin to incorporate some of these methods as a result of work by Donald Johnson at the University of Wisconsin supported jointly by NSF's atmospheric sciences program and DISE program. Because similar needs exist in other environmental sciences, these systems should be useful beyond departments of meteorology.

A number of projects are concerned with continuing education for nonacademically employed scientists and engineers. An example is a project conducted by the Utah State Board of Regents, through which industries and universities cooperatively develop science-related training programs for industry. Entitled "Restructuring Science Education for Flexibility, Occupational Preparedness, and Industrial Alignment," the project is now completing its period of NSF support; it has obtained $200,000 in local contracts in 1979. In addition to providing technical updating for industrially employed scientists and engineers, the project is notable for its impact on increasing university-industrial cooperation.

67. MATERIALS DEVELOPMENT IN PRECOLLEGE MATHEMATICS USING COMPUTERS (MDPMUC)
1980

Technology for Science Education

In view of the need to improve mathematics education for school children and to take advantage of the rapidly increasing rate at which low-cost microcomputers are becoming available in schools, NSF began a special effort in 1980 to support development of prototypes of quality educational software and courseware for teaching and learning mathematics. This activity is jointly funded with the National Institute of Education and emphasizes both research and development aspects of the problem.

The projects supported address mathematics education in all the precollege grades, and several involve adults who are studying precalculus mathematics. Topics include the improvement of spatial skills (emphasizing the needs of women), problem solving, and mathematical modeling. A number of projects take advantage of the graphics capabilities of computers to involve the student in dynamic interactions as a means of visualizing a variety of algebraic and geometric concepts. Several projects call for participation of local schools, teachers, students, and parents. The students are the target population of most projects; in one, however, the primary focus is on teachers.

Examples of projects are:

- Investigators at Wittenberg University in Springfield, Ohio, will develop 10 to 15 computer games to supplement mathematics instruction in grades one to four. The games will provide practice in basic math skills—including problem solving, estimation and approximation, computation skills, and measurement—and will introduce students to problem-solving techniques. Color graphics and animation should increase student motivation and involvement. The project will involve elementary teachers in development of materials and will test the programs in public schools.
- A project at the University of Pittsburgh will do research and related development on the difficulties that children in the primary grades have in learning addition and subtraction of whole numbers. Important mathematical principles, especially place value, will be demonstrated using both physical materials and computer graphics. Student responses will be analyzed by the computer and by teachers to identify systematic errors in student computation processes. The computer will then provide meaningful instruction designed to increase student understanding of the underlying mathematical principles. The project intends to provide practical instruction, usable in classrooms at a reasonable cost, as well as an opportunity to test the validity of a developing theory of the origin of arithmetic errors and ways of preventing these errors through instruction.
- A team at Rensselaer Polytechnic Institute will develop and test materials to train students' skills in spatial visualization and orientation. The project uses the dynamic, responsive medium of

computer graphics as a tool in spatial visualization and orientation training. The software will enable teachers to design new training experiences without special knowledge of computing. Since sex differences in spatial abilities have been widely reported, the project's research component will compare the changes in spatial skills shown by males and females. If the materials developed by this project are successful, they can be expected to improve mathematical performance among women and thus increase their access to careers in science and mathematics.

- A team of mathematicians, mathematics educators, and computer scientists at Drexel University will design, develop, and field-test a laboratory course in mathematics to accompany and be an integral part of a high school course on elementary functions. This laboratory component will consist of a series of "mathematical experiments" that use a microcomputer with graphics capabilities. The experiments are a carefully constructed sequence of tasks designed to probe the essence of a mathematical concept, formula, algorithm, or theorem. The project is a cooperative one involving the School District of Philadelphia.
- Many projects are supported that address the use of computing in higher education. John Hamblen of the University of Missouri, Rolla, has just completed *The Fourth Inventory of Computers in Higher Education 1976–77.* He reports that the expenditures for academic computing in higher education have more than doubled over the past decade. This year institutions of higher education will spend approximately $1 billion on academic computing; 2,163 institutions with an enrollment of 9.9 million students will provide students with access to computing. In addition to the inventory, an interpretive report examines and evaluates trends in administrative, instructional, and research uses of computing, as well as analyzes the uses of computing in minority institutions over a ten-year period.

INSTRUCTIONAL MATERIALS DEVELOPMENT

Objective of the Program

This program provides support for the development of new or improved instructional materials in science, mathematics and technology for elementary, middle, and/or secondary level students and their teachers. The program encourages the development of materials that fill content gaps in previously developed curricula, present new approaches to the study of traditional subjects, introduce recent discoveries, or demonstrate applications of scientific and mathematical concepts. An important goal is to involve the most capable scientists and science educators in the Nation in the process of upgrading the quality of the science and mathematics materials used in precollege classrooms.

Scope of the Program

Appropriate project activities include, but are not limited to, the following:

- materials that more effectively present single topics or collections of topics in science, mathematics or technology, including those that exhibit relationships between disciplines;
- materials that introduce new subjects or that present new applications of science, mathematics or technology;
- materials that support new or revised curricula, especially curricula designed to raise the level of achievement of the Nation's youth in science, mathematics and technology;
- materials tailored to the special needs of particular groups of students, such as women, minorities, physically handicapped students, college bound students, those entering the work force immediately following high school graduation, and the gifted and talented;
- materials that use alternative methods of delivering instruction, such as computer software, computer simulation, television, film, videocassette and videodisc, including those that integrate technology into a particular science curriculum;
- materials that take into account findings of recent research on how students learn science and mathematics.

Characteristics of the Program

In addition to the general characteristics described above for materials development and research programs, the following points are pertinent.

Projects may include the development of entirely new materials, the updating or revision of existing materials of high quality, and the testing and evaluation of the materials developed. In all cases, projects should lead to instructional materials that are bias-free, scientifically and educationally sound, and suitable for widespread distribution, preferably through the private sector.

In the development of new materials, consideration should be given to the implications for use by teachers, such as the necessity for teacher training or the development of coordinated teacher materials. The materials proposed for development should be suitable for use in many locales throughout the country.

The products developed may be printed materials, computer software, films, videotapes, videodiscs, or laboratory equipment.

All principal investigators should direct their attention to sharing the results of their proposed projects. The involvement of publishers or other relevant organizations early in the process of materials development is encouraged so as to facilitate distribution of the materials and their consideration for adoption. Consultation and negotiation with publishers or distributors may take place prior to proposal submission.

Source: NSF/SEE, Program Announcement: Materials Development and Research, NSF 85-10, April 1985.

52. SPECIAL PROJECTS IN SCIENCE EDUCATION (SPISE)
1958

Special Projects in Science Education Program

Complementing the Institutes Program of the Foundation, this program is concerned principally with the experimental testing and development of promising new ideas for the improvement of science instruction, and with new and more effective methods of increasing the understanding of science on the part of our young people. Approximately $1.5 million was obligated in fiscal year 1958 to carry out this program. Projects fall readily into the three following types: (a) Student Participation Projects, (b) Teacher Training Projects, and (c) Course Content Improvement Studies.

Student Participation Projects

These projects are planned to enlist the interest in and understanding of science, mathematics, and engineering by students at all educational levels. Activities in this area that have been supported by the National Science Foundation include the following:

1. *The Traveling High School Science Library Program.*—In many areas of the United States high school students with an interest in science have little or no access to books about science and mathematics other than their textbooks. The primary purpose of this program is to furnish to secondary schools, on a loan basis, a carefully selected library of general-interest books chosen to cover a broad spectrum of science and mathematics. A secondary but important result is the stimulation of book purchases by school and other libraries in response to student demand.

The program is conducted for the Foundation by the American Association for the Advancement of Science. It was started on an experimental basis in fiscal year 1956, and has been expanded each year since then. In fiscal year 1958, 54 sets of 200 books each were circulated among 216 high schools. Each school receives 50 books at a time. Through periodic exchange, all 200 books are made available to each school served during the academic year. In the summer, the libraries are made available to Foundation-sponsored Summer Institutes.

A list of the books in the Traveling Science Libraries is published separately and is given wide distribution. It is being used in many communities as a guide to the purchase of books for libraries. A larger and more comprehensive list of science and mathematics books for secondary school and community libraries is being prepared, and a special list of science and mathematics books available in inexpensive paper-bound editions is also issued to encourage students who wish to buy them for their own use.

An evaluation study of the program has been conducted applicable to the 1956–57 program which served 104 schools. This developed considerable information regarding the reading habits of high school students. Outstanding among the conclusions were the following:

a. In schools served by the Traveling Science Libraries, 39 percent of the students read at least one of the books. Half of these read more than three of the library books.

b. Small high schools make more intensive use of the library books than large schools.

c. At schools where there is a strong teacher interest in science, as determined by the number of library books checked out by the teacher, student interest in the books is more intense.

d. A majority of the schools served by the libraries subsequently added some science books to their own libraries. Lack of funds is the principal reason for not buying more books.

The Foundation plans to continue this program in the future, and to expand it as funds permit. There are over 13,000 high schools in the United States with a student body of less than 200 students.

2. *The Traveling Science Demonstration Lecture Program.*—Supported jointly with the Atomic Energy Commission and administered by the Oak Ridge Institute of Nuclear Studies, this program provides opportunities for secondary school students and teachers to see and hear science lecture demonstrations stressing the scientific principles involved in such subjects as solar radiation, atomic structure, nuclear reactions, space travel, and other subjects of scientific interest. Selected high school teachers are trained at Oak Ridge during a Summer Institute session and then during the academic year travel widely over the country providing lecture-demonstrations in selected high schools.

The training program for 1957–58 was much like that for the first year. Seven teachers were carefully selected for participation in the program and underwent a period of preparation and special training at Oak Ridge during the summer. The summer training period included courses and lectures on fundamentals of physical sciences, radioisotope techniques, science experiments, and techniques in science teaching.

Six weeks of the three-month summer session consisted of lectures and demonstrations in chemistry, physics, biology, and mathematics given by prominent scientists and teachers. Concurrently with the lecture-demonstration training, the traveling teachers designed and built many pieces of apparatus for use in their subsequent visiting lectures. Many of these inexpensive "home-made" assemblies were used as models which later were duplicated by high school teachers working with their students. During the 1957–58 school year the traveling teachers made visits of 1-week duration to 260 high schools throughout the country. They gave, on the average, one lecture-demonstration per day in the schools and were usually invited to provide many added lectures to parent and civic clubs. In addition to the schools visited, other neighboring schools were often reached while the teacher was in the community, so that a total of 892 schools (including some elementary schools) received at least one demonstration-lecture. More than 226,000 high school students and some 5,700 high school teachers were reached by this program.

The activities and previsits of the traveling teachers were cooperatively planned by the high school principals and the science departments of the various high schools. This cooperation aided the high school teachers to anticipate what would be covered by the visiting lecture-demonstrator and permitted them to arrange their work in the science courses to fit into the material covered by the visitor.

From reports of school principals, teachers, and parents, there is abundant evidence that the high school traveling lecture-demonstration program has had increasing success. By May 1, 1958, the number of visits requested for the year 1958–59 had exceeded 3,200.

The 1958–59 program will make use of a group of 19 traveling teachers—7 completely supported by National Science Foundation and Atomic Energy Commission funds and at least 12 supported during the 9 months of the school year by State departments of education, with National Science Foundation funds covering the teachers' stipends during the summer months and Atomic Energy Commission funds providing the demonstration equipment.

The fact that educational systems in individual States are willing and able to include the Traveling Science Demonstration Lecture Program in their "normal" educational pattern is an indication of the validity of the program. It is a good indication that this program will probably function smoothly when it is expanded during the coming year to provide a more widespread coverage of schools.

3. *The Visiting Scientists Program.*—This is a program which enables distinguished scientists to visit small colleges and universities for periods of several days to give lectures, to conduct classes and seminars, and to meet students and faculty members on a formal as well as informal basis in order to stimulate interest in science.

The Visiting Scientists Program was initiated in the 1954–55 school year when the National Science Foundation made a grant to the Mathematical Association of America for a series of visits to various small colleges and universities. Since that time the program has been expanded to include similar programs in chemistry, physics, biology, and astronomy.

In the past year, grants have been made to the following organizations to support Visiting Scientists Programs: American Chemical Society, American Institute of Physics, American Institute of Biological Sciences, American Astronomical Society, and the Mathematical Association of America. About 500 visits to colleges and a few high schools will have been made during the academic year, reaching an audience of over 60,000 students. The visiting scientists and the administrators of the institutions visited, as well as the faculties and students, have expressed enthusiasm for the value of the program.

The present programs in mathematics, chemistry, biology, physics, and astronomy have proved so successful in arousing interest in the subject matter presented that in 1959 they will be expanded to make more contacts possible. In addition, new scientific disciplines will be included, such as the earth sciences and engineering.

In view of the importance of interesting high school students in scientific careers, an active program, administered by appropriate scientific groups, will be developed in the next fiscal year, so that able scientists can visit high schools, lend their stimulus to science education at that important level, and provide a better appreciation of career opportunities.

4. *Science Clubs and Student Projects.*—This program stimulates interest in science and in scientific and engineering careers among students below the college level by supporting extracurricular science projects under the guidance of national youth organizations.

Since 1952, the National Science Foundation has been providing a limited amount of support to Science Clubs of America, administered by Science Service, Inc., a nonprofit organization with other sources of income. Approximately 19,500 local Science Clubs, composed predominantly of students of senior and junior high schools, are affiliated with Science Clubs of America. Each has an adult adviser, usually a science teacher.

Many club members carry out individual projects which frequently culminate in exhibits displayed at a school science fair. The most worthy of these are selected for showing at a city, regional, or State science fair, and each of these in turn usually selects two finalists who are sent, with their exhibits, to the annual National Science Fair.

At the National Science Fair held May 9–11, 1958, exhibits were shown by 281 finalists from 146 areas. The supporting fairs showed a more impressive growth rate. On the basis of reports from 98 of the 146 affiliated fairs, it is estimated that the 281 exhibits at the national fair were selected from a total of more than 468,000 exhibits at local fairs, an increase of 60 percent over the preceding year.

Public attendance at science fairs is encouraged. In 1958 attendance at the national fair was over 30,000, and an estimated 4 million persons saw the exhibits at the supporting fairs.

Geographic coverage of this program is extensive but not intensive. There are only three States where there are no science fairs, but few of the remaining States have anything approaching complete coverage. Of about 16 million students of the 7th through 12th grades, about 4 million would probably be interested in this kind of activity if the opportunity were available. Total membership in the 19,500 Science Clubs is estimated at about 500,000 students.

A recent study of National Science Fair finalists from 1950 to 1957 reveals a very high degree of interest in higher education. Of 589 individuals on whom data were received, 156 were still in high school and 23 were in military service. Of the remaining 410, 95 percent were taking college courses or had received a college degree.

In view of the results obtained from this program, the Foundation plans to continue its support of Science Clubs of America and also to explore the possibilities of science programs in cooperation with other national youth organizations such as the 4–H Clubs, Future Farmers of America, the Boy Scouts, and the Girl Scouts.

5. *Summer Training Programs for Secondary School Students.*—A primary purpose of this program is to encourage the scientific interests of high-ability secondary-school students by providing them with opportunities to participate in study and research programs set up especially for such students by interested college groups.

Pilot programs supported for the summer of 1958 include those of two State university short summer institutes for high school students and one research foundation's summer-long research participation program. In the two university institutes—"science camps"—two or three weeks were devoted to lectures, laboratory experience, visits to other laboratories or museums, and field trips, together with orientation lectures in the various branches of science and mathematics. Their aim was to acquaint the students with the many facets of scientific activity so as to provide a better comprehension of the sciences and a better basis for a choice of future careers. In the Waldemar Research Foundation summer program, high school students participated in supervised research which not only complemented their wintertime classroom instruction, but also offered them the stimulation and intellectual discipline of experimental scientific research.

Both types of programs utilized high school science teachers as counsellor-participants, to the ultimate benefit of their future classes. In these 3 pilot projects, 145 students and 8 high school teachers participated.

High school students also took part as members of demonstration classes in mathematics and science which were part of the program of some of the Summer Institutes for high school teachers.

A number of other proposals for the summer of 1958 to aid in developing the scientific interests of high school students were received, but the Foundation was unable to support them all. However, for 1959, the Foundation expects to support as many as 80 such projects.

6. *Other Student Participation Projects.*—Included under this heading are projects such as support of the preparation and distribution of pamphlets and brochures describing career opportunities in the various science disciplines and designed to awaken student interest; a program to bring to science teachers and their students, by means of poster exhibits, a balanced and comprehensive understanding of the IGY and a constructive realization of the interdependence of the scientific disciplines involved; studies of ways in which the Foundation can best provide assistance to State Academies of Science in furthering their interests in science education; production of pilot films relating to science to be made available to American schools, not strictly as teaching aids but directed to achieving a broader understanding of science by all students; support of a 4-week summer workshop at the University of Chicago to introduce qualified college students to the field of meteorology as a subject for graduate study and as a profession, and partial support to the American Institute for Research to conduct a planning study for research on the identification, development, and utilization of human talents.

62. PROBLEM ASSESSMENT AND EXPERIMENTAL PROJECTS (PAEP)
1974

PROBLEM ASSESSMENT AND EXPERIMENTAL PROJECTS

The Problem Assessment and Experimental Projects program was begun in fiscal year 1974 to initiate studies and experimental projects on specifically identified problems in science education. The program's aims are: to gain knowledge about possible solutions to specific problems and to explore and develop techniques to alleviate those problems; to formalize an analytical and quantitative approach to program and project evaluation and planning, and to synthesize the results of problem assessment studies and experimental projects to provide guidelines for the creation of program alternatives responsive to projected as well as current needs of the science education community.

Problem areas in which staff-identified studies were initiated in fiscal year 1974 included:

- Current state and effectiveness of continuing education in the United States for nonacademic scientists and engineers,
- Barriers to the movement of women and ethnic minority group members into science and technology careers,
- Barriers to implementation of newly developed teaching materials and modes of instruction, and
- Effective means of moving new knowledge from the research community into undergraduate classrooms.

The staff-identified experimental projects areas included:

- Developing techniques to increase the number of ethnic minority group members and women in science, and
- Increasing availability of high school student project activity as an integral part of high school science programs.

In addition to the staff-identified study and experimental project activities, the program handled a variety of proposer-identified projects and studies. In the course of the year, the group considered 285 preliminary proposals and 95 formal proposals, and recommended support of 69 activities. Among these was a major study of graduate education being carried out by the Council of Graduate Schools in the United States that will develop reliable instruments and procedures that can be used for evaluation and improvement of doctoral education. In another study, the American Institutes for Research will look at career guidance factors that affect the development of high school students' scientific potential to determine what high school students know about careers and what they need to know.

At the University of North Dakota, in a project partly funded by the Bureau of Reclamation, students proficient as pilots will be trained in the technical and scientific background needed for weather modification research. Brigham Young University will carry out a project in association with the Entomological Society of America to investigate barriers to teaching of new materials and modes of instruction in entomology.

The NSF Chautauqua-type short courses for college teachers received continued support in fiscal year 1974 through grants to 12 field centers for operating costs, and one additional grant was made to the American Association for the Advancement of Science for intercenter coordination.

64. RESEARCH IN SCIENCE EDUCATION (RISE)
1979

Research in Science Education

Scientific knowledge changes, as do the contexts in which it is taught. These changes have implications for public issues, technology, and individual decision-making. The processes by which people may be helped to acquire what they need to know are not well understood. The research in science education (RISE) program assists in creating and organizing a body of fundamental knowledge that can be used to improve the quality and effectiveness of science education for a wide spectrum of individual needs. RISE supports both research evaluation and synthesis, and empirical research. Within these two categories, projects were supported in 1979 on science education for the early adolescent, science for women and minorities, technology in science education, and science literacy. In addition, the program, jointly with the National Institute of Education, sponsored research on cognitive processes and the structure of knowledge.

Of the RISE awards this year, 20 are directed to research in science or mathematics education for the early adolescent. Some 13 of the new RISE awards focus on understanding the underrepresentation of minorities and women in science and science-related careers, while three RISE projects are concerned with the continuing education of scientists and engineers. The RISE awards continue to show an increase in collaboration of investigators from a variety of scientific disciplines with research workers in science and mathematics education research. Examples of RISE projects supported in 1979 follow.

Experts on early adolescence cite the need for the collection and organization of extensive demographic information on the early adolescent. A newly supported project directed by Herbert Walberg at the University of Illinois at Chicago Circle will attempt to demonstrate the feasibility of using data from the National Assessment of Educational Progress (NAEP) for secondary analysis purposes. Over the past 10 years NAEP has gathered and reported information on the knowledge, skills, and attitudes of American 9-, 13- and 17-year olds. The University of Illinois group will collaborate with research teams at Northern Illinois University, the University of Minnesota, and key NAEP staff. Another project, "School, Family, and Individual Influences on Commitment to and Learning of Science Among Adolescent Students," directed by Ronald Simpson at North Carolina State University, is trying to determine how interest and competence in science develops in the early adolescent student.

A research team led by Alma Lantz at the Denver Research Institute has been interested in the pervasive belief that mathematics acts as a selective barrier to science careers for women and that early decisions made to opt out of mathematics courses foreclose opportunities. In a comparative study of junior high school level males and females, these researchers are studying influences on student choices in taking (or not taking) the first optional courses in mathematics.

Widespread concerns have been expressed about potentially detrimental effects of the use of calculators on children's mathematics abilities. A team of investigators led by Grayson Wheatley at Purdue University has been studying the initial impact of calculators in elementary school mathematics with 1,500 students (grades 2-6) in 50 classrooms in Indiana, Iowa, Michigan, Missouri, and Ohio. Their year-long study, which tested students in basic facts of addition, subtraction, multiplication, and division, in mathematics concepts and attitudes, indicates: (1) that no measurable detrimental effects can be ascribed to calculator use; (2) that children have a high positive attitude towards calculator use; and (3) that children learn to use calculators quickly and perform computations much more successfully than their counterparts with no calculators.

What do mature adults (ages 50-70) learn of science policy issues from television—specifically, from viewing selected NOVA programs on public television? Robert Gagne and his coworkers at Florida State University are seeking answers to such questions in a study that is expected to shed light on how specialized instruction can help to increase scientific literacy in adult Americans.

At the Massachusetts Institute of Technology, a group of investigators from the fields of psychology and the philosophy of science, led by Susan Carey, is investigating the parallels between conceptual development during childhood and conceptual change in the history of science. They will analyze the development of the child's concepts of weight, volume, and density, in comparison with the differentiation of these concepts in the history of science, and will study the historical development of the concepts of heat and temperature in order to pursue the comparison further.

66. RESEARCH ON COGNITIVE PROCESSES AND THE STRUCTURE OF KNOWLEDGE (RCPSK)
1980

Cognitive Processes and the Structure of Knowledge

Research into mental processes and the structure of knowledge in science and mathematics has received increasing emphasis by NSF for each of the past three years. Project support has grown from about $0.5 million in 1978 to more than $1.5 million in 1980. This reflects several factors, including the fact that NSF was virtually the sole source of support for research of this kind in 1980 owing to reductions in funds available from the National Institute of Education, with whom NSF had shared the responsibility for project support in prior years. The increase in NSF support in 1980 reflects other realities too, however, including the increase in interest in this type of research by scientists and mathematicians and the improvement in the quality of proposals being received.

But this growth is primarily a reflection of the greater degree of understanding and collaboration across disciplinary boundaries. Physical, mathematical, biological, behavioral, and computer scientists are increasingly familiar with one another's work. Some are prepared to collaborate, even to the point of willingly employing psychologists within physics departments and vice versa (which occurred at the University of California, Berkeley, and at Carnegie-Mellon University, for example).

The purpose of such research is to discover the mental processes and structures that underlie competence, skill, or "understanding" in some important area of science or mathematics. The general approach is to study intensively the knowledge and behavior of individuals at different levels of expertise, then identify consistent differences in knowledge and skills that might account for differences in competence.

This is usually preceded by a detailed logical analysis of the knowledge and skills that seem to be required. It is increasingly common for researchers to write computer programs that simulate understanding of the science or mathematics—using only the specific knowledge and processes inferred from the study of individuals. Because computers are extremely simple-minded and unforgiving, this forces one to make explicit "every little bit" of knowledge required in the process.

Research of this kind differs in important ways from most of the educational research that was undertaken in the past, particularly that which compared the effectiveness of different instructional programs on student achievement or attitudes. The ultimate objective—to increase the effectiveness of learning—is unchanged, but the more immediate goal is to explain, in considerable detail, what constitutes learning or knowledge. This necessarily requires a different method of research, namely intensive observation (and subsequent simulation) of individuals, rather than the aggregation of statistical data.

Several interesting findings emerge from recent research of this sort, particularly in projects studying competence in solving problems in physics or mathematics. One finding is that experts, when confronted with a problem to solve, consider it qualitatively before they begin a quantitative solution. That is, the expert engages in much more planning than the novice and is aided by a great deal of specific knowledge about the problem domain. This planning is triggered by features of the problem, which identify it as an instance of a particular kind of problem for which the expert possesses a rich network of information and strategies. The novice may well "know" many of the specific facts and conditions in isolation, but seems not to have integrated them into a richly interrelated structure. As a result, the novice attends to the more obvious (surface) features of the problem, retrieves from memory one or more equations thought to apply to such problems, and proceeds algebraically.

Major achievements of this research have been the discovery that both experts and novices proceed consistently when working on problems and the finding that there are clear differences in knowledge and strategies associated with differences in problem-solving ability. Specific knowledge of these differences permits us to design instruction that should "close the gaps." Work by Jill Larkin and Herbert Simon at Carnegie-Mellon University has contributed considerably to such understanding. Fred Reif, a physicist from the University of California, Berkeley, is engaged in what he calls "human cognitive engineering," designed to close the gaps through particular instruction and practice.

STUDIES AND PROGRAM ASSESSMENT

Description of Activities

The Studies and Analysis Program was established in this office to help determine the status and condition of elementary and secondary education in science, mathematics, and technology in the U.S. The objective is to provide data to help with policy formulation and to support leadership efforts of the Foundation in science and engineering education.

Among the responsibilities of this office are to:

- Support the collection, analysis, evaluation, and dissemination of information on the status and condition of education in mathematics, science, and technology in the U. S. by means of a program of external grants and contracts and internal analysis and publications of major indicators;
- Establish and maintain data systems designed to monitor the status and progress of education in the U. S.;
- Determine through the design and implementation of systematic program evaluation the impact and outcomes of past and present NSF support for science and engineering education.
- Conduct a study to respond to Public Law 98-371 which provides that "$2,000,000 shall be made available for a contract to develop a science education plan and management structure for the Foundation."

Studies and Analysis projects were first funded in FY 84. During FY 84-85, 28 awards totaling $3.7 million were made to support these objectives, exclusive of the congressionally-mandated study.

For More Information

All types of organizations, both nonprofit and profit making, are eligible to submit proposals at any time. Contact the Studies and Analysis Program by writing the Directorate for Science and Engineering Education, Office of Studies and Program Assessment, National Science Foundation, Washington, D.C. 20550.

Source: NSF, Directory of Awards, October 1, 1983-September 30, 1985, Directorate for Science and Engineering Education, February 1986.

RESEARCH IN TEACHING AND LEARNING

Objective of the Program

This program supports basic and applied research on significant factors that underlie effective teaching and learning of precollege science, mathematics, and technology. Anticipated outcomes include knowledge of how students learn complex concepts in science and mathematics, of how they learn to apply these concepts effectively in real problem-solving situations, and of those factors that are most influential in governing their participation and performance in school science and mathematics courses.

Scope of the Program

Appropriate project activities include, but are not limited to, the following:

- research on teaching and learning in specific disciplinary and knowledge domains (chemistry, physics, mathematics, biology, computer science, etc.);
- research on the early development of cognitive competence, and on the processes by which students learn to solve problems in logic, mathematics, and science;
- research on the acquisition of knowledge and its representation in specific areas of science and mathematics;
- research on information processing models as they relate to science teaching and learning, on the effects of incorporating information processing technology into the traditional school setting, and on the distribution and adoption of new technologies;
- research on factors that influence the quality and effectiveness of instruction in science and mathematics and the participation and achievement of students at various ages;
- research on factors that are influential in the development and maintaining of interest, including early development of motivation and talent, in science, mathematics, and technology.

These examples are illustrative only and research proposals on other topics dealing with teaching and learning are also encouraged. This area is being pursued in collaboration with NSF's Directorate for Biological, Behavioral and Social Sciences and is also described in a separate announcement, (NSF 84-74).

Characteristics of the Program

In addition to the general characteristics described above for all materials development and research programs, the following points are relevant.

Projects should focus on critical questions related to teaching, learning and cognitive processes. Research results should add to the cumulative body of knowledge; consequently, proposals should be based upon a sound theoretical foundation and demonstrate an understanding of the relevant literature.

In its support of research in the subject matter domains, the program encourages involvement by scientists, mathematicians and engineers, and wishes to encourage their collaboration with researchers from the behavioral and social sciences and education.

The program especially encourages proposals that combine research with the development of instructional materials and model teacher education programs, as well as the application of new technologies.

Source: NSF/SEE, Program Announcement: Materials Development and Research, NSF 85-10, April 1985.

12. STUDENT SCIENCE TRAINING (SST)

1978

Student Science Training

In this program, university research scientists are involved directly with groups of talented high school students. Of the 150 projects for 11th and 12th grade secondary school students supported in 1978, 83 were designed for the educational development of high ability students with excellent training and 67 were designed for students with demonstrated high potential but limited educational opportunities. These latter projects focused on students with inadequate facilities or instruction who were located in the inner cities or in isolated rural areas and who belonged to educationally disadvantaged populations. Projects ranged from intensive programs in a single science discipline to multidisciplinary activities in oceanography, operations research, textile engineering, urban geography, and environmental assessment. Two projects were designed and operated specifically for the physically handicapped. The following are examples of projects funded.

An academic year project at Portland State University involved 25 high school students who traveled throughout Oregon observing and talking with groups representing Indian, European, and Oriental settlers in the area. The students also carried out in-depth research projects on topics related to Oregon's heritage, and many of these are being placed in the Portland State University library as part of the social science holdings. As a direct result of the project a new undergraduate course, an in-service course for teachers, a course for students ages 11-15, and a course for adult members of local cultural/ethnic organizations are being initiated in the region.

A Wayne State University project focused on the engineering challenges to the automotive industry. The project involved 32 participants and utilized lectures, laboratories, field trips, and individual research. Student research projects included the effects of driver-controlled variables on the fuel economy of a car and the effects of various seat belt designs on the safety of a car's occupant in an accident. The faculty involved in the project are encouraging and helping the students to prepare presentations for their own high schools on their study and research.

Thirty high school students with limited educational opportunities, and primarily from minority groups, were given an opportunity at Louisiana State University to understand the analytical thought process and activities of engineering and to participate in engineering design projects. Many of the students, though the best in their classes in their rural schools, had never been challenged and were not aware of real-world technological problems. Places visited included NASA's Johnson Space Center, Texas Instruments, and the Louisiana Power and Light Company. Faculty and guest lecturers presented talks on careers in the various fields of engineering, job prospects, and requisite preparation, and students participated in project-design work in engineering fields of their choice.

68. WOMEN IN SCIENCE (WIS)

1975

Women in Science—Studies and Experimental Projects

In order to find ways to increase the number of women in scientific and technical careers, an activity comparable to the one for members of ethnic minority groups was continued into the second year. Of the eight new activities in 1975, four were studies and four were experimental projects. Two studies are directed to the attrition of women students of science and engineering during their college years; one is concerned with the relationship between mathematics learning and intellectual and cultural factors for female and male students in grades 6 to 8; and another is a longitudinal study of the science career crises experienced by approximately 2,600 high-ability, young women who participated in NSF-funded Student Science Training programs during 1974 and 1975. The experimental projects include a workshop for career guidance personnel, the evaluation of a film on women in engineering, the large-scale distribution of career-related materials to girls in the 9th and 12th grades, and a cooperative venture by four liberal arts colleges to evaluate the relative effects of role models, improved counseling, and internships. These eight awards bring the totals for fiscal years 1974 and 1975 to 17 studies and 13 experimental projects. A contract has been awarded to the Denver Research Institute to do an impact analysis of the projects.

69. MINORITIES, WOMEN AND THE HANDICAPPED (MWH)
1978

Minorities, Women, and the Physically Handicapped in Science

These programs develop and test methods to attract, encourage, and motivate the participation in science by minorities, women, and the physically handicapped. Activities include studies, workshops, and special training opportunities beyond those available in existing formal science education programs.

Minorities

Using the proven models of the student science training and undergraduate research participation programs, the Foundation supported projects to motivate and train more minority students and provide them with the opportunity to study and do research in a variety of scientific disciplines. For example, at Texas Tech University ten participants are working with research faculty on projects in energy-related research, including: the development of computer-generated masks for use in optical data processors, which would reduce costs in information retrieval; the development of an electrostatic energy analyzer; and a study related to contrasts and clutter in aerial photography. Through these activities the participants will be better informed about the nature of scientific research and will be able to make more realistic career decisions.

Women in Science

Twenty-five workshops involving approximately 5,000 women students in colleges and universities were carried out in 17 States to provide in-depth information on careers in science and engineering. Considerable interest has been generated by the visiting women scientists project. This draws on the work experience of career women scientists, who also serve as role models to motivate girls in secondary school to continue studying science so they don't cut themselves off from a possible career in science. Over 600 women applied to serve as visiting scientists; 40 were selected to visit 110 high schools.

Six projects were to assist women with science degrees who are currently not employed in science or are underemployed in terms of their potential. On completion of special training to update their science backgrounds, these participants are prepared for entrance into graduate school or for direct employment in science.

Physically Handicapped in Science

Fiscal year 1978 was the second year of operation for the physically handicapped in science program. Six of the projects directly involved handicapped students of science. Typical was an environmental research activity involving 20 high school students who participated during the summer at Marist College in Poughkeepsie, N.Y. They attended lectures, did laboratory experiments in water testing, performed parasitology studies on fish, and learned ecological sampling techniques. Another project modified a college general biology course for the visually impaired so as to use other senses, such as touch and sound, to augment or replace sight. Two conferences assessed the current state of science education for the handicapped and looked at ways to eliminate barriers in postsecondary education, and four workshops dealt with the generation of career information for the handicapped. All projects were designed to help facilitate the entrance of handicapped students into careers in science and science education.

18. INFORMATION DISSEMINATION FOR SCIENCE EDUCATION (IDSE)

1979

Information Dissemination for Science Education

Now in its third year of operation, this small grants program helps school administrators, subject-matter specialists, teacher-leaders, school board members, and other decisionmakers in State and local school systems to obtain information about instructional materials and practices prior to selection.

Thirty-six awards in fiscal year 1979 for conferences and workshops enabled such school decisionmakers to become familiar with the large variety of science instructional materials, practices, and technologies currently available for use in elementary and secondary schools. In some projects information on current research results in pre-college science and mathematics education was presented to participants along with potential classroom applications.

It is interesting to note the increase in the number of awards addressing two of NSF's special emphasis areas: science for the early adolescent and science for handicapped students. All but one of the 36 awards are targeted in whole or in part at the early adolescent educational level. Six awards and approximately 11 percent of program activities are aimed at the special problems of science for handicapped students. As in previous years there continues to be considerable interest in the dissemination of information about alternative curricular materials and information on computers and handheld calculators.

This year's projects include six regional conferences held in Ohio for junior and senior high school mathematics educators under a grant awarded to Ohio University. These conferences provide direction on problem solving, alternative curricular materials, and the use of handheld calculators in the secondary school classroom. East Carolina University is conducting four workshops to inform educators throughout North Carolina about the goals and organization of several science programs designed specifically for mentally and physically handicapped students. The Wisconsin Academy of Science, Arts, and Letters is working with State science supervisors and university personnel to conduct regional conferences in Iowa, Minnesota, and Wisconsin on new ideas of intellectual development and their implications for helping students to develop reasoning ability while learning science. The University of California, Berkeley, is arranging conferences on calculator-assisted mathematics materials, teaching ideas, and strategies including calculator hardware and commercially available instructional materials.

50. RESOURCE CENTERS FOR SCIENCE AND ENGINEERING (RCSE)

1979

Resource Centers for Science and Engineering

This program, a successor to the earlier minority centers for graduate education in science and engineering program, increases participation in science and engineering by minorities and persons from low-income families. As in fiscal year 1978, the Foundation was authorized to establish a single resource center in 1979. Criteria for selection were that it: (1) be geographically located near one or more population centers of minority groups or low-income families; (2) support basic research; (3) serve as a regional resource in science and engineering; and (4) develop joint educational programs with nearby pre-college and undergraduate institutions enrolling substantial numbers of minority students or students from low-income families.

Atlanta University received the first award as a result of the first competition. The next two ranking proposals from that competition were invited to submit a joint proposal for 1979. These two institutions, the University of New Mexico and New Mexico State University, subsequently received support in the amount of $2,742,000 for a Southwest Resource Center.

The Southwest Resource Center is addressing itself to graduate and undergraduate education, 2-year colleges, public school education, and community affairs as they relate to increased science awareness and to the development of young scientists and engineers. The University of New Mexico and New Mexico State University will be joined by at least 15 educational institutions and two scientific laboratories in their efforts to increase both science awareness and the number of scientists and engineers among the Mexican-American and American-Indian communities in New Mexico, western Texas, Arizona, and Colorado.

Activities within this center will be conducted primarily through two major components. Among the activities proposed for the *pre-college and community programs* are teacher/counselor workshops, science fairs and exhibits, visits to scientific laboratories, development and dissemination of career guidance materials oriented to Mexican-Americans and American Indians, educational television programs, regional conferences focusing on minority issues in science, and a visiting scientists program. The *academic and research programs* will support faculty and student research projects, provide a limited number of postdoctoral fellowships and faculty-student research internships, assist participating institutions in their minority science faculty and student recruitment efforts, and provide counseling and tutoring services for minority science students.

70. PHYSICALLY HANDICAPPED IN SCIENCE (PHIS)

1979

Physically Handicapped in Science

This program supported 16 projects in (1) student science training; (2) development of career information; and (3) field testing and evaluation of science courses adapted for the physically handicapped. For example, under one of those awards the American Chemical Society (ACS) is reviewing introductory college chemistry courses to assess the need for modifications in lectures and laboratory activities and equipment for handicapped students. The ACS will produce and distribute a manual to aid college personnel in teaching general chemistry to physically handicapped college students.

16. RESEARCH APPRENTICESHIPS FOR MINORITY HIGH SCHOOL STUDENTS (RAMHSS)

1980

Attracting and Supporting Minorities in Science

NSF continually monitors its level of effort in supporting minorities underrepresented in science through all of its science personnel improvement programs. Overall, in 1980, $5.7 million, or 18 percent, of the program funds were used in direct or indirect support of minorities. Of that amount, $2.7 million was in support of specifically targeted programs, while $3.0 million involved minority scientists or potential scientists in the absence of any special minority targeting.

The research apprenticeships for minority high school students have the youngest minority target pool. Interest in the program this year was so intense that only one out of ten applicants could be supported. Program operations are basically identical with the student science training program, except that the apprenticeships include stipend support. Indeed, 97 percent of the apprenticeships project directors have had student science training experience at some point. This dual experience should benefit the operations of both programs in the future. The research apprenticeship program also allows project directors to experiment with recruiting techniques and to test the effectiveness of retention mechanisms. One of the projects, at the Illinois Institute of Technology, will be making links to industry throughout the coming year.

APPLICATIONS OF ADVANCED TECHNOLOGIES

Objective of the Program

This program supports research and development on the application of advanced technologies—particularly the computer—to science and mathematics education. Support is provided for the exploration, development, and proof-of-concept demonstration of advanced computer and telecommunication technologies utilization in education. Projects may focus on technology as a tool, a medium, or an object of study. Among the anticipated products are innovative educational systems, authoring languages, problem solving tools, courseware, microworlds, tutors, and expert systems that increase the efficiency and effectiveness of instruction at all levels.

Scope of the Program

Appropriate project activities include, but are not limited to, the following:

- development, testing, and evaluation of advanced computer-based systems for precollege mathematics, science, and technology education that augment human intelligence, intuition and problem solving—for example, intelligent videodisc;
- development of innovative computer applications that offer exceptional promise of educational effectiveness and efficiency;
- development of mechanisms to facilitate the widespread use of these products and concepts—for example, networks and authoring systems.

Characteristics of the Program

In addition to the general characteristics described above for all materials development and research programs, the following points are pertinent.

This program is concerned only with issues at the forefront of technology applications to science and mathematics education. For example, although the computer has been demonstrated to be effective for drill and practice, can it be used to foster deeper cognitive development? Can knowledge-based expert tutorial systems be designed to diagnose and address student conceptual and reasoning difficulties in science and mathematics? Can interactive computer programs be developed to help students acquire the ability to solve problems in different technical contexts?

Projects are particularly encouraged that seek to augment human learning, thinking, and problem solving through application of the most advanced technologies.

Source: NSF/SEE, Program Announcement: Materials Development and Research, NSF 85-10, April 1985.

51. PUBLIC UNDERSTANDING OF SCIENCE (PUOS)
1975

Public Understanding of Science Program

Since World War II, science and technology have enriched our lives and made them more complex. Because of the rapid pace of scientific development, it is no longer possible even for scientists themselves to remain completely abreast of current discoveries. The layman's task is far more difficult, and yet some level of scientific comprehension is essential if the public is to make sound judgments on those many public policy issues heavily permeated with scientific and technical elements. Recognizing this need, the National Science Foundation established the Public Understanding of Science Program in 1959 to provide modest support for projects across the country directed at improving public knowledge of the potential and limitations of science.

During fiscal year 1975, the program, continuing the trend of recent years, concentrated much of this support on the interrelationships of science with public policy issues. Experience has shown that science becomes less mysterious and more personal when it is related to problems facing the individual, either personally or through his family, community, or nation. Therefore, many public understanding of science projects dealt with the scientific and technical elements of such major questions as energy resources, growth and the environment, food, and similar subjects.

As in previous years, projects were supported at a variety of institutions and utilized a wide range of communication channels, including print and broadcast mass media, museums and other community-based educational institutions, and public forums and workshops at the regional, State, and local level. A strong research component was built into the program this year to complement and support ongoing projects.

In television, this was a banner year as the NOVA science series (supported by NSF, the Carnegie Corporation, Polaroid, and The Corporation for Public Broadcasting) continued its excellent coverage of many areas of basic and applied science. In all, 23 programs were produced, and the year culminated in receipt of the prestigious Peabody Award by NOVA producers. A major research study was completed by Educational Expeditions, Inc., in Boston during fiscal year 1975 for the development of a television series on Indian migration and history, "The Peopling of the New World." The series, to consist of nine programs, has involved many archaeologists, anthropologists, and historians in the preliminary research and script drafting. Finally, a promising statewide program was initiated with the Montana Academy of Science, which will produce a series of television programs highlighting areas of science of direct interest to citizens of that State. This project, if successful, could be a prototype for other statewide programs in the future.

Museums received support in fiscal year 1975 for both cooperative science exhibition programs and for the development of special traveling exhibits on science-related subjects. The Field Museum of Natural History is completing work on a traveling exhibit, "Man and His Environment." The University of Colorado, Denver, is now entering the fabrication stage of a traveling exhibition on the potential of solar energy. This exhibit will be completed by the spring of 1976. Michigan Technical University, with support from the Foundation and private industry, inaugurated a traveling science and technology program which brought special exhibits and demonstrations on energy, space, and the environment to communities throughout rural upstate Michigan. A major bicentennial-related museum program has premiered at the Boston Museum of Science with a large exhibition, "Yankee Ingenuity," which focuses on the inventive propensity of Americans throughout our first 200 years. The first of four environment-related traveling exhibits has been completed by the Smithsonian Institution's Traveling Exhibition Service. This first exhibit deals with the problem of population and is currently booked in museums around the country for the next 2 years.

In addition to the mass media programs, a large number of "dialogue" projects were supported, including workshops, seminars, and public forums. These included a series of lectures on the basic sciences sponsored by the University of Florida, and a series of citizen workshops on energy and on food developed and sponsored by the American Association for the Advancement of Science in various cities across the country. An attempt to reach the blue collar audience was inaugurated by faculty at Tulane University in New Orleans, with the cooperation of State and local AFL-CIO. The Tulane group organized and conducted a series of special workshops for union officials on the impact of technology on the work force—both today and as forecast into the future. These workshops will be continued next year and may form the basis for similar programs with other union groups across the country.

Much attention was paid this year to the development of a research focus for the program. A major national survey on public understanding of science and public attitudes towards science is under development at the Center for Policy Research in New York. Preliminary planning meetings have been held, and a series of open ended oral interviews have been conducted with citizens in the New York area. The survey itself will be concluded by the summer of 1976. Gerald Holton at Harvard University has continued his analysis of the intellectual challenges to science literacy, and this year, with support from the program, has undertaken an analysis of the interrelationships between the public understanding of science and concern about the ethical uses and implications of science. A series of similar research projects was initiated during fiscal year 1975 to analyze the effectiveness of various ways of communicating science to the general public. An evaluation of the impact of television on science communications was conducted in San Diego, and other experiments are planned for next year.

74. ETHICS AND VALUES IN SCIENCE AND TECHNOLOGY (EVIST)
1978

Ethics and Values in Science and Technology

The ethics and values in science and technology (EVIST) program is directed toward identifying, analyzing, and resolving the ethical and social dilemmas that arise in the work of scientists and engineers and in their interactions with citizens affected by their work.

An International Symposium on Social Values and Technology Choice, organized under the auspices of the U.S. Pugwash Committee and the American Academy of Arts and Sciences, was held in Racine, Wisconsin, in June 1978. The symposium brought together 35 scientists, scholars, and Government officials from the United States, Latin America, Western and Eastern Europe, Asia, and Africa. Issues included: What potential exists for the control of technology and its direction toward the attainment of social goals? Can "appropriate technology" in its varied definitions serve as a guide to the technological choices that must be made in the industrialized and developing nations? Is there a possibility for an international convergence of appropriate technologies? Edited proceedings of the conference will be published in book form during the spring of 1979.

A series of workshops and a final summary conference on ethics and values in agricultural research were held during the spring and summer of 1978 by a group at the Social Science Division of the University of California, Santa Cruz. These meetings brought together agricultural researchers, consumers, labor union officials, harvest workers, growers, and State agricultural agency and legislative personnel to explore varying value assumptions about agricultural research and to identify the most important ethical issues that are implicit and explicit in setting priorities for that research. The results of the project will be published as a monograph.

A group at Purdue University completed a 2-year, in-depth study of the case of the three engineers who were discharged by the Bay Area Rapid Transit (BART) system in June 1972, after they had taken their concerns about the safety of the system to the public through the mass media. During the course of their research, the Purdue group assembled and studied a large number of documents and interviewed the engineers, their colleagues, the BART Board of Directors and management, and members of the California Society of Professional Engineers in an effort to assess various perspectives on the ethical problems associated with the case. The results, being published as a monograph, will be an important contribution to the debate on the increasingly compelling issue of dissent within technology-based organizations whose activities have direct bearing on the public interest.

A group at the Institute of Society, Ethics, and the Life Sciences in Hastings-on-Hudson, New York, has completed the first year of a 2-year study of ethical problems associated with scientific research on aggression. The study is focusing on the details of three cases in which research projects dealing with aggressive behavior were aborted due to external social and political pressures. These case studies are providing the basis for a broader analysis of the ethical issues associated with research in areas on the frontiers of science, where there may be major differences of professional and public opinion about the legitimacy and morality of conducting and applying research.

A group at Montefiore Hospital and Medical Center in New York City is engaged in a project on ethical issues in the delivery of health care within detention and correctional institutions.

Its objectives are twofold: (1) to provide health care professionals, students, and trainees with the skills required to identify, articulate, and analyze the relevant ethical and legal issues; and (2) to develop teaching methodologies and materials that can be used at other institutions. The project is being carried out at the Riker's Island Correctional Complex and is being overseen by an advisory committee of physicians and former inmates at the complex.

A grant from the EVIST program permitted the American Association for the Advancement of Science to complete and publish, in fiscal year 1978, a resource directory of programs and courses at U.S. colleges and universities related to ethics and values in science and technology. The survey revealed that nearly 120 programs and over 900 courses in over 500 institutions are directly concerned with these issues. The directory outlines current academic efforts in the area, thus serving as a useful resource to institutions that are already offering courses and programs on ethics and values in science and technology, as well as to those that are contemplating such activities.

75. SCIENCE FOR CITIZENS (SFC)

1978

Science for Citizens

The overall goals of the science for citizens (SFC) program are twofold: (1) to make scientific and technical information and expertise available to citizens at the times and in the ways most useful to them; and (2) to increase the knowledgeable participation of scientists and citizens in resolving major issues of public policy that involve science and society.

In fiscal year 1978, its second year, the public service science residencies and internships program awarded 25 residencies to scientists and engineers and 9 internships to science and engineering students. These awards allow them to undertake up to a year's activities with citizen groups and other organizations in need of their expertise. Examples of the projects being undertaken by fiscal year 1978 residents and interns include a resident, working with the Navaho Nation and Colorado State University, who is studying the nutritional status of native Americans and conducting training sessions on health and nutrition policy for native American decisionmakers. Another resident is producing and moderating bilingual radio programs focused on scientific issues in proposed State legislation for the Association of California Public Radio Stations. An intern is working with the Center for Local Self-Reliance and the Minnesota State Legislature to evaluate urban energy conservation programs and to encourage citizen participation in developing energy policies.

Some preliminary results from the fiscal year 1977 science for citizens forums, conferences, and workshops indicate that those projects were able to bring scientists and citizens together to shed light on and help resolve issues of public policy that involve science and technology. A number of publications are currently available from these first projects. The Citizen Involvement Network (Washington, D.C.), for example, has published *Retrofit '78*, the proceedings of a New England conference on community-focused home insulation and energy conservation programs. Another publication, *The Community Communications Workbook* of the Knoxville (Tennessee) Communications Cooperative, is intended to assist persons interested in understanding or undertaking community-based cable radio or TV services.

In 1978 the SFC forums, conferences, and workshops program supported 16 new projects, among which are a workshop, with radio coverage, held by the Turtle Mountain Community College on the forest ecosystem, so that tribal members can participate in the formulation of timber cutting policy on the Turtle Mountain Indian Reservation in North Dakota. The Public Resource Center (Washington, D.C.) is conducting a series of Appalachian community forums to look at the changing environmental and occupational health needs resulting from industrial expansion in the area. Northeast Louisiana University is establishing a Regional Utilities Information Center to hold workshops on energy-related issues, which will involve fuel suppliers, utility companies, regulatory authorities, and consumers.

As a new initiative in fiscal year 1978, the science for citizens program also awarded 17 planning studies grants to community groups, public interest science organizations, and educational institutions and service organizations. These grants are intended to help them develop stable organizational structures and processes (such as public service science centers or networks) that can provide timely and intelligible scientific and technical assistance to their communities. Examples of the fiscal year 1978 planning studies grants include a project where the Metrocenter Y.M.C.A., in collaboration with the City of Seattle, the People Power Coalition, and the University of Washington, is planning a Seattle Metropolitan Technology Assessment and Transfer Center to link area scientific and technical resources with citizen groups. In another, the Georgia Community Action Association will evaluate methods for providing technical advice on science- and technology-related policy issues to disadvantaged citizens in urban and rural areas, and will prepare guidelines for the establishment of a Citizens Technical Advisory Center. The Southwest Research and Information Center is producing a model for a network of New Mexico organizations that can deliver scientific information to citizens to help them work with scientists in identifying and resolving public policy issues involving science and technology.

INFORMAL SCIENCE EDUCATION

Objectives of the Program

- Provide greater and mutually reinforcing opportunities for the public to make use of the rich resources for scientific, mathematical, and technological learning which exist outside the formal educational systems.
- Allow for increased interactions between the formal educational systems and the resources and staff of museums, zoos, and other institutions responsible for the preservation and exhibition of scientific phenomena and specimens.
- Encourage communications media to take a more intense and greater interest in imparting knowledge about scientific, mathematical, and technological concepts to both the public at large and selected groups.
- Encourage private supporters of the media to focus efforts on increasing the scientific and technological literacy of the American public.
- Encourage local-membership groups to provide mathematics- and science-based activities for their members or groups served by them, in order to increase the amount of active engagement in out-of-school mathematics and science.
- Provide an incentive to examine the roles of women, minorities, and the physically-handicapped in mathematics, science, and technology and to develop ways to encourage their full participation.

Scope of the Program

This program supports projects that help to provide a rich and stimulating environment for informal learning, for a wide variety of audiences, in a cost-effective manner.

A principal characteristic of informal learning is its highly personal and internalized acquisition. Each person visiting a museum, watching a television program, or pursuing a science hobby develops different insights and understanding—and the pattern of understanding that develops is the result of many overlapping impressions and experiences.

For this reason, the program supports activities in a variety of media—broadcasting, museums, clubs, and other sources of direct science experience. A principal goal of the program is to encourage projects that are both cost-effective and mutually reinforcing. At the same time the overall pattern must serve the needs of a full spectrum of age and interest.

Representative projects include museum, zoo, and other activities that encourage personal interactive learning about science, mathematics, and technology. In addition to exhibits and special programs, these include outreach activities, such as training teachers to use museum and zoo resources effectively, offering special out-of-school programs for students and parents, or designing innovative ways to take the museum to the schools and the public rather than the reverse.

Other projects, in print and broadcast mass-media, are able to reach extremely large and varied audiences, providing an intriguing overview of the scope and excitement of science—on a scale that cannot be matched by any other means. NSF is particularly interested in encouraging a well balanced array of such large-scale communication activities. This includes science series for both children and adults, via both radio and television. The NSF is also interested in periodic series on major areas of science and technology, especially when these promise to have lasting value.

A parallel development of interest in science activities within local-membership clubs (for example, Girl and Boy Scouts, the "Y", amateur science societies, and service clubs) is necessary to encourage early and continued learning outside of school. Not only students, but parents, teachers, and all citizens, need to have opportunities to experience the joy and enthusiasm of exploration and discovery for themselves.

In all cases, projects should lead to programs or print materials that are bias-free, scientifically and educationally sound, and cost-effective in terms of their ultimate audience and impact. Synergistic projects among the institutions involved in informal science education are particularly welcome—projects that will encourage further personal involvement in reading and hands-on activities—cooperative activities between broadcasting and museums as a center of community interest in science.

Source: NSF/SEE, Program Announcement: Teacher Enhancement and Informal Science Education, NSF 85-9, April 1985.

Each area of activity has complementary strengths and purposes.

- Broadcasting reaches uniquely large audiences, providing an initial stimulus and overview that is unmatched by any other means.
- Museums provide a direct personal experience with the phenomena and principles of science and technology.
- Personal activities develop a depth of insight and involvement that cannot be matched by any less involving presentation.

The strategy of the Informal Education Program is to encourage all three, especially in modes where they complement and reinforce each other.

Characteristics of the Program

Because the range of possible out-of-school learning experiences in mathematics, science, and technology is so large, the Division has chosen to focus its selection of projects on the following strategic considerations:

- *A balance of key projects:* The program is a pragmatic effort to improve the environment and opportunities for out-of-school learning. A balance is maintained between support for major activities that have national impact and significance and support of more limited projects that serve to explore special needs and opportunities.
- *Linking and strengthening the media of informal education:* Projects that will strengthen the institutions of informal education by recognizing their strengths and weaknesses, and by encouraging cooperative and complementary activities are emphasized.
- *Significance and urgency:* Projects that have a significant effect on the overall pattern and quality of informal education, as well as the strength of its institutions and their relation to formal learning are emphasized.
- *Contribution to the pattern of general education:* Informal learning as an integral component of general education is encouraged. Informal education should provide stimulus, awareness, and background before school, support and reinforcement during formal education, and an opportunity to continue learning and awareness when formal study ends. Lifelong learning should be a habit of all persons regardless of age or role.

In its support of television and radio projects, the Foundation is committed to the development of high quality programming made widely available to all children, youth, and adults. Under normal circumstances, the Foundation requires that:

- NSF retain the right to use the programs for government purposes in perpetuity;
- off-the-air recording rights by educational agencies or institutions shall be guaranteed for a minimum of three years;
- all television programs must have closed captions encoded on the master broadcast tape and all programs must be broadcast with closed captions;
- all broadcasts, exhibits, and other materials must include a clear indication of the source(s) of support (both NSF and any other contributions), and should include the NSF logo;
- a copy of all materials, e.g., videotapes of programs and copy of teacher's guide, be provided to the NSF; and
- a quarterly letter-report on the activities of the project be submitted.

PART FOUR:
COMMISSIONED PAPERS

- Joel B. Aronson, "NSF Initiatives--A Minority View"

- Gerald Kulm, "Mathematics Education: The Roles of Mathematics Educators, Mathematicians, and the National Science Foundation"

- Elliot Soloway, "Computer Science Education at the Precollege Level"

NSF INITIATIVES--A MINORITY VIEW

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NSF INITIATIVES--A MINORITY VIEW

NOTE: The following observations are those of the author and more than 20 individuals around the country who are active in their concerns for minority precollege math and science education. Phone interviews were conducted with practitioners at several levels of involvement: those who help shape science education policy at the national level, those with extensive experience with precollege science and math programs funded by NSF and others, superintendents of school systems with heavy minority enrollment, principals of schools with high minority enrollment who have implemented special math and science efforts in the last few years, directors of math and science programs in school systems with high minority enrollment, university and college deans, and former NSF/SEE staff who worked closely with minority programs while there. The objective of this report is to reflect those needs and concerns of minority precollege education which could be affected by National attention and leadership by NSF and to suggest activities and mechanisms which could be employed by NSF/SEE to respond to those concerns.

INTRODUCTION

The Report of the NSB Task Committee on Undergraduate Science and Engineering Education to the National Science Board, points out that though the number of women and minorities entering the study of science and engineering has increased significantly during the past ten years, even if those numbers continue to rise, "this increase will probably not offset the fall in the total number of persons entering the student stream that results from the demographic decline in the total number of available 18-19 year olds" between now and 1995.

The decline in absolute numbers of students available will perhaps be accompanied by a downturn, recently identified, in the proportion of college freshmen who opt for majors in engineering and the sciences (cited in the "Chronicle of Higher Education;" January 15, 1986.) Of the total number of 18-19 year olds, minorities will make up an increasing proportion due to differential birthrates, reaching 40% by about the end of the century. That statistic is important because at the precollege level, the rate of advanced math and science coursetaking among minorities is only 50-75% (from data published by NSF in "Women & Minorities in Science & Engineering," 1986) of the rate at which nonminorities take the same courses (Algebra II, Trigonometry, Calculus, Chemistry and Physics) and minorities elect science majors in college 20% less often and engineering majors 38% less often than non-minorities (1980 data).

The 18-year-olds of 1995 are now in elementary school. In just a few years they will begin to make choices which will govern the rest of their academic careers. A few will conclude early, by the sixth, seventh or eighth grade, that they want to pursue study and a career in science or engineering. Most will be undecided as they select programs and courses in junior high school and high school. All too frequently, they will be left to make important academic selections by themselves with information that is insufficient to make those choices wisely. They will pursue short term rather than long term goals and they will naturally tend toward paths of least resistance. Before they can understand and feel the impact of the consequences, many students drop Algebra for General Mathematics and opt for a commercial course over Biology or Chemistry. By making such choices, large numbers of able students abruptly and prematurely close the door on a wide array of potential careers in science and engineering.

Unless there is significant change in the rate students, and particularly minority students, choose science and engineering careers, "both the quality and number of newly-educated professionals in these important fields will fall well below the nation's needs - with predictable harm to its economy and security." (NSB Task Committee on Undergraduate Science and Engineering Education.)

That such change can take place has been amply demonstrated. A group of major U. S. corporations, recognizing the demographic truths, has provided a dozen years of funding and encouragement for a number of broad-scale precollege minority engineering efforts with excellent results at locations across the country. These programs, all members of the National Association of Precollege Directors (NAPD), reach more than 40,000 mostly minority precollege students every year, though that is only a tiny fraction of the potential eligible minority student population. The NAPD experience, and the experience of a variety of other programs, are a clear demonstration that inexpensive intervention techniques can improve the flow of minority students into technical careers dramatically.

THE PROGRAMS OF THE NAPD

The nineteen programs which make up the membership of NAPD are mature efforts which have been in operation for years. They assist hundreds of high schools, junior high schools and middle schools located around the country and function across a wide range of school demographics and community environments. Each program operates using a variety of strategies, but all have the same basic mission:

--To increase student academic achievement in all subject areas, especially mathematics, science and language arts.

--To heighten student awareness of careers in engineering, science and technology.

Though independently organized and operated in response to local needs, the NAPD programs have many elements in common.

--Each is a collaboration among the school system, local business and the university which brings expertise and resources to the school to supplement what is already available. Through this collaboration, they help students and teachers see how the study of mathematics and science is related to the practices of engineering and technology.

--With all programs, interaction with students begins early (usually at eighth or ninth grade, but often before) and continues throughout the student's secondary schooling. Once a student becomes involved, contact usually continues up to college entrance.

--All are sustained, open-ended efforts, not special projects which exist for only a limited grant period. Teachers and students can count on these programs . continuing and know that anticipated future support will, indeed, be theirs.

--Program costs are low. The programs make maximim use of volunteers and work within the existing school administrative structure rather than adding more organizational layers. Virtually all of the work done with the students is done willingly by their teachers on their own time because they can see that their inputs are making a significant difference. The result is a set of extensive programs which have yearly per-student costs which are well within the easy reach of most school systems.

The programs work closely with the students to ensure their enrollment and achievement in the subject areas prerequisite to college study of engineering and other math-based fields. They supplement the mathematics and science curricula with technical applications, they provide guidance and tutorial services, they introduce the students to the university and industry through class visits and visits to the class, they provide many role models, and they keep the detailed records which allow continual monitoring of student academic performance.

The programs have been operating successfully in all kinds of schools from those which are strongly academic to those which are in "bad" neighborhoods and from which college attendance was minimal for years before the NAPD program began and which is now much improved. At most of the schools, expanded student interest and achievement has resulted in larger mathematics and science classes and more upper-level courses being offered. SAT performance has improved and high schools report higher rates of college acceptance among their graduates with much larger proportions headed toward engineering and other math-based courses of study.

Over the years and across the nineteen programs, about 25,000 NAPD participants have graduated from high school. More than 80% have gone on to a four-year college and of that group, nearly half have studied engineering with an additional 25% opting for other math-based fields.

Though the efforts of the NAPD programs have been directed towards engineering and most of the students who benefit are underrepresented minorities, there is nothing inherent in the model which limits it to either minorities or engineering. On the contrary, the objective of NAPD programs has always been to make sure that each student builds a strong academic foundation as well as a sense of confidence and determination which can be utilized to pursue college study successfully. What NAPD is doing for students, and the way it is being accomplished, is consistent with the national need to draw more students into the science and technology fields and also with the National Science Board recommendations for meeting that need.

THE NSF ROLE AS AN AGENT FOR CHANGE

The Science and Engineering Education (SEE) Directorate of the National Science Foundation has been concerned with minority equity questions for some years and has provided several programs aimed specifically at minority participants. The Resource Centers for Science and Engineering (RCSE) and the Minority Institutions Science Improvement Program (MISIP) were models of their type and brought about significant change during the few years of their activity. (RCSE made one major grant each year from 1978 to 1981; MISIP began in 1974 and was transferred to the Department of Education in 1980.) However, SEE emphasis on minority concerns has been mitigated by brief program durations and modest program budgets, compared with other SEE programs.

Other than through set-aside funding, participation of minorities in SEE programs has been modest. With a few recent exceptions, notably through the Teacher Enhancement and the Education Networks programs, grants have been made only rarely to minority institutions or in situations where the chief beneficiaries are minority students or teachers. Moreover, based on partial information, it appears that only a sprinkling of minorities participate in SEE grants involving non-minority institutions and project directors. The net result of both set-aside and non set-aside funding over the last several years has been that minority students, teachers and institutions have had relatively little benefit. This is not an indictment of SEE's interest or good faith; rather, it describes a situation in which one another's purposes and concerns are incompletely understood.

The need to bring much larger proportions of minority scholars to technical pursuits is apparent. NSF/SEE can provide important national leadership for that effort, but before that can happen minority students and the institutions they attend must have true access to the full benefits of SEE programming.

SOME CONTEXT FOR THE CONSIDERATION OF MINORITY PRECOLLEGE EDUCATION ISSUES

Throughout minority communities, economics is a pervasive modifying factor. Where income levels are low, elementary and secondary schools have meagre resources and tend to produce graduates with flawed skills. Families have less education and are able to provide less, educationally, for their children. The students' world view is narrow and the lack of stimulation results in modest career expectations. The traditional minority post-secondary institutions also have resources strained by the lack of large endowments and the relatively poorer skills of the students arriving from secondary school which require a great deal of faculty attention to correct.

At the <u>family</u> level, single parents are common and earning enough income is a constant pressure. Thus, though parents are interested, they are less likely than more comfortable families to be involved with the school or with school-sponsored programs. Students often must work afternoons or on weekends to supplement the family income or to be at home to watch younger siblings, so after-school involvement with science clubs or special projects can be difficult to arrange. Many times, minority students cannot afford the extra busfare or the lunch in order to participate in special after-school activities. (One respondent in this inquiry is a principal in Mobile, Alabama whose school is 70% minority and where 1100 of the 1300 students are on the Federal free lunch program. This is not unusual.)

At the <u>secondary school</u> level, most minority students lack the resources in their home environment which allow them to make life-long education choices based on the council of family and friends. Though education is a goal in most families, few of today's students are the children of college educated parents and there are very few engineers or scientists available in the community as role models. While a large proportion of college-bound non-minority students come to a decision about career choice at about the time they enter high school (and thus can plan their program with particular objectives in mind), minority students more often decide at a later point, and frequently not until after they have passed by algebra or a science critical to pursuit of a science or engineering career.

This is not just a matter of better guidance. Studies of how students choose careers show that by far the most influential factors are family and teachers, not the career or guidance counsellor. The less affluent communities cannot easily attract the math and science teachers who are in such short supply, so high schools tend to have many uncertified teachers assigned to secondary math and science courses. Of course, this is a concern for both minorities and non-minorities, but the minority student's support network is more fragile and supplies little outside encouragement, so a non-minority student is far more likely to emerge with science interests intact from a year of uninspired teaching. For reasons such as these, there are many general issues of national concern to precollege educators are of special concern to minority educators.

At the <u>minority colleges</u>, they must deal with students who, though smart, are not well prepared for college level work. Much time is spent on remediation and, in general, the faculty is much more heavily oriented toward teaching than toward research. Teaching loads of 18 to 21 contact hours a week are common, so there is little time for individual research or the pursuit of an extra outside project. Proposal writing for the purpose of acquiring research funds for science departments is not a prominant part of the reward system, so few faculty develop the skills. When SEE announces a program, minority faculty feel themselves at a competitive disadvantage. They expect that most program awards will go to the "in-group" of formerly successful proposers at large institutions which will result very tough competition for the few remaining dollars.

The above few paragraphs are not meant to summarize a complex social situation, but to alert decision makers to some of the more prominant factors in the context of precollege minority science and mathematics education. The following issues and suggestions are derived from a series of interviews with people who have a past, current or potential association with SEE, and who are deeply involved with the precollege education of minority scientists and engineers. Effective response to several of the issues will require SEE to adopt a somewhat more proactive stance than has been traditional in the past. It will need to initiate data gathering and information dissemination and it will need to work more closely with representitives of the minority constituencies so that effective problem-solving can proceed.

NSF/SEE ADMINISTRATIVE ISSUES

--Minority concerns are felt most compellingly by minorities and can be articulated most clearly by them. Though many non-minority staff have worked hard for minority concerns, and empathize with the problems, they are very unlikely to develop the same network of practitioners and advisors a that a minority staff member would bring to the job. There is currently no real minority presence on the SEE staff, nor is there any longer a minority advisory board. Without a senior level minority staff member or two whose opinion counts, there tends to be a mechanistic response to minority problems in terms of dollars spent or people involved rather than a real concern with movement toward solving problems.

> <u>RECOMMENDATION</u> Minority concerns are often different from non-minority concerns and SEE policies and practices should show sensitivity to that fact. In addition to an emphasis on hiring senior level minority staff, SEE should constitute a minority policy board which can be freely consulted about minority issues and which can alert SEE management to problems and concerns relating to specific programs or important grant decisions. In contrast to the former Minority Advisory Committee, this board should be a working organization connected to the day-to-day operations of the Directorate. The model is that of ombudsman, but a single individual would not be likely to have the breadth of information and contacts needed among all four of the under-represented minority groups.

--Many minority practitioners feel that SEE has not internalized the need to work with minorities and therefore deal superficially with minority issues. The very positive statement, now regularly found in SEE program announcements, that "Projects involving women, minorities, and/or physically-handicapped persons as part of the staff or as target audience are especially encouraged..." is seen as merely rhetoric which is never followed up by SEE to see if something productive is really taking place. If SEE wanted to convey a concern about minority involvement, it could require feedback from each Program Director.

RECOMMENDATION SEE--or NSF more broadly--should contract for, or otherwise produce, a Guide to the recruiting of minority participants which would be sent to proposers along with program solicitations or would be otherwise distributed. The Guide would offer concrete advice and alert the reader to any impact the actions may have on a project's budget. For example, most minorities respond more readily to personal solicitation (face-to-face) than to impersonal (mailed) solicitation and that may require travel funds not otherwise considered.

--SEE should be more clear about their goals and objectives with respect to minorities and should be proactive in its support of those goals. There are a number of ways in which a series of "SEE Studies" could be beneficial to the minority precollege effort and to the better understanding of the process of science and math education, generally. Currently, there is no national focus on the need to understand the problems of minority students, nor any national initiative or leader. Practitioners have to deal with symptoms without really knowing what the problems are. Available minority data collection at the precollege level often does not distinguish between Blacks and Hispanics and only rarely between Puerto Rican and Chicano. Not all the education problems of the under-represented minority groups are the same, nor for any one group are they the same in the rural areas and in the urban areas. It is difficult to address a problem unless its dimensions are known. This is not a suggestion that NSF try to solve these problems, but they could provide the national leadership needed in the attempt to DEFINE them.

RECOMMENDATION Good information about precollege science and mathematics course-taking does not exist for either minorities or non-minorities and therefore it is very difficult for practitioners to focus on problems and discontinuities. NSF should initiate a regular data collection effort which takes advantage of the resources of the National Center for Educational Statistics, the various national ethnic organizations, and others to piece together the clearest picture possible.

RECOMMENDATION NSF should provide national leadership for minority math and science efforts by providing clearinghouse activities through competitive bid on the same model as the ERIC centers. One clearinghouse could provide detailed descriptions of exemplary precollege models. Though obviously applicable to all, a large proportion of the exemplary models listed in Educating Americans for the 21st Century, were developed for minorities. A second clearinghouse could establish a national register of corporations willing to interact with school systems with organizational advice, personnel time for visits, donations of obsolete equipment, or cash. In a poll of businesses published in A Nation At Risk, more than half responded that they would be interested in becoming more directly involved with local education. The minority precollege programs of NAPD have involved industry for a decade and have ample expertise about how to do it.

--Over the years, NSF has paid scant attention to disseminating the results of the inquiries it has funded. NSF has provided millions of dollars over the years to fund pilot efforts and projects of potential utility to the nation, but little of that knowledge has ever found its way into the hands of the next cohort of practitioners. Both the Information Dissemination for Science Education program (1977-81) and the current Science and Mathematics Education Networks program have supported (in quite different ways) information-sharing, but they are reactive rather than proactive efforts which stimulate information flow within an area or locality, but not between NSF and its constituents. Especially at the precollege level, there is an urgency that the outcomes of operational projects reach others quickly and in a way which gets the information directly to the practitioner. The classroom teacher at the local level needs to have access to information about good programs and a way to learn about successful models. LEAVING DISSEMINATION UP TO THE PROJECT OR TO THE ACADEMIC NETWORK IS NOT EFFECTIVE.

RECOMMENDATION NSF/SEE needs to consider an array of methods to capitalize on its research and development investments. Only if those investments lead to broader, more successful activities can they really be called "leveraged." Probably best done through direct contract, SEE needs to devote a portion of its budget to reporting results and summarizing techniques, funding of duplicative efforts in new contexts and producing "how to" books and materials.

Obviously, dissemination is not just a minority issue, but it is an important minority concern, perhaps because they feel an urgency to move forward as quickly as possible.

BOUNDARY ISSUES BETWEEN NSF/SEE AND ITS MINORITY CONSTITUENCY

There are a number of issues which are related to NSF policies and structure which interfere with the relationship between itself and potential and actual grantees. They are recorded here as a way of making NSF aware of them, but there are no specific recommendations because few of these issues can be resolved by changing regulations or initiating new programs.

--The removal of the Minority Institutions Science Improvement Program (MISIP) to the Department of Education, coupled with what is seen as on-again, off-again funding of other minority programs, has created an aura, clearly perceptable to many minority researchers, that NSF commitment to minority needs is vague and uncertain. For many, NSF is not seen as a reliable resource.

--The mechanism of dealing with precollege programs through a university, though encouraging collaboration, causes problems in two ways:

> Many minority schools do not have easy or positive contact with the local college or university because of distance or differences in interest. Therefore, requiring the post-secondary link forecloses program opportunities for many schools.
>
> Minority programs which have been successful at gaining NSF support under the umbrella of a college or university sometimes find that the grantee (the university) taxes the grant in ways unforseen by the Project Director with the result that the project effort has to be curtailed in important and occasionally crippling ways.

--The timeliness of grants continues to be an issue with SEE, as it has for many years. Directors of large projects and small complain that the extreme length of time it takes a proposal to move through the consideration and funding process--recently, up to nine months--makes it very difficult to plan for new staffing, for interconnection with other institutions, for joint funding of a project effort, for coordinating separately funded efforts, and for keeping staff interested and available. Minority institutions are particularly affected because they have few funds to put toward keeping staff together or spending money up front to get a project going to meet external time constraints such as those imposed by the academic school year.

--Minority proposers have a frustration with SEE's apparent inability to consider proposals with an understanding of the context in which they are written. Proposals must have merit, but merit is not unidimensional. A minority project may not be at the "cutting edge" educationally, but that is mostly a function of the target population, the resources available to it, and the procedures necessary to deal with it rather than a lack of sophistication on the part of the proposer. For example, a project dealing with rural Indian schools has to deal with the fact that teaching is done very traditionally--science is "hard stuff in a book"--and the introduction of new text material or teacher skill enhancement must be done gently. A reviewer unsophisticated in minority issues might well dismiss such a project as "old stuff," but someone who is sensitive may see an opportunity to make a positive impact on a segment of the population which is educationally very needy. This is a very subtle and complex issue which is directly related to the need for adequate minority representation on SEE's staff.

--Rightly or wrongly, minority program directors and other practitioners see NSF as the "funder of last resort" for science education. For example, teachers and students of science at the fringes of standard education are defeated by the lack of texts which are relevant to the isolated farm community, the reservation Indian's practical understanding of nature and the environment, or the Alaskan native's world without much technology. They would like to have the chance to deal with a science which fits with the things they know, but text book publishers find them a "thin" market.

<u>SUGGESTION</u> An NSF initiative to provide funds for special projects in precollege science could help with the development, inexpensive production, distribution and training in the use of unique materials in cases like those above. A special

Projects in Science Education (SPISE) program did exist at NSF for a few years in the late 50's and could perhaps be used as a model.

MINORITY PRECOLLEGE MATH AND SCIENCE ISSUES

--Expectations of rejection are hard to overcome when there are generations of experience to refer to, so minority students volunteer for very little which is controlled and supervised by non-minorities. When programs are announced at the local level, minority students don't think that they are included. Such programs are also forbidding when there are no minority staff members who can act as bridges to the content. An old (1977) analysis of minority participation in the precollege Student Science Training (SST) program based on a 20% sample of the 133 non-minority projects operating that year, found that less than 25% of the projects had more than 2 minority participants and less than 20% had any minority staff. Minority representation was slightly worse for the college level Undergraduate Research Participation (URP) grants which were also studied. That was nearly ten years ago, but by all recent accounts, nothing has changed significantly.

> RECOMMENDATION NSF needs to put teeth into its stated desire to have minorities included in all grant projects. The "Guide" for recruiting minority participants, suggested elsewhere in this paper, is one step which should be taken, but other measures are also needed to make minority participation something which "counts" toward the quality of the project and obtaining the next grant.

--Math and science teacher preparation at both the elementary and secondary levels needs to be improved through inservice training. Poor preparation of teachers hits minority students especially hard because they have few other influences in their lives helping them toward those goals. Among other things, teachers need to be able to help students, particularly minority students who suffer from a lack of an experiential base and role models, think about the decisions necessary to planning their education.

> RECOMMENDATION NSF/SEE should continue its teacher training efforts, but it needs to make

sure that the training is carried into the classroom and that there is impact feedback to NSF. SEE also should consider assistance to elementary and middle school teacher retraining programs, on a school system by school system basis, with feedback on ways and means to NSF and prompt dissemination of that information. Some systems are doing this on their own, others need help. NSF can spearhead some efforts and provide important guidance to many more. The Mobile, Alabama City School System is in the process of refurbishing all of its science programs and retraining many of its teachers. Perhaps its experience can be a model for others.

--Economics is a major factor in whether minority students opt for science and technical careers. Many minority students who get into college, can't stay because of finances. Others, very capable but believing that finances are not going to be available for college, opt out of the college track early in order to concentrate on building skills (usually shop skills) which they can use immediately upon graduation from high school.

<u>RECOMMENDATION</u> There is clearly a need to identify bright, but poor, students early and make sure that they will have the money to get to college. Several of our competitor countries and our own military service promise free or low-cost college training to capable students identified early as long as they continue to qualify through their performance. NSF should establish and administer a scholarship program modeled on its Graduate Fellowship Program which would make scholarship grants to precollege students at about the tenth grade level. It would not have to fund these scholarships itself, but could take the lead to bring other contributors (including the college which enrolls the "NSF Scholar") together in the way a financial aid package is constructed for college students by ETS. Awards would be conditional on superior performance during high school and college acceptance for study in a math-based field.

--For reasons already discussed, minority project directors tend not to view NSF/SEE as a ready source of funding. They see SEE initiatives as requiring very sophisticated proposals and feel that their network is less well-connected with the "cutting edge" of education research. Thus, during the first year or two of a new program, grants are rarely minority connected. Ultimately, after some successful models have been described and good examples have been identified, minority proposals will be submitted.

> SUGGESTION Project Directors' meetings are an excellent way for the less experienced to rub shoulders with the more experienced people and to develop a broader resource network. A special SEE effort to bring minority Project Directors and potential Project Directors to these meetings will strengthen their ability to compete and should lead to a greater volume of proposals.
>
> RECOMMENDATION The "Proposal Development Workshops" which were conducted for about a year under the MISIP program should be re-instituted. Reports from the field suggest that the workshops were welcome and useful and that several successfully-funded proposals were written as a result.

--Because of heavy teaching loads and a reluctance to devote time and energy to an effort which is seen as having a low probability of success, minority researchers often do not write proposals even when they have good, workable ideas. SEE has recently made it a requirement in some programs that a pre-proposal be submitted and reviewed before time is spent on elaboration. That requirement could be the first step toward the generation of many new proposals from minority sources.

> RECOMMENDATION NSF should make technical assistance available to the authors of pre-proposal ideas where that is needed in ordert to produe a fully articulated proposal for NSF's consideration. The mechanism for technical assistance would be through a list of consultants who qualify for the work through experience, knowledge and success at proposal writing and project management. Where proposal development is fairly well advanced, the consultant might work via phone or mail at low cost, but where the proposal idea seems to be fruitful but in rough form, it might be necessary for the consultant to make a brief site visit of one or two days for working meetings. The National Institutes for Mental Health has had such a program in operation.

> They arranged a pool of consultants with a variety of expertise and assigned them to proposals which fell into areas of targeted priority. The consultants were available to both minority and non-minority proposers, but special efforts were made to advertise their availability through minority newsletters and professional organizations. NIMH reported that they saw an improvement in the quality of funded programs as a result of this iniative.

If significant change in the number of students preparing for math-based careers is to take place on a country-wide basis, NSF/SEE is probably the only institution which can lead the effort to bring it about. It is the only national organization with responsibilities for science and engineering education across disciplines and across levels from precollege through graduate training. Much of great importance has been accomplished over the years by NSF's grant programs and its impact will certainly continue to be felt in the future, but grant programs are only one way to bring about change. With a relatively modest investment of dollars and personnel, but a necessarily long-term commitment to change, NSF can provide a national focus on the issues by convening leadership conferences, underwriting action committees, commissioning data collection, and serving as the clearinghouse for information and guidance about new and successful local programs, whether supported by NSF or other sources.

INTERVIEWEES

In order to write this paper, the issues of National Science Foundation involvement with minority precollege math and science education were discussed with a number of people, all of whom have long experience as practitioners in the area. Some have worked with the Science and Engineering Education Directorate of NSF, some work with school systems which have heavy minority enrollment, and some are involved with special programs designed to encourage minority students to consider careers in science and engineering. A few individuals who are nationally recognized spokespersons were unavailable during the relatively brief period of this inquiry, but the varied backgrounds of the people who did respond makes it unlikely that the observations and recommendations would have been much different.

Don Colesto Ahshapanek	Biology Department, Haskell Indian Junior College; formerly member of the SEE Advisory Committee for Minority Programs in Science Education and the NSF Committee on Equal Opportunities in Sciene and Technology
Gary Allan	Executive Director, Native American Science Education Association, Washington, D.C.
Colleen Almojuela	Mathematics and Science Specialist, United Tribes of Washington, Seattle
George Bland	Dean of Engineering, North Carolina State University
Carolyn Chesnutt	Executive Director, Southeastern Consortium for Minorities in Engineering
William Craft	Associate Dean of Engineering, North Carolina A & T University
Glynda Cryer	Program Director, Memphis City School System
Marjorie Gardiner	Director, Lawrence Hall of Science, University of California, Berkeley; formerly, SEE Program Director
Lawrence Hatfield	SEE staffmember, Teacher Preparation Program

Willy Herenton	Superintendant, Memphis City School System
Shaik Jeelani	Engineering Department, Tuskegee University and Engineering Faculty Consultant to several school systems in southern Alabama.
Gil Lopez	Director, Comprehensive Math and Science Program (CMSP), Columbia University, New York
Patricia MacGowan	Director, Mathematics, Engineering and Science Achievement (MESA) Program, University of Washington, Seattle
Shirley Malcom	Director, Office of Opportunities in Science, AAAS; formerly, SEE staffmember
Shirley McBay	Dean of Student Affairs, MIT; formerly, SEE Program Director
Joyce Pinkston	Science Supervisor, Memphis City Schools
Grady Polk	Principal, Chattanooga City School System
Annette Sanders	Principal, Mobile City School System
Richard Santee	Acting Director, Mathematics, Engineering and Science Achievement (MESA) Program, University of California, Berkeley
Ollye Shirley	Member, Jackson, Mississippi School Board and Director of the Childrens' Television Workshop program to establish 3-2-1 Contact Clubs in elementary schools
Elisabeth Stage	Director of Mathematics and Computer Education, Lawrence Hall of Science, University of California, Berkeley
Melvin Webb	Dean, Clark College; formerly Assistant Director of the first Resource Center for Science and Engineering, the Atlanta University Center.

MATHEMATICS EDUCATION

The Roles of Mathematics Educators, Mathematicians and the National Science Foundation

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Washington, DC

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ABSTRACT

This paper provides background information and discusses current issues in mathematics education. The objective of this analysis and discussion is to provide a context for developing future policies for the National Science Foundation's Directorate for Science and Engineering Education (SEE). Recent trends and directions in the emerging discipline of mathematics education are explored. A primary focus is the changing role of mathematicians in mathematics education, as the emphasis in SEE programs has shifted from curriculum to teacher preparation and research. The implications of recent renewed attention to curriculum and teacher preparation are examined, especially as they relate to the professional interests of mathematicians. The paper concludes with recommendations for policies and initiatives for SEE programs in materials development, research, and teacher preparation.

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MATHEMATICS EDUCATION

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I. Historical Context

Beginning in the 1950s, the National Science Foundation, through projects funded by its education offices (now known as the Directorate for Science and Engineering Education), has had a significant impact on precollege mathematics education. While the success or effectiveness of some programs may be difficult to assess, they produced important and self-evident effects on practice. In retrospect, some of the programs have defined or changed the way we think about mathematics education.

NSF programs in mathematics and science education have generally been divided into three broad categories: Materials, Teaching, and Research. At various times over the past 30 years, the emphasis has shifted among these three areas. In many cases, it is difficult to say whether NSF funding generated increased interest or emphasis in one or the other of the categories by math and science educators or whether interest produced pressure for funding. There is always a complex interplay between the availability of federal funding and the intensity of perceived need for research or development work in education. Historically, major crises in education seem to have been the primary source of pressure for increased funds for mathematics and science education which, in turn, have generated activity in one or more of the three major categories.

While this paper will not trace the history of NSF funding in mathematics education, some historical context will be helpful in exploring the roles of mathematicians and scientists in educational programs. In the remainder of this section of the paper, some major efforts by NSF in each of the three categories will be explored. The intent is to discuss the roles in and the influences on these programs by mathematicians and scientists, rather than to assess the effectiveness or impact of the programs themselves. By its nature, such a discussion can only be descriptive and cannot avoid subjective opinion.

Materials Development Projects

The curriculum projects of the 1950s and 1960s were by far the most ambitious and far-reaching effort in the history of NSF precollege mathematics and science education programs. Some attention to an improved mathematics curriculum had already begun in the early 1950s but the launching of Sputnik in 1957 provided the impetus for a phenomenal amount of federal funding for more than 20 precollege mathematics curriculum projects from the late 1950s to the early 1960s.

Many of the curriculum projects involved writing teams of mathematicians, teachers, psychologists, and educators who produced the text materials. Some writers have noted the uniqueness of this team approach, which had not been typical of textbook or material development previously. On the other hand, it is clear that the conceptualization and leadership of the major projects was provided by mathematicians and scientists. Among the large and influential projects were Begle's School Mathematics Study Group (SMSG) at Stanford, Beberman's University of Illinois Committee on School Mathematics (UICSM) at the University of Illinois, and Davis' Madison Project at Syracuse. Like these three, most of the projects were located at centers within major universities, producing both an implicit and explicit impression of the locus of influence on the directions and emphases to be taken.

What were the primary roles of mathematicians in these projects and how successful were they in them? The purpose of the projects, especially in the early years of development, was to prepare students for university work in mathematics and the sciences. Clearly, the mathematicians at the university were seen as the most qualified people to make judgements about the content that should be required for success in college. Advances in mathematics, science and technology after World War II produced an incredible gap between the mathematics and science studied in high school and the prerequisites for university work, especially at the graduate level.

The leaders of the curriculum projects proposed that by focusing on modern mathematical structure, concepts, and language the gap would not only be narrowed but students could learn more mathematics more easily. They were convincing in their arguments that the old skill-based, topically-organized curriculum made little sense to students, was inefficient, and produced no satisfaction in experiencing the beauty of mathematics or motivation to explore and discover new concepts. In these arguments for modern mathematics, the mathematicians provided both a vision for the nature of precollege mathematics and a strategy for for attaining that vision. The school mathematics that they proposed would be not only better but easier to learn than the current material.

In the execution and production of materials that reflected the spirit and substance of their vision, the mathematicians were extremely successful. We may never again see such a prodigious effort as some of the summer writing teams which produced the first experimental versions of the textbooks. Not only was the mathematical content new and innovative, but many of the examples, activities and exercises were creative, interesting, and motivating. These activities probably reflect the best of what is possible in a cooperative effort between mathematicians and educators.

Mathematics and mathematicians also had influences on the psychologists of the era. Jerome Bruner's structuralist approach in which discovery was an important component developed a symbiotic relationship with some of the projects. Bruner's hypothesis that "any subject can be taught effectively in some intellectually honest form to any child at any stage of development" was pushed to the limit by some of the elementary and junior high curriculum projects. Anecdotes have been passed along that some mathematicians on summer writing teams tried out content on their own children (with a fair amount of coaching), affirming Bruner's hypothesis, and thus including some highly abstract and difficult topics in the experimental texts.

Later commercial versions of the texts tended to follow the behaviorist approach of Robert Gagne, thus losing much of the discovery and creative flavor of the original experimental versions. In a real sense, it can be argued that the materials that the mathematicians envisioned and helped to produce were considerably different from the versions that later became commercially successful. One important reason for this was that teachers and publishers were more comfortable with the behaviorist approach of breaking content into bite-size chunks. The behaviorist influence on education, coinciding with the commercial implementation efforts of the modern math materials, probably was a major factor in the distortion of what the projects originally intended. The second significant limiting factor was the attempt to extend the approach to students in the lower quartiles of ability, for whom an emphasis on structure and discovery was a less appropriate approach. Too much was asked of the materials for too many different students.

The notion that college entrance should be the goal for studying mathematics and science at the precollege level was an innovation of these projects. In fact, the term "precollege" seems to have entered our vocabularies at about that time. Previously, elementary and high school work was primarily a terminal program aimed at students who would enter the workforce. These projects, and the subsequent pressures to make them applicable to youngsters with a wider range of ages and abilities, have changed our thinking about the purpose of precollege mathematics. We now expect both conceptual understanding and skill development. The swings in emphasis and success between these two goals have precipitated many of the "crises" that continue to plague us.

Teacher Education Projects

On the heels of the curriculum development projects of the 1960s, a major NSF effort in teacher education took place. Most of this work was aimed at retraining classroom teachers so that they would be able to handle the modern mathematics being introduced. While there were variations, the primary focus of these programs was to upgrade and update the mathematics content knowledge of inservice teachers. The inservice work was offered in three types of prorams: Academic Year Institutes, Summer Institutes, and Inservice Courses in the evenings for full-time teachers. Of these, the Summer Institutes were the most ubiquitous, providing the greatest contact between mathematicians and teachers.

Table 1. Percentages of Mathematics Teachers Surveyed in 1977 Who Had Participated in One or More NSF Institutes or Courses

K-3 teachers	4-6 teachers	7-9 teachers	10-12 teachers
5.4 %	5.5 %	27.2 %	38.2 %

Source: Science and Engineering Education: Data and Information, National Science Foundation, 1982.

While the teacher education projects may not have had a vision as well-defined as the curriculum projects, their goal was fairly simple and straight-forward. Teachers were to study modern mathematics so they could be effective purveyors of that same content to their students. In the minds of the mathematicians who designed and directed the Institutes and courses, there was little doubt that providing teachers with more and better mathematics was the pathway to effective implementation of the new materials.

Special mathematics courses were often designed with titles such as "Analysis for Teachers." In some cases, new textbooks were written for the courses, since the usual graduate texts and courses could not be used. Many mathematics departments added a special new degree, the Masters of Arts in Teaching, for teachers who completed 30 or so credits of these special courses.

Unfortunately, the books and courses for teachers did not always have the spirit of discovery and activity that many of the experimental student texts had. Certainly the material was new and many teachers were excited about topics such as sets, axiomatic approaches to algebra, and coordinate geometry. On the other hand, the teaching approaches used by the mathematics professors were often the traditional lecture presentations which did not provide teachers with models or ideas about presenting these difficult topics to their own students.

While the mathematical content of the Institute courses provided an underpinning for the modern curricular materials, little effort was made to align or relate the courses to the materials that the teachers might actually be using. There was little contact between the Institutes and the schools in which teachers worked. Often, teachers would travel to another state or region of the country to attend an Institute. The Institute directors and mathematics professors had little sense of accountability for the success of their programs or courses in helping teachers to do a better job. In some cases, there was such a lag in schools' implementing the new materials that teachers participating in an Institute would go back to teach in the fall eager to apply what he or she had learned but found no new materials. Sometimes, teachers would try to develop their own new course from Institute notes but usually they simply returned to teaching the "old math." This phenomenon was common, leading the NACOME report to conclude that modern math never really had a chance to succeed.

In these teacher education projects, mathematicians succeeded best in their roles as developers of new courses and degree programs for teachers. These courses and degrees provided teachers with status and a recognition of their intellectual worth. The degree programs defined a new type of graduate education for teachers that emphasized mathematics knowledge and, at the same time, recognized that teachers in graduate programs had needs for special mathematics courses.

Research Projects

In the late 1970's, research in mathematics and science education received a significant boost through the Research in Science Education (RISE) program at NSF. While results and impacts of research are not always evident immediately, it seems clear by now that several important areas of research that were funded by RISE have begun to bear fruit both in implications for practice and in paving the way for current applied, classroom-based research. While it is not possible here to review the areas of impact in any detail, the topics of problem solving, early number operations, rational numbers, and algebra can be identified as those in which important advances in research have been made. In a fairly brief period of time, we have learned a great deal about how children learn mathematics and solve problems.

The reasons for the success of the RISE program are a combination of circumstances, along with some reasonable leadership in the form of mathematics educators as rotators at NSF who valued and supported research. Jim Wilson, Tom Cooney, Dick Lesh, and Doug McLeod provided consistent and continual contact with mathematics education researchers over a three- or four-year period. The permanent staff at NSF managed to secure sufficient funding for an emphasis on research over a reasonably sustained period of time.

The circumstances that prepared the way for the success of the RISE program were due primarily to the readiness of mathematics education researchers to attack the important learning issues. This readiness consisted of two parts: the development of a cadre of professionals who had been trained as mathematics education researchers, and some groundwork having been done to identify the critical areas and research problems that needed to be addressed. During the late 1960s and early 1970s, doctoral programs were developed which began to produce people trained in the new profession of mathematics education. (More discussion of this emerging specialty will be provided in the next section.) By the mid 1970s several leaders in mathematics education had emerged at a few large universities.

In 1975, NSF funded the Georgia Center for the Study of Teaching and Learning Mathematics at the University of Georgia. Through this very modest funding effort, a series of research planning workshops were held, producing an effective and productive network of leaders and colleagial groups eager to pursue research programs in some clearly identified areas. These groups carried out some early pilot studies using university funds, then published several monographs reporting early results and agendas for further research. When the RISE program was initiated, the mathematics education researchers were ready to begin a productive program of work, having already completed much of the necessary pilot work.

II. The Emergence of Mathematics Education

The discipline of mathematics education is relatively young. This section will characterize the field and describe its brief history over the past 20 years. The discussion will focus on the gradual shift of leaders in the field from mathematicians with special interests in education to a new professional with training in mathematics, education, and psychology. Special attention will also be given to the roles of teacher education and research in the professional lives of mathematics educators.

The emerging field of mathematics education as a discipline in its own right can be characterized in a number of ways: the types of people involved, the professional activities of its members, the content and issues addressed, the organizational and publishing outlets, and the interactions with other disciplines. While there are many obvious overlaps among these characterizations, they provide an interesting and useful context for examining the emergence of mathematics education as well as the shifting emphases in directions as the field has begun to mature.

The mathematics curriculum projects of the 1960s provided the impetus for training and developing the first mathematics educators. Mathematics teachers came to these projects to work on writing teams, to help with implementation and teacher training efforts, or to work on studies to assess the impact of the materials. Some of these mathematics teachers became closely involved with the work of the projects and stayed on at the universities to earn their PhDs. Other mathematics teachers who attended summer or academic year institutes were also motivated by the challenge of graduate work and decided to remain at the university and continue their work toward a PhD.

Because many of the projects included psychologists on their teams, and since many of the implementation and assessment projects involved teaching and learning issues, it was natural that these new mathematics education doctoral students sought out courses and developed dissertations that focused on instructional and learning themes. The balance of the coursework consisted of graduate work in mathematics, so the PhD program in mathematics education produced a person well-grounded both in mathematics and in the psychology and research methods of instruction and learning.

So a new type of professional mathematics educator came into being. They were influenced significantly by their visionary mathematician mentors who directed the curriculum projects: e.g. Begle, Beberman, Mayor, Fehr, Goldbloom and by other mathematicians such as Klein, Polya, Birkhoff, Moise, Kline, and

Dieudonne. One the other hand, they drew from psycholgists such as Bruner, Gagne, Dienes, Rogers, and Piaget. Their interests began with mathematics content and curriculum, but unlike their predecessors, they soon became concerned with the problems of teaching and learning mathematics. Since most of them had spent time as high school or junior high school teachers, they had a very practical orientation, looking for materials, approaches and theories that could be applied in the classroom.

Most of the people who became the first mathematics educators have now advanced to positions as full professors. They have developed undergraduate and graduate degree programs at their universities, and participate in a wide range of professional activities involving teaching, research, and service to the educational community. The next section outlines the many roles that a "typical" mathematics educator fulfills.

III. Roles of Mathematicians and Mathematics Educators

The challenge of being a mathematics educator carries with it an automatic requirement for a "split personality." At most universities, mathematics educators are not mathematicians. They may be members of a mathematics department and they may teach mathematics courses, but their areas of interest are very different from their mathematician colleagues. More often, mathematics educators are members of an education department, along with science, english, and social science educators. This arrangement often estranges them even further from their colleagues in mathematics, computer science, statistics and science departments.

Table 2. Estimated Numbers of Mathematicians and Mathematics Educators in Colleges and Universities

	Active in R&D	Total
Mathematicians	8000	25,000
Mathematics Educators	400	2000*

*Since 1960 there have been about 5000 doctoral dissertations in mathematics education. This estimate is a very rough guess as to the number of those persons who are now at colleges or universities.

Sources: Renewing U.S. Mathematics, National Academy of Science, 1984. Membership Directory: Special Interest Group for Research in Mathematics Education, 1986. Suydam, M. & Osborne, A. The Status of Precollege Science, Mathematics, and Social Science Education: 1955-1975, Volume II Mathematics Education, Ohio State University, 1977.

Teaching, Research, Service

At the university, the demands to attend to teaching, research, and service produce different tensions for mathematicians and mathematics educators. The pressure to "publish or perish" is very much a fact of life at many universities. For mathematicians, the situation is best characterized by a statement made by a mathematics department chairman about tenure and promotions: "No matter how good a teacher he might be, if a mathematician does not do good research, he will not succeed. On the other hand, no matter how poor a teacher he might be, an excellect researcher cannot fail (to be promoted)." For a mathematics educator, the requirement to excell in teaching and the obligation to provide inservice education for teachers produce demands that are sometimes counter to survival in the competition for tenure and promotion. The low status of teaching and service at many universities has produced some noticable effects on the types of scholarly pursuits of mathematics educators.

As a "new kid on the block" in the world of tenure, promotions and allocation of resources at the university, mathematics education has worked hard to earn its place as a legitimate field of scholarly endeavor. A few "oldtimers" in the 1960s were able to earn promotions through work on curriculum projects and the subsequent publication of precollege mathematics textbooks and occasional articles in teacher magazines dealing with better teaching approaches. However, in the 1970s with universities in financial trouble and faculty turnover almost nil, the requirements for tenure and promotion stiffened. Hard data-based research and publications in refereed journals were demanded. Promotion committees were suspicious of publications about teaching, even in respected, refereed educational journals. Textbooks for precollege students and "how-to" articles did not count at all in one's resume. Since they were not prepared or interested in doing research in mathematics, most mathematics educators turned to the other part of their graduate training and emulated the research methodology and issues of educational psychology.

Research in Mathematics Education

Much of the early research in mathematics education consisted of "methods comparisons" studies. At first, the methods consisted of different content approaches that investigated factors such as the sequence, context, format, or structure of the material. For example, is one axiomatic system better than another in teaching geometry? Mathematicians were often interested co-investigators or consultants in these kinds of studies. Next came a flurry of interest in "teaching comparisons" studies. Various teaching approaches such as discovery, inductive, laboratory, and individualized methods were compared with the traditional lecture method. Since these studies often dealt with the preparation of materials, texts and curricula for presenting mathematics, there was still some interest and involvement in them by some mathematicians.

In the mid 1970s, research attention began to be increasingly directed at the learner. The influence of Piaget was especially influential in compelling mathematics educators to consider developmental factors and to question whether content and teaching approaches could be successful without knowing how the child's mind works. This emphasis also shifted attention from upper grades in which mathematical content seemed most important to earlier grades where learning and instruction were uppermost. As a consequence, many mathematicians seemed to be left out of the picture. First of all, child psychology was not something they were trained in and, secondly, elementary school arithmetic was not very interesting as a curricular topic. While the Piagetian influence has waned somewhat, mathematics educators continue to rely heavily on psychological theories as the basis for their research and scholarly efforts. This development has maintained if not widened the gap between the professional interests of mathematicians and mathematics educators.

Table 3. Number of Research Reports in Mathematics Education

	Summaries	Journal Articles	Dissertations	Total
1955	4	20	26	50
1965	7	67	92	166
1975	3	99	266	368
1985	20	203	342	565

Source: Suydam, M. & Osborne, A. <u>The Status of Precollege Science, Mathematics, and Social Science Education: 1955-1975, Volume II Mathematics Education</u>, Ohio State University, 1977.

The emphasis of research on mathematics learning and cognitive development over the past ten years has produced some notable results and advances in our knowledge. There is reason for optimism that the research approaches and theories that have been developed for young children's learning of addition and subtraction, for example, can show the way for similar and more rapid advances in our understanding of other areas of mathematics, extended to other age levels. These advances have come, however, at some cost to the other two areas: materials development and teacher education. Part of the reason for the decline in work in these areas can be attributed to lack of funding. Curriculum development and teacher education projects are expensive and funding from NSF and other agencies has not been available until fairly recently. On the other hand, the low status associated with teacher education and the decreasing involvement of mathematicians who might be interested in curriculum development have contributed to the problem.

Teacher Preparation

The development of mathematics education as a separate discipline has affected the field's relationship with mathematicians in other ways. In the area of teacher preparation, many mathematicians seem to believe that if a teacher knows mathematics, little else is required. If mathematics is presented logically with proper attention to developing a mastery of the prerequisite knowledge and skills, students will learn. Beyond making sure that the chalkboard is used correctly and that students do homework, there is little else to be said about instructional or learning issues. Many mathematicians are not aware of the content of teaching methods courses and some are curious how an entire course can be devoted to such matters.

At many universities, the mathematics department offers the content preparation and the school or department of education offers the "professional" courses. The education faculty also has the major responsibility for designing the overall program for teacher certification. While a mathematics educator will sometimes teach mathematics courses, especially those for elementary teachers, it is rare for a mathematician to teach a methods course. This built-in schism between the two parts of a teacher preparation program often produces varying degrees of misunderstanding, animosity, or simple apathy between mathematicians and mathematics educators.

Table 4. Bachelor's Degrees in Mathematics Specialties, 1979-80

Area	Number
Mathematics	10,160
Statistics	467
Actuarial Science	146
Applied Mathematics	801
Secondary Teaching	1,752
Other	580

Source: Fey, J. & Fleming, W. Undergraduate Mathematical Sciences in Universities, Four-Year Colleges, and Two-Year Colleges, 1980-81, Conference Board on Mathematical Sciences, 1981.

Mathematics educators select from courses offered by the mathematics department in developing a mathematics education major for their students. However, they seldom have much direct influence on the content of these courses, especially those for secondary teaching majors. There are often too few secondary teaching majors for a mathematics department to offer special courses for them. At best, a mathematics faculty member with a special interest in education will teach a special section designated for teaching majors. Most often, courses are chosen from those offered for other mathematics or engineering majors. Many teaching majors see these courses as irrelevant to their needs, being far too abstract in relation to the school curriculum. The lecture approach to instruction used by most mathematicians becomes the only model for teaching mathematics that most education majors experience for four years.

The mathematics courses for elementary teachers are usually special courses taken only by elementary education majors. These courses are very low in prestige and are avoided as much as possible by mathematics faculty. Often, these courses are taught by graduate assistants or are assigned on a rotating basis to faculty. Since mathematics departments are not particularly interested in these courses, they are sometimes taught by mathematics educators or their graduate students. In some universities, the mathematics content courses for elementary teachers are offered by the school of education rather than by the mathematics department.

In spite of the fairly large number of education courses required for certification, only one course deals with the methods of teaching mathematics. In this course, the mathematics education faculty must present effective teaching strategies, introduce approaches to planning and managing classroom lessons, present theories and examples of how children learn, and review the precollege mathematics curriculum. Most students come to these courses with one idea about how to teach and learn mathematics, drawn from their own high school experience and their recent college courses. The secondary teachers often have completed college-preparatory programs in high school and have little notion of how to deal with students who have difficulty learning mathematics through lectures and memorization. The elementary teachers have avoided mathematics in high school and their recent college coursework has probably been somewhat traumatic.

In the face of these odds, methods courses are usually fairly successful. The students are highly motivated, happy at last to be dealing directly with their chosen major. They are eager for new ideas, recognizing that the way they have been taught has not always been the most effective approach. Research studies have shown large positive gains in attitudes toward and expectations of success in teaching after completing mathematics methods courses. Unfortunately, these gains and attitudes are difficult to maintain once the beginning teacher confronts the reality of the classroom. The necessarily brief introduction to new methods, the lack of continual support during early teaching experiences, and the absence of role models in the schools contribute to many beginning teachers falling back to the familiar lecture-memorization mode of instruction. This vicious cycle of gaps between mathematics, mathematics education, and the schools works against the best efforts of each of the three groups.

Graduate and Inservice Education

Virtually all states require that teachers complete approximately 30 credits beyond the undergraduate degree to obtain permanent teacher certification. In addition, many state and local school districts require varying amounts of inservice training for the purpose of keeping teachers up-to-date with recent content, teaching methods and curriculum developments. These requirements present a continuing need and opportunity for mathematicians and mathematics educators.

The content and structure of university-based graduate and other post-baccalaureate programs for teachers often turns out, in practice, to be a patchwork of courses spread over a period of several years. The coordination between mathematicians and educators in planning and developing the courses and programs is sometimes even more haphazard than for undergraduate programs. The situation is due somewhat to the same circumstances that exist in undergraduate programs, but is exacerbated by the changing needs of teachers and the limited availability of suitable courses over the extended and variable time periods that teachers are able to devote to graduate work.

Except for universities in metropolitan areas, mathematics departments find it difficult to offer graduate courses after school or during the evening for teachers. Consequently, most teachers take the required mathematics courses, often one at a time, over several summers. Furthermore, in many states, of the 30 total credits, as few as 6 credits (two courses) must be in the content major (mathematics in this case). Most teachers opt to take only this minimum, filling out their program with education courses. This situation makes it very difficult to develop or sustain significant progress toward improving or extending the mathematical knowledge of teachers. These factors have significantly reduced the role of mathematicians in graduate teacher education over the past 10 years. The M.A.T. programs developed in many mathematics departments in the late 1960s have all but disappeared, replaced by master degree programs in education. Some universities have recently revived the M.A.T. program as a special degree for people from other careers who are retraining as mathematics or science teaching.

Non-credit inservice education for teachers is administered by state and local education agencies. Much of the inservice work is accomplished through relatively short workshops lasting a few hours; however, semester-long courses are sometimes offered. In some states, a limited number of non-credit course hours can be used to satisfy the 30 credit requirement for obtaining or renewing permanent certification. There are extreme variations in the content, quality, and source of inservice work. Large school districts often employ a staff to do much of their own inservice work, only consulting university mathematics educators or mathematicians occasionally. Other districts contract with private firms which offer professionally marketed and packaged programs for teachers. Textbook companies often offer extensive inservice work, especially for elementary teachers, as part of their marketing and sales efforts. Museums, community agencies, and government programs are other sources for mathematics and science workshops for teachers.

Because university mathematics educators and mathematicians are often assigned full-time to teaching, research, and university service obligations, they find it difficult to respond to requests for inservice education workshops when they are asked to provide them. Furthermore, the university reward system does little to recognize efforts in inservice teacher education. Even when they find time to present workshops, university faculty are often frustrated by the lack of opportunity to plan and develop a program that meets the needs of teachers. School administrators often simply request a workshop in "math" or "computers" without prior planning with the potential participants or presenters.At best, the workshop may meet the needs of a few teachers; at worst, the teachers are unmotivated participants in a one-shot presentation by a mathematician or mathematics educator who is unfamiliar with the district's mathematics program.

Only a fraction of the necessary money and effort is devoted to inservice education. The result of this situation is reflected in the previous paragraphs. Schools have turned to a number of sources in attempting to provide inservice work for mathematics and science teachers. While recent federal programs such as the Education for Economic Security Act have provided some help, they are the proverbial "drop in the bucket." Economic and a variety of other factors have substantially reduced the role of university mathematics educators and mathematicians in inservice education programs. While there are many competent and knowledgeable mathematics educators outside the university, the effect of this recent trend in inservice education has often been a reduction of emphasis on mathematics content in favor of faddish programs or workshops designed by people with somewhat short-term goals.

IV. Current and Future Directions in Mathematics Education

Mathematics education has become increasingly complex. In addition to the traditional problems of curricular emphasis, instruction, and student achievement and the cyclical concerns of teacher training, shortages and qualifications, there are new issues associated with technology, computers and changing student populations.

Perhaps the most ubiquitous recent influence on all areas of mathematics education is the increased attention to learning with understanding and to improving higher order thinking abilities. This trend began with pleas from leaders in mathematics education for renewed emphasis on problem solving, and has been fueled by results from the Second and Third National Assessments of Educational Progress. Many mathematics educators recognized and predicted the effects of the "Back to Basics" and "Minimal Competency" movements on student achievement long before the 1983 national furor over a crisis in education (see, for example, the recommendations of the NACOME report, 1975; and the NCTM's Agenda for Action, 1980). The recent national reports seem to have begun to convince administrators, teachers, and the public that the focus on computation of the past decade has had serious consequences. Mathematics education is faced with the difficult task of reconstructing school mathematics, working with teachers and students who believe that mathematics consists entirely of a set of rules and algorithms for finding answers to textbook exercises. At the same time, we must deal with teacher shortages and with difficult choices in modernizing an outdated curriculum.

In this section, some of the most pressing concerns and the current approaches to them will be discussed. In order to relate these issues to NSF themes, they will be considered within the traditional categories: research, teacher preparation, and materials development.

Trends in Mathematics Education Research

The "Back to Basics" concerns of the late 1970s, and the federal funding that supported associated research programs had at least one positive outcome. In an attempt to learn how children developed computational skills and in order to explain why they made errors in computational algorithms, breakthroughs were made in understanding early mathematical thinking in children. Working somewhat independently at first, mathematics educators and cognitive psychologists came to some similar conclusions about children's abilities to invent and apply their own algorithms in solving problems that were sometimes beyond their expected capabilities. Perhaps equally important as the findings from this work was the development of a new research methodology based on careful, first-hand observations, interviews, and teaching experiments to determine how children think. This approach is very different from earlier mass-testing or controlled comparison methods for determining the extent and nature of mathematical learning or achievement. This methodology is now being used to investigate other areas of mathematics learning.

One consequence of recent research methodologies is a focus on the development and thinking of individual students and an appreciation for the complexity of mathematical knowledge development. It has become clear that children learn gradually, building more and more elaborate and accurate mental models and networks of mathematical concepts and skills. This view is much different from earlier notions children master one concept or skill after the other, like stacking building blocks or filling file drawers. Similarly, teachers' knowledge of mathematics is structured and linked in unique ways that determine how effectively that knowledge is communicated. This view of learning and teaching has significant implications for instructional materials and teacher training. It seems clear, for example, that most textbooks are not written with this new view of learning in mind. Curriculum development and teacher education programs of the future must be more closely aligned with ideas of how students learn than they have been in the past.

At about the same time that some researchers were studying how students learn computational concepts, other "diehards" continued to study problem solving, even though it was not very popular in the schools or among textbook publishers. The research methodology involved asking students to "think aloud" while solving problems, in order to determine what strategies they could use and which ones they might learn through careful teaching experiments. Also, "expert" problem solvers were studied in order to understand what they did that might be different from "novices" who were younger or less able in problem solving. This work revealed a complex relationship among mathematical knowledge and problem solving ability. While a few general strategies can be taught, a great deal of well-integrated mathematical knowledge is needed in problem solving. Also, good problem solvers monitor their own progress, making decisions about proceeding or changing directions. This ability is developed through long practice in solving a variety of mathematical and applied problems. Again, this view is quite different from the usual approach of learning bits of mathematical content, then solving a few story "problems" at the end of the chapter.

Research aimed at understanding how children learn rational numbers, algebra, and geometry has applied similar methodologies. Generally, this work has found that students learn much differently from what many teachers expect. Mathematical knowledge, while it is in the early stages of being learned, is fragile and rule-bound, not effectively applied to problem situations. It is important that strong, concrete links be built that connect conceptual understanding with procedures and rules. Little of this type of teaching and learning occurs in the schools.

Much of the recent research in mathematics education, especially that which has developed a new view of the way children learn and apply mathematical knowledge, reflects strong influences by cognitive psychologists. Recently, active collaborations among mathematics educators and cognitive psychologists have produced powerful alliances which are effective in obtaining funding and in influencing directions in mathematics education. In fact, a few cognitive psychologists have become so well-identified with work in mathematics learning that they have become the leading spokespersons on policy and direction in mathematics education research.

One criticism that has been aimed at cognitive psychologists is that they tend to study the learning of existing school mathematics topics. The current school curriculum is computationally oriented and that is the area in which recent advances have been made. There is some question whether similiar theories or approaches will extend to more advanced or conceptually rich mathematical content. Lacking a background in mathematics, some cognitive psychologists may not have a broad enough perspective to identify and study these concepts in the proper mathematical context.

Table 5. Number of SEE Research and Advanced Technology Awards for 1985

	Mathematics	Total	% Math
Research in Teaching & Learning	10	15	66.7
Applications of Advanced Technologies	8	21	38.1
Totals	18	36*	50.0

*Includes 7 Multidisciplinary awards.
Source: Unpublished NSF/SEE summary of 1985 awards.

It seems critical that mathematicians become involved more closely in learning research. Recent work has underlined the importance of mathematical knowledge in higher order thinking. Also, the way mathematical knowledge is structured as it develops is critical for learning. As research moves beyond simple arithmetic and algebraic concepts, mathematicians can help to extend these ideas to advanced topics. Equally important is the need for teachers' mathematical knowledge to be developed fully. Mathematicians who are involved in university courses for teachers must be aware of the results and implications of learning research. A partnership among mathematics educators, mathematicians, and cognitive psychologists is necessary for making progress in the future.

Trends in Teacher Education

Very little has changed in the past 30 years in the way teachers are trained. Recent emergency certification and teacher retraining programs, many of which have mathematics teachers as a primary focus, have actually done little more than speed up or shorten the traditional process of providing some combination of mathematics content and pedogogy, interspersed with or followed by a supervised practice teaching experience. The reforms in many states deal primarily with testing and assessing fairly low-level teacher knowledge and do little to affect teacher education programs. Even the recommendations of the Carnegie Forum and the Holmes Committee would change mainly the sequence of teacher education programs rather than their structure, content, or approach. For example, students would learn mathematics as undergraduates and pedagogy as graduate students. This approach completely separates teachers' mathematics learning from pedagogical concerns.

Relatively little research effort has been expended on mathematics teacher education. The major funding efforts by the Education Department in supporting R&D Centers for teacher education have studied generic teaching tasks such as effective questioning and classroom management. While some useful results about effective teaching have come from this work, only recently have the researchers begun to recognize that content is central to the teaching process.

Recent work has used case studies, interviews, and observational approaches to study mathematics teachers and teaching. This research has found a complex interplay between a teacher's mathematical knowledge and the choices that are made in selecting examples, in developing explanations, and in providing learning activities for students on a particular mathematics topic. In addition, a teacher's attitudes and beliefs about the nature of mathematics has a significant influence on classroom performance. This research is in an exploratory stage, making attempts to identify and catalog the relationships between teacher knowledge and attitudes, and their impact on instructional effectiveness and student learning.

Table 6. Number of SEE Teacher Preparation and Enhancement Awards for 1985

	Mathematics	Total	% Math
Teacher Preparation	5	27	18.5
Local & Regional Teacher Development	7	73	9.6
Leadership Activities for Precollege Teachers	2	40	5.0
Science and Mathematics Education Networks	1	9	11.1
Totals	15	149*	10.0

*Includes 68 Multidisciplinary awards.
Source: Unpublished NSF/SEE summary of 1985 awards.

Even though more research must be done, it seems clear that the present approaches to teacher preparation are inappropriate. Mathematics courses are taught with little thought about how they might effectively structure a future teacher's knowledge. A calculus course for an engineer or even for a future PhD mathematician many not be the most effective one for a future teacher high school mathematics teacher. Few secondary mathematics teachers emerge from a major in mathematics with a clear idea of the essential concepts and how they relate to one another. They have an even poorer idea of how these essential concepts are reflected in the K-12 mathematics and science curriculum. The small amount of mathematics that elementary teachers study is necessarily little more than a review of K-8 arithmetic. This narrow view of mathematics does not include applications of even the simplest arithmetic concepts to the natural and social sciences. Very few elementary teachers have been introduced to more advanced or fundamental notions of the mathematics that most of their students will eventually study. The mathematics preparation of teachers is perhaps the most overlooked and critical factor in all of mathematics education. The problem continues to exist primarily due to the gap between the mathematics and education communities.

Trends in Curriculum Development

After a decade of inactivity, mathematics curriculum development is once again coming to life. Much of this effort appears to be in response to the pressures to modernize the curriculum in the light of computers and other technology. While none of the work is on the same scale as the projects of the 1960s, two major privately-funded groups (WICAT and University of Chicago/Amoco) are multi-million dollar efforts which are sure to have significant impact. Recent NSF materials development programs have included special calls for proposals which would develop prototype elementary school mathematics materials.

In addition to the emphasis on computers, these projects include attention to higher order thinking and problem solving, to applications in mathematics, and to "new" topics such as probability and statistics. Some special attention is also being directed to processes, topics, and skills seen as being important in the future. Examples of these include estimation, mental computation, graphing, and measurement. Finally, some of the projects integrate the implications from recent learning research into the materials. Attempts are made to build more carefully on students' intuitive knowledge and to tie understanding and procedural knowledge together more effectively.

At least two major projects have significant input or leadership from mathematicians. One of these is the University of Chicago School Mathematics Project which is directed by a mathematician and has as its principal writers mathematics educators who were trained as mathematicians. Another major project dealing with curriculum in mathematics and science is the AAAS Project 2061. This long-term effort aimed at defining, developing, and implementing curriculum guidelines for the 21st century involves panels of mathematicians, scientists, andd engineers in its first phase. Mathematicians are working to answer the question "What are the important ideas of mathematics that everyone should know and understand by the age of 18?" In the second and third phases, educators and administrators will work on teacher education and curriculum efforts to implement these ideas in the schools. This project has purposefully identified specific, and more or less separate roles for mathematicians and mathematics educators in the curriculum development and implementation process.

Table 7. Number of SEE Materials and Informal Science Education Awards for 1985

	Mathematics	Total	% Math Awards
Materials Development	12	33	36.4
Informal Science Education	1	15	6.7
Totals	13	48*	27.1

*Includes 17 Multidisciplinary awards.
Source: Unpublished NSF/SEE summary of 1985 awards.

The recent NSF calls for proposals in materials development have not attracted mathematicians, but have received responses from people involved in a variety of areas including local curriculum development, teacher education, computer work, research, and a few "oldtimers" who did curriculum work in the 1960s. Partly due to the focus on research over the past decade, and partly because there has been little attention to curriculum during that time, there are only a handful of mathematics educators with interest, training, and experience in curriculum work. The people attracted to this program seem more interested and capable in developing materials for innovative segments and mathematics topics at specific grade levels than in working on broad, comprehensive curricula. It is interesting to note that mathematicians are most heavily involved in major, broad-ranging projects, just as they were in the 1960s. The smaller, prototype development efforts with an emphasis on innovation and experimentation seem less attractive to mathematicians.

In the near future, multi-million dollar funding from federal agencies for curriculum projects does not appear to be realistic. Some efforts have been explored by NSF to develop cooperative projects with textbook publishers in order to extend the leverage of available funds. Direct involvement by mathematicians and scientists in this and other smaller scale curriculum efforts should be explored. It is also important to consider the role and training of mathematics educators in curriculum development. Since instructional materials are the most direct and significant influence on both teachers and students, this area requires thoughtful and effective policy.

V. Conclusions and Recommendations

The programs of the NSF Directorate for Science and Engineering Education have had a significant impact on mathematics education. Regular funding in support of a variety of programs produces "ripple effects" far beyond the actual results of the projects themselves. People are energized to write proposals, rethink approaches, adopt new materials and methods, and respond to research findings. All of this activity keeps the field alive and responsive to changing needs in mathematics teaching and learning.

In order for its programs to be maximally effective, the Directorate must not only recognize the current and future needs in mathematics and science education, but also recognize how the programs relate to the professional lives of the mathematicians and mathematics educators who will develop and direct them. The most successful programs that have come from SEE have been those which responded to both of these requirements at once. Some past successes seem to have been a result of propitious timing. However, future policies must be come from careful planning based upon a clear and accurate assessment of goals and who can accomplish them. In the following section, some recommendations are made for SEE policy and action. The first set of recommendations deal with general concerns. The others are summarized according to the major program areas of materials development, research, and teacher preparation.

General Policies

Attention to mathematics education at SEE has varied. Competing for limited funds, mathematics must attempt to hold its own with the other sciences and engineering. Even the name of the Directorate does not reflect the place and importance of mathematics. Coincident with the variations in emphasis on mathematics has been the composition of the rotational staff at SEE. Over the years, there has often been at most one mathematics education rotator. Sometimes, that role has been filled by a mathematician with little experience or contact with precollege education or research. The first year for such a person is often spent learning who the leaders in mathematics education are and acquiring a familiarity with what is going on in the field. Proper balance in programs for mathematics education and an awareness of developments in the field can be improved by adopting or strengthening the following policies and practices:

o The name of the Directorate should be changed to the Directorate for Science, Mathematics, and Engineering Education.

o The Assistant Director for the Directorate should be a leading mathematics or science educator with a strong background in mathematics or science or a mathematician or scientist with a strong background and substantial experience in precollege education.

o The Directorate should publish an annual plan for future program development and emphasis. The plan would assess needs and opportunities in the coming two or three years and invite comments from the field.

o At least one mathematics educator should be a member of the SEE Advisory Committee.

o Both mathematics educators and mathematicians should be agressively recruited as rotators. A balance should be maintained in the numbers of these two groups. Appropriate NCTM committees and other leaders in mathematics education should be consulted about qualifications. Research mathematicians are less likely to be able to judge the reputation or abilities of mathematics educators.

- o Within SEE Divisions, a mathematics educator or mathematician should be assigned as Director or Deputy Director of one of the two major divisions: Materials Development, Research and Informal Science Education or Teacher Preparation and Enhancement. They should be assigned as Program Directors or Associate Program Directors for each of the programs within both of these divisions.
- o A mathematics classroom teacher should be appointed to a yearly rotator assignment as Special Advisor to the Assistant Director.

Materials Development Initiatives

There are several important needs and opportunities in the area of materials development. Materials are needed which integrate current research knowledge about mathematics learning. Materials are needed which integrate new technologies. In addition, a clear idea or plan is needed on how materials development can be coordinated and integrated with the mathematics curriculum, since it seems unlikely and perhaps inappropriate that NSF fund comprehensive curriculum projects. Mathematicians and mathematics educators must be encouraged and supported in materials development efforts through projects which are consistent with their professional goals. These issues can be addressed through the following recommendations:

- o Materials development projects should have a research component to determine their effectiveness in producing student learning. This research would be more detailed and comprehensive than the usual evaluation of materials for their success in producing achievement and their ease of implementation by teachers.
- o Planning projects should be supported which produce outlines and directions for innovative content development. Interdisciplinary teams of mathematicians, mathematics educators, scientists and technologists should study the essential mathematics for inclusion in the curriculum.
- o Special incentive programs should be developed for schools which adopt or integrate new materials, through providing teacher workshops and consultant support by mathematicians and mathematics educators.
- o In addition to regular funding, a separate Fund for Materials Development should be established. Incentives would be provided for publishers to contribute to the Fund, and matching funds would come from NSF. The Fund would be administered by SEE with an advisory board of mathematicians, scientists, publishers, and educators.
- o The Applications of Advanced Technologies program should be broadened and coordinated with other materials

development programs. Projects to apply and integrate current technology should be focused on projects that involve mathematics educators as well as computer technologists.

- o Projects should be funded which explore successful strategies to implement and integrate new materials and technologies into the mathematics and science curricula.

Research Initiatives

Research in mathematics education has made some significant advances in the relatively short time that it has existed as a discipline. As with other disciplines, mathematics education research is most dependent upon funding from federal and other agencies. The NSF has been the main source of funding for research in mathematics education, and while other sources are available, it will continue to bear the major responsibility for this support. It is critical, therefore, that a continual and balanced program of research support be a part of SEE policy. The effect of impulsive starts and stops, rapid changes in emphasis and direction, and variations in administrative support of research have extremely negative effects. Since practical outcomes are expected to take time to develop, research must be sustained in order to be effective. The following recommendations are made for maintaining a balanced, sustained research effort:

- o Research in mathematics and science education should be given Division status in the Directorate, rather than being a program within a division. An experienced mathematics or science education researcher should be assigned as Director or Deputy Director of the division.
- o A balanced program of projects should be supported which include major centers, small teams, and individual researchers.
- o A balanced program of projects should be supported to include research on teaching, learning, and materials.
- o A balanced program of research focused on single subjects or topics as well as on interdisciplinary work should be supported.
- o Projects should be supported which encourage colleagial interchange, group efforts, and apprenticeship of younger researchers. It is especially important that researchers in mathematics, science, and social science education communicate and cooperate in projects.
- o Projects should focus on manageable, yet important content areas of teaching and learning. When possible, several projects with different perspectives should focus on an important area.
- o Agenda setting and synthesis activities and conferences should be a regular program effort. These efforts should include researchers, mathematicians, scientists, teachers, and publishers.
- o Workshops should be supported in which mathematicians,

teachers, and school administrators study recent results and methods of mathematics and science education research.

Teacher Preparation Initiatives

The preparation, certification, and assessment of teachers is likely to remain at the center of attention in education for the next several years. Policies and recommendations being developed now by national panels and study groups will find their way into requests and proposals for funding by NSF and other agencies. It is important that SEE anticipate and develop its own policies and priorities for science and mathematics teacher preparation. While SEE will surely want to be in step with current national directions, there are specific issues that apply to the preparation of mathematics and science teachers.

As was pointed out earlier in this paper, the content preparation of mathematics teachers is in need of drastic reexamination and repair. The best cooperative efforts of mathematicians and mathematics educators, supported by funding from NSF and other agencies, must be marshalled in order to solve this problem. The teacher preparation program at SEE should make this issue its priority in the next few years. The following recommendations are made for putting this program into action, as well as for continuing appropriate attention to other areas:

- o The Teacher Preparation Program within the Division of Teacher Preparation and Enhancement should be strengthened. A leading mathematics or science teacher educator should be assigned on a long-term basis as Program Director.
- o A series of conferences and other activities should be initiated to explore approaches to mathematics content preparation. These programs should involve mathematicians, mathematics educators, and deans and department chairpersons of mathematics and education.
- o Projects should be supported which examine the alignment of university mathematics courses with the current school mathematics curriculum, and with new curriculum projects, for coverage, emphasis, and philosophy.
- o The development of new mathematics and science courses for teacher preparation should be supported. The emphasis for these courses should be on mathematical processes and how they relate to content, structure, and formalism.
- o New structures of teacher preparation should be examined which integrate university work, responsible school-based practice, and experience with mathematics applications in science, industry and business. Rather than separating mathematics coursework and applications from teaching practice, it should be further integrated.
- o Programs for the involvement of mathematicians and mathematics educators in inservice work should be explored.
- o States, regional school districts, and professional associations should be supported in developing standards and prototypes for inservice mathematics and science courses that are accessible to teachers throughout the country.

Summary

Although this is a fairly long and somewhat ambitious list of recommendations, it represents the range of serious issues that confront mathematics and science education at the present time. This is a critical time of potential for reform and meaningful change. It is important that NSF recognize not only the overall opportunities brought about by the recent pressures for change, but also the specific problems within mathematics and science education. NSF has had an historical role as the major source for supporting programs that had significant impacts on American science and mathematics education. In responding to the many current needs, SEE must be strengthened and its policies directed so that they are closely in tune with the needs of the field and of the mathematicians and mathematics educators who carry out the work. Mathematics education must be maintained as a fundamental area of support, in recognition of its importance as a basic literacy subject, a foundation for study in the sciences and engineering, and as a rapidly growing discipline of study.

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ASSESSMENT OF INITIATIVES AVAILABLE TO NSF TO ADDRESS PROBLEMS AND OPPORTUNITIES IN SCIENCE EDUCATION

Computer Science Education at the Precollege Level

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1. Introduction: Motivation and Goals

SRI International has been funded to conduct an assessment of the Science and Engineering Education Directorate (SEE) within the National Science Foundation (NSF). As a part of their report, we have been asked to write a statement that focuses specifically on computer science at the *precollege* level. In this report, then, we attempt to address the following question: *what types of strategies could SEE support in order to most effectively and most beneficially affect the teaching of computer science at the precollege level?*

In the past, the science education directorate at NSF has played a major role in getting computer science into the precollege classrooms. In particular, they were the prime movers behind BASIC becoming the de facto standard for non-professional computing. One of their basic motivations, as we read it, is the same now as it was then: to make available to schools the tools that scientists on the cutting edge of science use in their work. For example, FORTRAN was a key tool for science research in the 60's. Unfortunately, it was too unwieldy for school children. Hence, the education directorate at NSF supported the development of BASIC. Similarly, LOGO development was supported by the education directorate at NSF: LOGO presented another opportunity for expanding our ideas of computing and mathematics in particular, and for expanding our ideas of thinking in general. Moreover, LOGO was purposely designed to be accessible to elementary school children. Currently, NSF/SEE continues to lead in the development of new ways to teach and learn using computing. In particular, the Advanced Applications of Technology Program (AATP) within NSF/SEE supports highly innovative research in exploring the use of cutting edge technology and science --- the opportunities that are becoming available --- in precollege education. Thus, we feel that NSF/SEE is doing the right sorts of activities in the computing area. Our intent in this report, then, is not to suggest a redesign of their efforts. Rather, our intent is to provide a focused discussion on (1) the goals of computer science education at the precollege level, and (2) suggestions for specific issues and areas that need continued and/or new research support.

The basic stance taken in this report is this: it is not a question of *whether* computer science needs to be included in the precollege curriculum, but rather, it is only a question of *what* needs to be included. Quite frankly, this stance echoes that taken in essentially all the reports on education in this country that have recently been published. For example, the Nation at Risk Report refers to computing as "a new basic." Children *are* taking computing courses en masse;

children *are* finding it *fun* to use the computer. Thus, there is an opportunity here for education: the computer provides a medium that is, by and large, intrinsically motivating to students and it gives them a most powerful and flexible tool. While there are naysayers with respect to the use of technology in education, their arguments continue to lack much force: computing is here to stay, and it *has* been shown to be educationally useful; we shouldn't look "backwards to the basics, but rather forward." The story told by the educational reports, and mirrored in this one, is this: to ignore computer science in precollege education is to risk the future of our children. They, more almost then we, need to understand and use computers and computer science.

One final issue before we get into the body of the report: the charter that we were given was to look at the teaching of computer science *per se*, as opposed to the more general topic of incorporating computing into the precollege classroom.[1] While in principle that separation sounds reasonable, the reality is different: one doesn't create a curriculum in a vacuum. Rather, in order to have a sharp idea of what teaching computer science at the precollege level should be about, we need to examine where computing is going in general, and how people will be using computing. Based on this sort of assessment, we are then in a position to identify specific computer science education issues that address the real needs of computing users. Thus, this report will deal with computer science education *per se*, but from the perspective of where computing appears to be heading.

The organization of this document is as follows: The first question that arises is, what *is* computer science? While there is no agreed upon definition of the content area called "computer science," in Section 2 we outline the broad areas that can come under that heading. Next, in Section 3, we identify the reasons that have been given for teaching computer science at the precollege level. Based on our sense of "where computing is going" and on how non-professionals will use computers (Section 4), these goals will be re-examined in Section 5. Finally, in Section 6, for the goals that still should be pursued, we identify (1) the research questions that need to be explored, and identify (2) the role that NSF/SEE might play in pursuing those research questions (Section 6).

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[1] This more general topic is treated in great length in the main SRI report.

2. What is Computer Science?

While it would make things tidy if there were a simple answer to this question, the reality is: there is no accepted, well-defined content area called "computer science." A better question to ask, i.e., one for which more agreement can be had, is: what are some core subject areas within computer science? They are: (1) theoretical issues (e.g., algorithm analysis, computability) (2) programming languages, (3) operating systems, (4) artificial intelligence, (5) applications (e.g., database systems). Within each of these areas, there is a well-developed set of core concepts that are taught. For example, in theoretical computer science, one learns about complexity and computability issues: how fast can a subtraction algorithm be? what types of calculations could take an infinite amount of time to compute?

Computer science topics can be studied in their own right. For example, much as a *learned* 19th century person needed to understand the basic concepts of geometry, it might be argued that a learned 20th century person needs to have some appreciation for basic issues in "computability." This line of argument goes significantly beyond the scope of this report, however. Rather, we take a more pragmatic view of what computer science education should be about: as we argue below, at the precollege level, computer science education needs to be in service of the larger educational need -- making students into effective problem solvers. Should they decide to become computer professionals, students will have time enough in college to tackle the corpus of knowledge called computer science. The key, then, is to identify the set of concepts within that corpus that can most profitably be taught at the precollege level. In determining this set of concepts, one needs to take into consideration valid, educational goals. It is precisely these goals that are the subject of the next section.

In today's precollege computer science courses, students are, by and large, simply taught a programming language. Moreover, students tend to have only a minimal amount of hands-on experience doing programming. For example, students taking an introductory college-level computer science course spend on the average between 8 and 10 hours per week hands-on, and end the semester writing a final program of between 5-10 pages of code. In contrast, students in precollege courses at best spend 1 hour per week hands-on, and end up writing a final program of at best 2 pages of code. The difference in time and content need not be one of "intellectual development." High school students, if given the opportunity, would find a typical introductory college programming course very accessible. Thus, under no stretch of the imagination can what is being taught today as computer science at the precollege level really count as computer science *per se*, nor can it be viewed as helping students become effective problem solvers. The content is too weak, and the exposure to minimal. Thus, if we take seriously the notion of teaching computer science at the precollege level, we need to accept the fact that a more comprehensive and intensive program of study will need to be developed. This is an important observation in light of the recommendations made in the national reports on education: we need to redesign what is being taught in the name of computer science at the precollege level, if we are to provide students with the necessary knowledge and tools to keep them functioning in our technologically-oriented society.

3. Why Teach Computer Science at the Precollege Level?

The students' school day is already jam packed with subjects. If we advocate that even some aspects of computer science be taught, we are really saying that some other subject must be cut short in order to make sufficient time available. While subjects such as geometry, geography, etc. were considered "untouchable" --- *of course* they should be taught ---- educators are beginning to re-evaulate the entire curriculum. In effect, subjects are vying for a place in the school day.

Is there, then, any special reason why we should teach computer science? Below we identify several goals that have been put forth to justify the teaching of computer science at the precollege level.

- **GOAL 1:** *Computer Literacy Provide students with a working understanding of computers and computing.* We need to teach students "computer literacy" because computers are becoming increasingly more pervasive in our society; a responsible citizen will need to have some awareness of computers in order to make informed decisions. This rationale has some merit, though detractors say: why don't we teach telephone literacy, etc. The point is that computers are playing decision-making roles, whereas telephones haven't and won't.

- **GOAL 2:** *Transfer of Problem Solving Skills Enable students to become better general problem solvers by teaching them programming.* Claims have been made that by learning to program one really learns general problem solving skills. Much of the commitment to LOGO was due to this type of claim.

- **GOAL 3:** *Computer Science as a Problem Solving Tool Provide students with the skills to use computers to solve problems.* Computer science is like mathematics, in that mathematics is used to solve problems in many subject areas. That is, whether someone is learning about physics or geography, the computer will be used as a problem-solving tool, and thus students need to learn some basic computer science notions --- much as they learn basic mathematical notions.

- **GOAL 4:** *Prepare Professional Scientists* *Expose students to the world of science in general, and computer science in particular, and provide them with some preliminary training.* The science profession needs highly trained --- and motivated --- individuals. Providing early, positive experiences with science in general, and computing in particular, should build a basis from which students can go on to master more explicitly the technical content of a scientific discipline.

Note that we have here only stated the goals, without any evaluation of their validity. After a discussion of the direction in which computing is heading, these goals will be re-examined in Section 5: what goals are still worth pursuing? are there any other goals worth pursuing?

4. How Non-professional Computer Scientists Will Use Computers --- and What They Will Need To Know.

It does not take a crystal ball to see the following major trend in the use of computers by "non-computing-professionals" (i.e., not professional programmers, but rather, experts in a domain, e.g., accounting, meteorology, medicine, teaching): *computers are being used to mediate actions between a user and the world.* For example, in the past pilots flew planes directly; however, now "fly by wire," where a computer is an integral part of the flying process, are becoming more popular. A more down to earth example: managers make decisions based on limited information; now, with the coming of databases, managers can glean all sorts of key information from a database in order to make a more informed decision. And one further example: business spreadsheets are a major form of communication. Now, with spreadsheet languages such as LOTUS 1-2-3, businessmen, accountants, etc. can conveniently and powerfully use spreadsheets in their everyday activities. In effect, "special-purpose, domain-specific programming languages" are being developed;[2] these languages are used by domain specialists, not programming specialists, and enable the domain specialist to solve domain related problems. We see no reason why this trend will abate; computers can be made into powerful tools that decision-makers need in their everyday activities.

Given the increasing pervasiveness of computers in every aspect of society, the next question to

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[2] To point out just a few domain-specific languages already on the market: algebraic symbol manipulation languages for engineers (e.g., muMath), spreadsheet languages (e.g, LOTUS) for businessmen, graphics packages for artists and designers.

ask is: how will users interact with the computers in order to pursue a user's goals? There are two views on this question:

- *The No Programming View:* Packages (e.g., word processors, database systems) with a prespecified set of commands can be designed for a user in an area (e.g., accounting, meteorology). These packages will give the user all the functionality that is and will be needed. A user gets access to the information s/he needs by simply selecting from the provided commands.

- *The Programming View:* Users will always be pushing the limits of a given software package: they will want -- nay, need -- to combine the given primitive operations in the package in ways that were unpredicted by the software designers and they will want -- nay, need [illegible]ing together sequences of these combinations.

If *The No Programming View* is correct, then users will not need to know anything deep about computer science: a pilot flying a 747 doesn't need to know how to program, even though s/he is flying only a model of the plane. In contrast, if *The Programming View* is correct, then users will need to know concepts from computer science: e.g., they will need to know what is and is not computable given what resources, know how to decompose a problem into a set of executable subcomponents, know how to represent data, know how to debug their solutions, etc.

Which view is more probable, more realistic? Time and time again in computing's, albeit short, history, we have seen initially "complete packages" opened up so that users can have new and different functionality: give users 10 commands, and immediately they want an 11th, or a different set of 10, or they want to compose sequences of the commands. Thus, history favors the *The Programming View:*[3] while individuals will not be using BASIC or Pascal, they will still be programming --- programming in domain-specific, applications-oriented languages.[4]

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[3] For the sake of contrast and emphasis we are pitting these two positions against each other. Clearly, however, this is not a black-or-white, this-to-the-exclusion-of-the-other situation: for some applications the *The No Programming View* will surely be appropriate. Nonetheless, it is our sense that for most situations, *The Programming View* will be the most appropriate.

[4] There is considerable debate in the computing community as to the design of these applications-oriented languages, e.g., should the languages be "declarative," enabling the user to specify only *what* s/he wants done, or should the languages have a "procedural" component, enabling/requiring the user to specify *how* to achieve the desired goals. Or, what is the role of graphics in programming (so-called "visual programming languages")? Frankly, it is too early to make any definitive statement on these sorts of issues: much more experience with applications-oriented languages is needed. While these issues are debated, the baseline for the debate has acceptance: computing is going in the direction of applications-oriented languages.

The position that people will need to program, albeit in applications-oriented, special-purpose languages, impacts directly on the goals of teaching computing at precollege level, and by implication, what SEE might best do to facilitate those goals. What, then, should be the goals of teaching computer science at the precollege level? The next section deals with this question.

5. What Goals Should Be Pursued: A Re-Examination

In light of the above observations, let us return to the educational goals identified earlier and see if they still should be counted as valid, pursuable goals.[5]

- **GOAL 1:** *Computer Literacy Provide students with a working understanding of computers and computing.* This goal was actively pursued through NSF/SEE support in the late 70's, early 80's. While hard data is not yet available, anecdotal evidence from students going on to college suggests that students are acquiring an understanding of computing during their precollege education. In particular, it is the sense of many teaching college level introductory computer science courses that *lately* students coming into college already know quite a bit about computing. Moreover, whereas in the early 80's a major portion of those enrolled in introductory college level computer science courses said, at the start of the course, that they had "a fear of technology, a dislike of technology --- especially computers" --- students *now* do not seem to be nearly as fearful.

  Thus, should further resources be pumped into the goal of attaining "computer literacy" at the precollege level? Given the above observations, a reasonable answer would be: no. Computer literacy programs, sponsored in large measure by the education directorate at NSF, are in place, and continue to be put in place; moreover, they seem to be successful. As SEE is in fact now doing, resources need to be redeployed in favor of new opportunities in computing.

- **GOAL 2:** *Transfer of Problem Solving Skills Enable students to become better general problem solvers by teaching them programming.* This goal tacitly assumes that the skills learned in programming *do* transfer. Empirical studies have been conducted that seek to assess this claim. As most transfer studies in education turn out, these studies too typically show no transfer. However, care must be taken in interpreting the negative results: for example, it is just not clear that students in the studies even learned programming, so it is not fair to expect non-existent skills to transfer. Moreover, the transfer studies typically did not focus on any specific programming/problem solving skill. Thus, definitive results on this goal are just not available yet.

  The importance of this goal will become even more paramount, given our discussion of where computing is going: if *The Programming View* is correct, then more and

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[5] Note that here we will restrict ourselves to identifying *what* goals are worth pursuing: in the next section (Section 6) we address the question of *how* they might best be pursued.

more students will be programming in the context of specific applications, and thus the potential for benefiting from programming is even more present. Moreover, for many students programming is a "hook" into learning about problem solving: there is something intrinsically motivating about programming and thus, if the problem solving skills do transfer from programming, it makes good sense to teach problem solving in the context of a subject that students find exciting and fun.

Thus, the goal of realizing transfer from programming to problem solving still merits pursuit. What is needed, though, is more focused research on the underlying claims; we will describe such a research effort in Section 6.

- **GOAL 3:** *Computer Science as a Problem Solving Tool* *Provide students with the skills to use computers to solve problems.* To our thinking, the biggest payoff for teaching computer science concepts in the precollege curriculum lies in the area of "computer science as a tool, in the same way that mathematics is a tool." As we argued above, the computer will be the tool that allows professionals from all walks of life to better perform on the job. Note, that we are being pulled in this direction, anyhow: the development of applications-oriented, problem-specific programming languages, and the hardware on which to run them, is and will continue to be developed. Thus, in addition to the importance and validity of this goal, SEE can piggyback on software and hardware developments that are beginning to take place now. For example, new, higher-powered personal workstations are daily being released. In sum, this goal deserves to be pursued --- *needs* to be pursued.

- **GOAL 4:** *Prepare Professional Scientists* *Expose students to the world of science in general, and computer science in particular, and provide them with some preliminary training.* This goal is still an important one; there is a thirst for scientists and computing professionals that will not diminish in the near term. Exposure to the excitement and wonder of science in general, and computing in particular at the precollege level is unquestionably appropriate.

In addition to the above goals, there is another goal that needs to be pursued, which only now is gaining recognition.

- **GOAL 5:** *Experience in Design* *Provide students with the skills necessary to synthesize artifacts.* Today, the precollege curriculum emphasizes *analysis* skills: skills that enable a student to analyze "what is." However, students --- and people --- constantly need to create artifacts to enable them to achieve their goals. Whether a person is constructing a plan for getting from point x to point y, or attempting to put an eyelet hook on a door, one needs *synthesis skills* in order to create an effective procedure for action. In effect, we need to teach students how to carry out *design*. We are here arguing that *all* students need to learn at least rudimentary design skills -- not just those that are going into a specific design discipline (e.g., engineering). In order to function effectively in the world, people need to constantly create "agents" that facilitate their actions.

By teaching programming, one teaches *synthesis skills*, as well as analysis skills: a program is an artifact, albeit a "soft" one, that enables us to achieve the ends we desire. Moreover, if our reading of the future is accurate -- that computers will be mediating more and more of our actions -- students will need to learn how to design, i.e. program, domain-specific agents in order to be effective problem solvers. Thus, we add this goal to the list of valuable, pursuable goals: teaching students synthesis skills by teaching them programming.

The next section provides some specific guidelines on how the above goals should be pursued.

6. How Should These Goals Be Pursued: Identifying the Tasks and the Actors

Given that the goals in the previous section appear to be valid ones to pursue, how might they be advanced? Below we identify a number of tasks that need to be undertaken in order to facilitate the realization of the aforementioned goals. In addition, we will identify the institutions that are in the best position to undertake the tasks we identify.

- **GOAL 2:** *Transfer of Problem Solving Skills* *Enable students to become better general problem solvers by teaching them programming.* In order to most effectively pursue this goal, research needs to be conducted into (1) identifying the skills that are being taught in programming, (2) determining whether or not these skills transfer. In fact, within the Applications of Advanced Technology Program of SEE/NSF, one of the four areas of concentration is precisely this topic.[6] This is a high payoff --- and high risk --- area: if it turns out that specific problem solving skills learned in programming do transfer, then, since programming does capture the interest of students (though, of course, not all), then there could be a big win in teaching programming.

  There is a very practical goal that will be achieved if some answers on this topic can be obtained. A main claim of the proponents of teaching programming is the transfer claim. There is a lot of emotion surrounding this issue. Moreover, significant resources are expended by schools and parents in the hope that they too can tap into this "Rosetta Stone." Some hard answers on this topic would help to provide educators and parents with information to make a more informed judgement on this topic. For example, if it were found that no skills economically transferred from programming, then the argument to teach programming would be greatly diminished. In turn, the resources freed up from not teaching programming could then be applied to some other area of computing. Thus, the topic of skill transfer from programming raises exciting, important scientific questions, as well as providing key input on the practical question of the role of programming in precollege curriculum.

  Should NSF be the agency to fund this research? Reasonably, one could argue that a

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[6] For example, Soloway at Yale [10], Linn at UC Berkeley [6], and Mayer at UC Santa Barbara [7] are investigating the cognitive consequences of learning to program under AATP support.

private foundation, such as Sloan, Carnegie, etc. could take on such a funding initiative. However, these agencies do not typically have the resources to fund a possibly lengthy research initiative; it will take approximately 5 years before definitive findings can be had on this topic. Also, this topic would most likely not be a high priority one for DOD funding agencies (e.g., ARI, ONR); the results from this research would not have a big impact on their *training* (as opposed to *education*) programs. NSF, with its mandate to focus on public education could do the country a major service by supporting research that provides results in this key area.

In sum, then, we recommend that AATP/SEE continue their support of research in this important area.

- **GOAL 3:** *Computer Science as a Problem Solving Tool Provide students with the skills to use computers to solve problems.* In what follows we will identify a number of tasks that need to be undertaken in order to realize this goal. Since we feel that this goal is a critical one for education, we will go to some length in discussing how and why the process should proceed. If children in school are going to keep pace with the tools --- and the learning that goes with the use of those tools --- available outside the classroom, then a program of the sort outlined below needs to be actively pursued.

  - *TASK: Develop exemplars of problem specific programming languages and integrate them into the curriculum.*

    In order to explore the effectiveness of problem-specific, applications-oriented programming languages, a number need to be built, incorporated into the school, and evaluated. In fact, several projects of this sort are currently being funded by AATP.[7] Undoubtably, commercial enterprises will continue to develop such languages (e.g, spreadsheets); however, their motivation will not be to further education, but rather, their motivation will be an economic one. Moreover, commercial enterprises will not be concerned with integrating their tools into a curriculum, and with carrying out a *scientifically* motivated evaluation. Thus, NSF, with its mandate to support public education, is the

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[7] It would not be a distortion to view the following projects, which are supported by the AATP, as investigating the development of applications-oriented programming languages: Hawkins [4], at Bank Street College, and Larkin [5] at Carnegie-Mellon University, are developing software environments for students exploring physics; Swets [12], at BBN, is developing a software environment for students studying statistics; Roberts [9], at Lesley College, is developing a software environment for students studying algebra.

first choice for supporting prototype development with a clear education focus.[8]

Note, however, that SEE can piggyback on developments in the commercial sector: commercial ventures may produce software that has utility in the classroom. For example, the new class of algebraic symbol manipulators (e.g., [MuMATH, REDUCE]), is a prime example. While the target population for these systems was not originally pre-college education, but rather practicing engineers, they might be nonetheless applicable to an educational setting. Thus, rather than developing such problem-specific, programming languages from scratch, researchers may be able to use these products as prototypes, and move directly into the integration and evaluation phases.

In sum, then, SEE needs to continue funding the development, deployment, and evaluation of exemplars of problem-specific programming environments. As is typical of technological innovations, the research base upon which to generalize and more accurately assess the impact of this type of innovation will take approximately 5-7 years to build.

- *TASK: Develop tools for building problem specific languages; ultimately we would like a user to be able to interactively construct his/her own problem specific programming language.*

While the cost involved in developing these problem-specific languages will initially be high, we need to develop techniques for aiding users in constructing these languages. Again, commercial enterprises will also be working on this problem. However, the science underlying these tools is still in no way well-understood. Leverage in funding this research can be gained, however, by noting that this topic will also be funded by others within NSF, most notably the Information, Science & Technology Division and the Computer Science Division. While their charters do not force them into focusing, say, on tools for a 12-year old in geography, their research will certainly complement that undertaken by SEE.

In addition to the basic computing issues involved in developing tools of this

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[8] The cost involved in doing this research is high: the medium — computers — can be costly. We certainly don't want to limit research to hardware widely available (so-called first generation personal computers, e.g., Apple II, Commodore 64). The high-powered personal workstations that are just becoming available are most suitable for doing research in this area: to provide a supportive user environment requires considerable computational power (memory and speed) as well as high-quality graphics. Thus, the issue of cost of this research must be faced squarely: there is no getting around the problem that doing research on computing environments of the future will be costly to conduct now. Waiting for those environments is dangerous: when they come, we won't know what to do with them. Frankly, the impact of the development of personal computers (e.g., Apples, Commodores, Radio Shacks), took the education world by surprise: only in the last few years has even marginally good educational software appeared. Thus, we need to be prepared for high-quality computing environments that will soon be relatively inexpensive.

sort, there are many cognitive issues that also need to be explored: what is the match of language primitives, problem type, and human problem solving strategies? These issues also play themselves out in problems of designing interfaces for the tools. Again, research is already being supported by a wide range of agencies on these topics. Nonetheless, an effort within SEE that focuses specifically on the needs of students is needed.[9]

In sum, then, developing tools to assist users in developing their own problem-specific languages should receive SEE support. However, in comparison to the above task, we see the funding by SEE for this task to be minimal: a few projects focused quite clearly on the needs of precollege students.

- *TASK: Re design curriculum to incorporate the new tool problem specific programming languages.*

There is a general consensus in science and mathematics education that one wants to teach students to do, for example, mathematics as opposed to simply learning about mathematics. For example, Papert [8] argued that in using LOGO to teach mathematical concepts, students would be put in a more active, discovery role. While the problems with actually achieving this goal have become evident, it is still (1) a valuable goal, and (2) one that programming in principle can help to achieve. That is, in writing computer programs, be they be in a spreadsheet language, LOGO, BASIC, or some problem-specific language, students must actively confront some input, and carry out some sort of analysis in order to achieve a goal. In effect, we are seeking to teach the students to be researchers, developers of knowledge, as opposed to just consumers of facts. Thus, in order to take full advantage of the potential of this style of instruction, curricula need to be redefined: current curricula does not foster this interactive style of learning.

For a whole host of good reasons, piecemeal introduction of this sort of technology into the curriculum may not result in appreciable educational gains. For example, if students see the technology in only one subject area, they may well not see the import of the technology, nor may they even learn how to use it effectively. In order to become active learners, students will need to adopt a mind-set different from the one they have now. Correspondingly, teachers need to view these problem-specific programming languages as integral parts of a subject matter, and not as an "add-on." Thus, curriculum development -- and its deployment -- present a serious problem.

SEE has funded curriculum development in the past. Moreover, SEE has

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[9] A project that addresses this area is already being funded by the Advanced Technology Program NSF/SEE. In particular, Dr. Andrea diSessa [3] has been funded to investigate what the computin environment for third graders might be in the 1990's. He is developing a programming language, calle BOXER, which is a extensible language: students can either use the language constructs provided BOXER, or they can create their own.

supported focused initiatives that seek to integrate technology into an entire component of the science/math curriculum. Similarly, in developing curriculum for the technology identified here, we recommend that SEE should set up a focused initiative which seeks to incorporate this technology into all sub-areas of math and science in the precollege curriculum.

- *TASK: Develop new teaching strategies that capitalize on the power that students will have in using problem specific programming languages.*

A student actively pursuing a problem, alone or in concert with classmates, is drastically different from the current lecture mode of instruction. How should the classroom be organized? What is the role of the teacher in this learn-by-doing situation? Moreover, what are the strengths/weaknesses of "cooperative" learning --- where students work together on a problem. Computing will facilitate the interchange of information, and provide a ready environment for cooperative work. How will this style of learning effect teaching? the classroom? SEE needs to play a key role in this task also.

- *TASK: Identify what concepts from computer science need to be taught in order for students to effectively use problem specific programming languages.*

Clearly, the mainstream student does not need to conquer the computer science corpus. While some concepts clearly should be mastered, the specific curriculum is a moving target: until we have a better sense of how computing will be used, we won't be able to accurately pin down the computing concepts needed by the mainstream student. Thus, we suggest that more exemplars of problem-specific programming languages be developed and incorporated into the schools, before this task of identifying computer science concepts be undertaken.

- *TASK: How should we teach students about programming in these languages?*

As we mentioned earlier, present instruction in programming is painfully simplistic in its approach: teach syntax and semantics. However, we need to rethink what counts as programming, and thus what the students need to know, and how they should be taught. In supporting research on this topic, NSF/SEE can again benefit from the training courses that commercial ventures will develop to teach people their proprietary, problem-specific programming languages. However, commercial companies may not focus on a real issue that needs to be faced in an educational setting: students may well need to learn *several* problem-specific languages. What are the cost/benefits in this type of situation?

- *TASK: What do we teach teachers in schools of education to better prepare them to make use of problem specific programming languages?*

Last, but absolutely not least, is the issue of teacher training. Teaching teachers about problem-specific languages is a micro-example of the larger

> teacher training problem: (1) technology moves so fast that the computing environments on which teachers are trained in schools of education are not the ones that they will use in the classroom, 5, 10 years after they have finished school, (2) by and large teachers are not taught to be domain experts that develop knowledge; thus, it is hard for them to teach students to do research, to learn-by-doing, when their instruction has not included such learn-by-doing efforts.
>
> We do not think that a research effort directed at teaching teachers about problem-specific languages is the right approach. Rather, we need to face head-on the problems of teacher training with respect to all of technology, of which problem-specific languages is but a part. We feel that this topic is a particularly vexing one, and needs some clear, focused attention by SEE.

Given our sense of the importance of this goal, we have spent considerable time here identifying issues that need exploring. Clearly, considerable resources will need to be expended in order to pursue the above identified tasks to some successful closure. If resources are not forthcoming, we can foresee that education will most likely miss out on an incredibly powerful, problem-solving tool.

- **GOAL 4:** *Prepare Professional Scientists Expose students to the world of science in general, and computer science in particular, and provide them with some preliminary training.* Besides simply adding new courses[10] to the curriculum, how can this goal be furthered? It is our opinion that *not* doing anything special for luring and educating would-be professionals is an appropriate strategy: if even parts of Goals 3 and 5 are implemented, students will be exposed to a considerable amount of computing. Thus, those that may eventually go into computing as a profession, should have sufficient computing in their milieu to whet their appetites. Frankly, it is not even clear that is a good idea to have students specialize during precollege in computer science. Thus, we don't advise SEE to put any significant resources into this achieving this goal.

- **GOAL 5:** *Experience in Design - Provide students with the skills necessary to synthesize artifacts.* We could be teaching design now, with the current crop of programming languages; while the next generation of languages (e.g., diSesssa's work on BOXER) and technology (individual, high-performance workstations) would facilitate and enhance the activity, we have components in hand now to teach students how to carry out design. Moreover, it is not the case that we don't have any good ideas on what should be taught and how: there have recently been a number of books and papers on precisely this topic (e.g., [1, 11]). The issue is the development of curriculum materials that make this topic more readily available to teachers, who in turn can make these ideas available to students. Moreover, it is our sense that a concerted effort at developing those curriculum materials would (1) be a

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[10] Adding new, more specialized courses may not even be an option: a real question facing schools is the lack of qualified computer scientists willing and able to teach. Increasing course offerings may only exacerbate an already difficult situation.

short-term effort (2-3 years), and (2) not require excessive resources (an initiative comparable to that now being supported by SEE to facilitate the incorporation of advanced technology into the teaching of basic math skills). The output of such an initiative should be materials that can be distributed to schools.

We feel that this goal is a moderate risk/high payoff goal: the materials necessary to achieve this goal should be developable in the near-term, without expenditure of unreasonable resources; and, most importantly, the skills imparted to the students are critically important ones, though they are sadly not currently incorporated into the precollege curriculum in any coherent, systematic fashion.

A task that needs to be undertaken in essentially all the above projects is that of evaluation. Mentioning "evaluation" last is not meant to relegate it to second-class status. Rather, our view is that evaluation can provide critically important feedback to the developers and participants of an educational product: evaluation tells one "what to do next." Thus, as an integral part of the tasks outlined above, we strongly suggest that resources be explicitly set aside to carry out evaluations.

7. Concluding Remarks

The amount of effort and resources needed to pursue the goals identified in Section 6 is significant. In fact, it may seem out of proportion: afterall "computer science" is but one of the science and math areas that is vying for a spot in a student's school day. However, computing (and the corresponding notions from computer science) is fast becoming the "queen" of the sciences --- of problem-solving, in general --- and thus we need to explicitly deal with making it available to students at the earliest possible moment.

What is the status of research directed towards that goal? SEE, and more particularly the AATP, has already been funding research directed towards many of the goals identified in Section 6. Thus, we endorse the efforts of SEE and AATP at providing both direction and results on the key goals facing the realization of computing's promise in education. They have both led in creating new research directions, and been responsive to the needs and opportunities arising from the community. They are to be commended for providing a key rallying point for workers in the field.

Finally, what might happen if essentially *none* of the proposals for research identified here are accepted? What might happen if computing is viewed merely as another subject area, and thus relegated to a seat equivalent to say, geometry? The commercial sector will continue its push to incorporate computing into all possible areas; the marketplace's drive for that economic edge that comes from being able to know something and do something better than the competition will naturally result in the intertwining of computing in all phases of the workplace. And where will education be? Students won't be exposed to the latest, newest thinking and doing; students will still be learning to do cube roots via pencil-and-paper. E. Bloch, Director of NSF, recently talked about making sure that America keeps its competitive edge in the marketplace: research needs to bring out new ideas, some of which will eventually find their way into furthering the growth of America [2]. The marketplace has already decided that computing can provide that competitive edge. Educational institutions run a great risk by ignoring the explosion of computing: schools will be the dinosaurs and companies the latest, most adaptive creatures --- and who wants to be with the dinosaurs in the face of a changing world?

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PART FIVE:

STUDY APPROACH AND PROCEDURES

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STUDY APPROACH AND PROCEDURES

Introduction

In 1984, Congress included in NSF's appropriations bill (P.L. 98-371) a requirement for a contract "to develop a science education plan and management structure for the Foundation." As part of the response to this mandate, the Directorate for Science and Engineering Education (SEE) issued a request for proposals (RFP) for a project to "assess initiatives available to NSF to address the problems and opportunities in science education."* SRI submitted a proposal in response to that RFP, was awarded the contract, and began work in March 1986.

Scope of the Study

NSF did not commission a project "to develop a science education plan and management structure for the Foundation." Rather, the project was to assess the advantages and disadvantages of NSF's current initiatives and of alternative initiatives in precollege science education; this assessment would help determine available options and guide NSF's own planning. The objectives of the study did not encompass studying or advising on management structure.

The term "science education" included education in mathematics, the natural sciences, engineering, and technology (as both a tool and object of study). The social sciences were not included, to keep the scope within reasonable bounds and because historically NSF had run into political difficulties in focusing on social sciences. The study was to focus on the K-12 levels (elementary, middle/junior high, and high schools), although it was not limited to formal education. We defined it to encompass in-school and out-of-school learning for children and youths from 5 to 18 years of age, whether or not they were going to attend college. The project dealt with undergraduate and higher levels of formal education only insofar as they influence education for learners at the K-12 levels. For example, the undergraduate, postgraduate, and inservice education of teachers of science and mathematics is central to K-12 science education instruction. Also, the SAT tests and the admission requirements for colleges have a significant influence on the high school science and mathematics curriculum.

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* SEE had earlier awarded a contract to Research Triangle Institute to assess initiatives related to science education (excluding mathematics) at the middle/junior high school level. Subsequently, SEE convened a series of panels concerning NSF's role in undergraduate-level science, mathematics, and engineering education.

The activities specified in the RFP for the project were:

(1) To review the prior experience of NSF in funding science education programs.

(2) To clarify the objectives of NSF's current and alternative initiatives.

(3) To assess the advantages and disadvantages of current and alternative initiatives available to NSF to meet its objectives.

(4) To develop evaluation plans for SEE to use, on an ongoing basis, to assess the quality and impact of its work.

SRI proposed that the first three of these activities be combined and carried out concurrently as Phase I of the project and that activity 4 be the focus of the second phase. The first study phase was thus aimed at assessing previous, current, and alternative initiatives for NSF in K-12 science education. This task included clarifying the objectives--and assessing the advantages and disadvantages--of initiatives available to NSF to address problems and opportunities in science education, based partly on lessons learned from previous NSF-supported initiatives. The findings of Phase I are presented in three volumes: *Summary Report, Volume 1 - Problems and Opportunities*, and *Volume 2 - Groundwork for Strategic Investment* (this volume). This methodological discussion describes the approach and procedures for arriving at these findings.

The purpose of the second phase is to develop a plan and procedures for SEE to use in assessing its own programs on an ongoing basis. In their final form, the assessment plan and procedures will reflect the results of testing evaluation procedures that SEE can use in managing its future initiatives. Methods for this activity will be described as part of a subsequent report.

The Phase I task--assessment of initiatives--included both evaluation and planning activities and, over time, the emphasis shifted from evaluation of previous and current programs to identifying available options and promising initiatives. NSF requested an objective appraisal of the effects of previous programs, a determination of the advantages and disadvantages of SEE's current initiatives (or programs) at the K-12 level, and an examination of the advantages and disadvantages of alternative initiatives.

Consultation with NSF

To carry out the assessment activities in such a way that the results would actually influence NSF's actions, SRI proposed to work closely with staff of the Education Directorate (where all of NSF's K-12-level science education programs are housed) to understand program objectives, resources, and constraints, and to obtain their findings about past and present projects that were pertinent to the design of new initiatives. We solicited feedback on our interim findings and reports to catch inaccuracies in program descriptions and to improve communication of the findings and their implications. We interviewed NSF officials outside SEE to understand the agency's overall role and the context for its science education programs. Thus, in evaluating SEE's programs to advise on current and alternative initiatives, we informed SEE staff at each stage and became mutually informed as the work progressed. We relied on many different methods and numerous sources of information and acted in the mode of a consultant to NSF.

Organization of the Project Team

Our project team comprised several basic organizational and functional components. The central organizing group of people, called the *core project staff*, was made up primarily of SRI staff members.* This group was responsible for the overall design and methods of the study, for decisions on the framework and assessment criteria, and for the final analysis and reporting.

The core staff was extended by a group of *primary consultants*. These consultants helped most in the first 6 months of the project, as members of working groups that were formed to assess initiatives from five content domains in--or perspectives on--K-12 science education. (A sixth group devoted itself to preliminary planning and conceptual work for Phase II.) Table 5-1 lists the membership of the working groups, including core staff and the primary consultants. The working-group consultants were selected for their particular expertise in the science education (or methodological) issues addressed by this project. Many of the consultants participated substantially, not only in the gathering and interpretation of information and in working-group meetings, but also in conceptualizing the study, synthesizing findings, and drawing conclusions.

In addition, we relied on the assistance of many "resource persons." These were individuals who provided important information, assistance, and perspectives on topics relating to their expertise in science education. The resource persons participated as authors of commissioned papers, participants in project review meetings, respondents in interviews with project staff, and providers of written information or opinions on project topics.

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* Wayne Harvey (formerly at SRI, now at Education Development Center), Michael Knapp, Margaret Needels, Debra Richards, Patrick Shields, Marian Stearns, Dorothy Stewart, Mark St. John (consultant to SRI), Mary Wagner, and Andrew Zucker.

Table 5-1

WORKING GROUP MEMBERSHIP

School-Based Science Education
- Paul Hurd, School of Education, Stanford University
- Michael Knapp, SRI*
- Mary Budd Rowe, Department of Science Education, University of Florida
- Mark St. John, SRI Consultant

School-Based Mathematics Education
- Wayne Harvey, Education Development Center**
- Jeremy Kilpatrick, College of Education, University of Georgia
- James Wilson, College of Education, University of Georgia
- Andrew Zucker, SRI*

Informal (Out-of-School) Science Education
- Milton Chen, Graduate School of Education, Harvard University
- Judy Diamond, San Diego Natural History Museum
- Robert Semper, San Francisco Exploratorium
- Mark St. John, SRI Consultant*
- Andrew Zucker, SRI

Technology in Science and Mathematics Education
- Wayne Harvey, Education Development Center*,**
- Kristina Hooper, Apple Computer
- Glenn Kleiman, Education Development Center
- Marian Stearns, SRI
- Robert Tinker, Technical Education Research Centers

Development and Support of Science and Mathematics Teachers
- Charles Anderson, Department of Education, Michigan State University
- Robert Bush, School of Education, Stanford University
- Michael Knapp, SRI
- Margaret Needels, SRI*
- Barbara Pence, Department of Mathematics and Computer Science, San Jose State University
- Pinchas Tamir, Hebrew University, Jerusalem

Evaluation Design
- Marian Stearns, SRI*
- Michael Knapp, SRI
- Alphonse Buccino, College of Education, University of Georgia
- Edward Haertel, School of Education, Stanford University
- Milbrey McLaughlin, School of Education, Stanford University
- Ingram Olkin, School of Education, Stanford University
- Patrick Shields, SRI
- Mark St. John, SRI Consultant

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* Working-group leader.

** Formerly at SRI.

Overview of the Study Approach

We had to create a study design, methods, and procedures that were tailored to the project's (contractual) objectives, that took account of the problems and opportunities in K-12 science and mathematics education, that maximized input from the community of potential grantees and other players, and that fit the characteristics of NSF and the capabilities of SEE. There was no specific assessment-for-planning methodology or formal precedent that we could adopt; instead, we adapted various evaluation, policy analysis, research, and planning methods and procedures as needed.

Initiatives as the Unit of Analysis

We started with a definition of the primary unit of analysis--that is, initiatives. We thought of initiatives not as individual projects but as corresponding to the level of programs or parts of programs (a priority target area within a program). That is, SEE's Instructional Materials Development (IMD) program or a subpart of it (the targeted elementary curriculum solicitation) could be considered an initiative designed to achieve the objective of improving the science education curriculum. As described in Part Two, we view initiatives as hypotheses: if SEE announces its interest in addressing a target problem by means of research, development, training, or other types of projects, then potential grantees will respond with appropriate proposals, be awarded grant support, and carry out activities that solve the target problem as envisioned by SEE. A program announcement with specified objectives and rationale signals an SEE initiative designed to achieve the objectives. The funding of a set of projects to address a targeted problem is an *investment* by NSF in the improvement of science education.

In the early months of the project, we developed a set of criteria for assessing initiatives. The criteria for weighing the advantages and disadvantages of various current and potential future initiatives for NSF are listed in Table 5-2. In addition to criteria for judging initiatives (or individual investments), we developed a list of dimensions on which initiatives could be characterized, but which do not necessarily reflect an advantage or disadvantage outside the context of NSF's whole portfolio of initiatives. Table 5-3 lists those dimensions that can be used to characterize the science education investment portfolio. (These criteria and portfolio dimensions evolved somewhat during the course of the project.)

Two Stages in the Evolution of the Project

There were two distinct stages in the evolution of Phase I of the study. Each was associated with a particular perspective on SEE's initiatives and a particular framework for arraying initiatives for assessment. The first stage can be characterized as looking at NSF's initiatives from the point of view of significant problems in five different science education domains; in the next stage we looked at promising opportunities for addressing problems from the point of view of what NSF can best do.

Table 5-2

CRITERIA FOR ANALYZING SEE'S APPROACH AND INITIATIVES IN EACH DOMAIN

1. *Significant Direct Impact on Target (e.g., learners, teachers, or content)*

    - Breadth of impact
    - Depth of impact
    - Importance of the problem/need addressed

2. *Significant Indirect Impact on the Field of Science Education*

    - Knowledge base
    - Available repertoire of models
    - Professional/leadership development
    - Stimulus to further activity
    - Participation of new groups, institutions

3. *Nature of External Responses*

    - The field (potential grantees available/ready)
    - Others (professional supporters/adversaries, political constituencies)

4. *Leveraging Potential*

    - How much an NSF dollar buys (impact relative to expenditure)
    - Stimulus to other resources (matching by others in short run and sustained effort by others after NSF support is withdrawn)

5. *Appropriateness to NSF*

    - Federal role
    - Science education grantsmaking agency

6. *Feasibility*

    - Funding requirements
    - Other resources and constraints in NSF/SEE

Table 5-3

DIMENSIONS USED FOR CHARACTERIZING PORTFOLIOS OF INITIATIVES

A. *Directorate Mission and Public Posture*

1. Service orientation (direct service vs. capacity/model building)
2. Intended beneficiaries (mainline, pipeline, target groups)
3. Risk level*
4. Political appeal (to Congress, OMB/White House, NSF hierarchy, science education community)

B. *Scope and Focus of Initiatives in the Portfolio*

5. Levels of education (elementary, middle, high, higher)
6. Activities supported (research, development, training, etc.)
7. Disciplinary focus (biological sciences, mathematical sciences)
8. Orientation to "pure" science vs. applications of science

C. *Mechanisms for Achieving Goals of Programs in Portfolio*

9. Specificity of programs (open grant, targeted solicitation)
10. Grant size range (large vs. small)
11. Time horizon for funding (short term vs. long term)
12. Orientation toward institutions vs. individuals
13. Types of funding recipients (agents)
14. Emphasis on collaboration

D. *Portfolio Size and Coherence*

15. Number of separate programs in portfolio
16. Levels of funding for programs in portfolio
17. Relationship among programs in portfolio (mutually supportive vs. discrete)

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* The dimension of "risk level" may sound like a criterion and "high risk" might be considered a disadvantage. However, if high gain or good effects on some aspect of science education can be achieved only through a high-risk strategy, then a high-risk, high-gain initiative might just balance the low-risk, low-gain initiatives in the portfolio and thus have advantages.

Our analytic approach evolved in four ways as the two stages progressed:

- *From retrospective to prospective views.* The task evolved from an evaluative assessment of previous and current programs to a planning-oriented assessment of promising opportunities, initiatives, and strategic options. Thus, we did most of the historical review of NSF's programs (before 1981 and since SEE's reestablishment late in 1983) in the first stage, and the principal results of the first stage were descriptions of SEE's current approaches and funded projects. We identified the problems and needs of each domain more clearly in the first stage and identified opportunities to solve them more during the second stage. The assessment criteria were used early on to determine how effective certain initiatives had been in the past, as well as to assess the current SEE programs. In the second stage, we used the same criteria primarily as a prospective measure. Thus, the "breadth of impact" criterion, for example, was used to ask: How likely is it that planned initiatives or proposed alternatives will affect a large number of students, teachers, or other target audiences? On the basis of the answers, we revised our suggestions for the design of initiatives.

- *From the outside in to the inside out.* Because we first got the help of experts from the K-12 science and mathematics education community, the point of view in assessing initiatives emphasized looking at the Foundation's initiatives and evaluating them in terms of the needs of the field. As the project progressed, we did more detailed analyses of NSF's unique role as a federal scientific agency and better appreciated SEE's capabilities and needs. Increased familiarity with the Foundation and its Education Directorate changed the emphasis so that we looked at current and potential initiatives more from NSF's viewpoint as an agency that had to choose its investments carefully. Options were narrowed to the kinds of initiatives for which NSF (SEE) would be the most appropriate supporter (given the roles of other players in science education).

- *From one to two levels of analysis.* The sole unit of analysis early in the project was the initiative. As the project proceeded, we found it necessary to go beyond the initiative and embed its analysis in a superordinate level of analysis. To determine the advantages and disadvantages of initiatives, it was necessary to see their objectives in the context of NSF's (SEE's) overall goal or mission in science education and their rationale for achieving objectives in terms of NSF's (SEE's) overall strategy for achieving that goal--that is, NSF's investment strategy for improving science education at the K-12 level. We therefore moved from emphasizing the program-level initiatives to emphasizing the Directorate-wide strategies.

- *From assessment by domain to assessment by opportunities.* The first assessments of initiatives were done from five different (working-group) perspectives reflecting the areas of activity around which members of the scientific and science education communities group themselves. At this stage, we examined the problems and assessed the previous, current, and alternative initiatives from the viewpoint of each working group.

In the second stage of the assessment process, we integrated the working-group perspectives and used promising opportunities for NSF across the domains as the framework. Using much of what we had already found by examining problems and initiatives from the five different perspectives, we determined the most promising opportunities for NSF as a grantsmaking agency in science education. We then reassessed the current programs against these opportunities and identified promising initiatives for addressing the opportunities. Many of the alternative initiatives were originally the products of working-group analyses; others emerged as part of the second-stage analysis.

Below we describe the procedures in each of the two stages of the study.

First Stage: Working-Group Assessment of Initiatives

The working groups represented five different "vantage points" for looking at the problems in science education and NSF's (SEE's) activities in relation to them. SEE's programs have traditionally been organized by function (e.g., Research in Science Education and Research in Teaching and Learning; Summer Institutes for Science Teachers and Teacher Preparation and Enhancement). We had considered organizing our analysis of SEE's initiatives by type of activity supported (e.g., research, development, training, dissemination, other), but we rejected this approach. Describing initiatives in terms of their method does not reflect the substantive problems in science and mathematics education to which NSF might target its initiatives. In addition, individuals in science education do not identify themselves or their work as much by function as by field, discipline, or domain (mathematics education, cognitive science, physics education, teacher education, etc.). Consequently, we decided to examine the problems and NSF's programs/initiatives through the substantive "lenses" of five science education domains. The domains were defined as follows:

- *School-based science education.* This group focused on "science education" narrowly defined to include school-based instruction (K-12) in the natural sciences (and the social sciences only to a very limited extent--i.e., to extract lessons from NSF's historical activities in this area), and education that falls under the rubric of "science, technology, and society" (STS). "School-based instruction" included activities that happen outside the school walls (e.g., field trips to laboratories) as long as they were in some way part of the formal school curriculum. The group concentrated its energies on research and development activities related to school-based science education (i.e., not focusing on teacher education).

- *School-based mathematics education*. The view of this group paralleled that of the science education group closely, only with a focus on mathematics. The group focused its attention on instruction from grades K through 12 in mathematics and the mathematical sciences (arithmetic, algebra, calculus, geometry, statistics, computer science, etc.).

- *Informal (out-of-school) science education*. This working group targeted its attention on the wide range of SEE activities designed to enhance the interest in and learning of science, mathematics, and technology in nonschool settings. The group divided up this domain by medium: television, radio, print, museums, etc.

- *Technology in science and mathematics education*. This group focused its efforts primarily on the creation of new technologies (future oriented) rather than on how existing computer software and other media can be used effectively in today's schools (this latter issue was addressed by the other working groups concerned with the specific subject areas to which the technology is applied). Issues addressed include research and development of technology applications in the classroom and in informal environments; the use of technology for testing or school administration; and the evaluation of the instructional design of computer software or videodisc materials.

- *Science and mathematics teacher development and support*. This domain included any efforts aimed at enhancing the knowledge and skills of K-12 science and mathematics teachers, attracting new teachers to these areas of instruction, and retaining them in the profession. Activities examined included networks among teacher educators and others to enhance the training and support of teachers and research in teacher education, as well as teacher education and teacher recruitment and retention issues.

Early in the first stage, each working group looked across all of SEE's programs at all activities relating to its domain and asked: What do we know from past projects about what to do and what not do? What are the significant problems in this domain today that need to be addressed? Are the projects funded by SEE addressing these needs? How should current activities be modified to address them and what alternative initiatives are advantages? The working groups examined the impacts of earlier NSF activities and explored the issues in science education (within the working group domain) that had bearing on significant problems or ways to address them.

Assessing Previous and Current Initiatives (by Working-Group Domain)

Activities of the working groups were coordinated so that each group took full advantage of what others were learning, and duplicate information-gathering efforts did not occur. Core staff meetings, shared interview schedules and field notes (facilitated by an electronic mail system), and overlapping membership of SRI staff on working groups served as important coordination mechanisms.

Analytically, each group:

- Mapped the territory of its science education domain and described ways to improve it (based on the state of the art and the problems in the domain).
- Described NSF's currently funded projects under all initiatives, inferred an overall approach to its domain, and assessed the advantages and disadvantages of the approach.
- Generated alternative approaches for investments in the domain.
- Assessed the advantages and disadvantages of alternatives for NSF investment in the domain.

We relied heavily on the knowledge and judgment of the experts from the five academically distinct domains in science education. These experts provided findings, models, or analyses about the sources of significant problems and the ways and means of addressing the problems. They judged the likely impact of current NSF-sponsored projects and other activities and helped us determine the lessons from prior initiatives of NSF's Education Directorate. The information on which the working groups based their analyses came from many sources. Several of the major sources are described below.

SEE funding history--Using NSF program summaries, annual reports, previous historical review documents, and other NSF reports and documents, project staff created a program funding chronology of NSF's education initiatives from 1952 to 1986 (see Part Three of this volume). This document showed the extent (level of funding) and duration of the Directorate's investments in teacher training, materials development, research, and other educational activities. This review was a useful tool for examining major trends and emphases in NSF's past education efforts.

A more detailed program funding history was compiled to show year-by-year funding by SEE program and by type of activity. This more detailed review was difficult. "Programs" were not consistently reported as clearly defined, separable entities. Sometimes reports aggregated data at the division level, making it difficult to identify the funding associated with a particular program in the division. Awards lists and other project documents often did not indicate the program or programs from which a project came (some projects were funded by more than one program); documents inconsistently reported project funding amounts: some reported the total award amount, others reported a yearly awarded amount, and others reported an actual project funding total. Current and former NSF staff helped resolve some of the discrepancies and missing data. Despite the remaining holes and uncertainties, we were able to put together a fairly accurate program-by-program, year-by-year funding history of all SEE programs through 1986. This document appears in Part Three of this volume.

We also created a data base of projects funded in SEE in the years since the Directorate's reinstatement (FY 1984, FY 1985, and the first half of FY 1986) to analyze NSF's most recent approaches to K-12 science education. The data base included the following information about each project: award amount, project duration, type of project (research, teacher training, etc.), primary subject matter, targeted education level (e.g., elementary, high school), and other information taken from project abstracts (NSF Form 9s). The data base allowed working group members to search for and sort projects according to major categories such as targeted level of education or primary subject matter focus.

Literature review--The working groups made extensive use of literature that shed light on the particular programs in question, on ideas for alternative initiatives, on the assumptions underlying these efforts, on the wider effects of NSF actions, and on the state of the domain more generally. Different items had greater importance to some working groups than to others, but, in general, the following categories of literature were considered:

- NSF documents (published reports, congressional hearings, internal oversight reviews, etc.).
- Other pertinent federal documents (e.g., history of SEE by the Congressional Budget Office).
- Evaluations of SEE's funded projects or similar programs.
- Analyses of the state of the field (e.g., through status surveys, examinations of trends).
- Other literature on the needs or activities within the domains addressed by the working groups.

Interviews--Much of the data for the working-group analyses came from interviews with a wide variety of professionals who represented different perspectives on the domain (irrespective of NSF's activity within it), on NSF and its programs, and on their effects on science education (within the working group domain). Working groups aimed at obtaining the widest possible representation of perceptions, opinions, and backgrounds. The kinds of perspectives they looked for included those of (1) scientists, mathematicians, and engineers; (2) science and mathematics educators concerned with elementary, secondary, or informal education; (3) NSF staff at all levels and from all fields; (4) former or current principal investigators of NSF projects; (5) proposers on NSF projects who did not obtain NSF funding; (6) staff from other federal government agencies; (7) professional society representatives; (8) reviewers of SEE's proposals; (9) developers or distributors of science education materials; (10) science education practitioners; and (11) others who could offer views on the state of science education in the domain and NSF's past, current, or potential role in it.

Interviews were conducted in person and by telephone by working-group members. Most interviews were formally arranged; however, informal interactions (e.g., through professional conference participation) also contributed to working-group analyses. Interviews were open-ended and exploratory and aimed at eliciting the interviewees' thoughts on the following topics:

- Perceptions of the field: problems, barriers, and opportunities.
- Appraisal of present and related past NSF programs.
- Ideas for different initiatives or changes in overall NSF strategy in science education.
- Perceptions of NSF operations and ways to improve them.

Interviews were guided by a topical guide adapted to the nature of the domain under investigation. For illustrative purposes, Table 5-4 shows the interview guide used by the school-based science education working group. Other working groups used similar guides tailored to the issues in their domains. The guide shown here, for example, includes topics such as the textbook creation bottleneck because of its particular relevance for school-based education in the natural sciences. Each working group conducted between 75 and 125 interviews; altogether (including individuals interviewed by the evaluation design working group), more than 600 people were interviewed. Interview notes were shared within the working groups and, as pertinent, with staff of other working groups.

Commissioned papers--In a few instances, to supplement information gathered from existing literature and interviews, we commissioned papers. One paper, written by Dr. Elliot Soloway for the technology in education working group, examined NSF's potential strategies in improving the teaching of precollege computer science. Dr. Gerald Kulm provided the school-based mathematics education working group with a paper on the roles of mathematics educators, mathematicians, and NSF in improving precollege mathematics education. A third report, by Dr. Joel Aronson, aided analyses of all five working groups by focusing on NSF's current and potential initiatives to provide effective leadership in addressing the needs of minorities in K-12 science and mathematics education.

Developing Working-Group Findings

After several months of information gathering and analysis, the working groups assembled their findings according to a common outline (see Table 5-5). To obtain independent reactions to these preliminary findings, we organized working-group review meetings (five separate 1-day meetings), to each of which we invited five to seven outside experts and several SEE staff members who were most involved with programs centered in the domain (three to five SEE staff members were present at each meeting). The outside experts were selected to represent different perspectives within the domain. For example, the informal science education group invited

Table 5-4

ILLUSTRATIVE INTERVIEW GUIDE

School-Based Science Education Working Group

Background Information on Respondent

- Institutional affiliation: current and during years associated with NSF
- Relationship with NSF over time: roles in NSF? recipient of NSF grants? Other (advisory, reviewer, program oversight...)?
- Listing of project(s) supported by NSF

Perceptions of the Domain: Problems, Barriers, Opportunities

1. What are the most significant problems in science education that can be addressed by a federal-level scientific funding agency like NSF? (NOTE: Listen to teacher-related problems but indicate to the respondent that these issues will be addressed more centrally by another working group.)

2. What new opportunities present themselves for NSF action that did not exist in the past? Probe the following issues as sources of opportunities (also challenges, problems):

   - Debate over the meaning of "scientific and technological literacy"
   - Differences in need at the elementary, middle, and high school levels
   - The textbook creation/adoption bottleneck
   - State-level science education reforms and the broader movement to reform education overall
   - Accumulating wisdom on the prerequisites for change
   - The challenge from overseas: models of science education from other countries
   - The changing profile of the student population
   - The neglect of the gifted and talented

3. In what ways do conditions in the field stand in the way of any effort by NSF to stimulate needed improvements?

Appraisal of Current (and Related Past) NSF Programs

NOTE: To jog respondent's mind or memory about what programs we are talking about, have him/her scan the attached one-page list of past and current NSF/SEE programs in the areas addressed by the working group.

Table 5-4 (Concluded)

4. How would you assess NSF's current programs/XYZ Program, both in terms of their strengths and their weaknesses as investments aimed at improving science education? (Probe on programs in area of respondent's expertise: research programs? materials or curriculum development programs? programs aimed at opportunity enhancement? other...? Don't probe teacher-related programs, but listen to what people have to say about these.)
5. Which programs are most/least appropriate to NSF? Feasible? Likely to exert leverage over resources, ideas, or other actors? Soundly or creatively conceived? Effective, in terms of achieving objectives and covering the targeted audience/needs? Important? Likely to enhance the opportunities of women, minorities, and handicapped individuals?
6. What have been the longer-range impacts of XYZ Program on the field? On what do you base your judgments of effect? (Probe: secondary effects as well as the intended primary effects?)
7. Have there been particular long-term impacts of projects you have done with NSF funding? What impacts? Evidence for these?

Ideas for Different Initiatives or Changes in Overall NSF Strategy in the Domain

8. Given a constant current level of funding for elementary and secondary educational programs (approximately $50 million), what alternative initiatives or programs would you propose that NSF consider in science education?
9. (For each initiative proposed) What are the most significant strengths of ABC initiative? What are its drawbacks?
10. How might NSF effectively alter its overall strategy in science education? More specifically, in research related to science education? Materials/ curriculum development? Other kinds of programs (see probe list above)?

Perceptions of NSF Operations and Ways to Improve Them

11. What are the particular strengths of the Science and Engineering Education Directorate and the way it implements its programs for improving science education?
12. Are there ways that its implementation of programs or other aspects of its operations need to be improved? How can this be done? (Probe for respondent's basis for perceiving a problem in NSF operations.)

Table 5-5

WORKING GROUP ANALYSIS OUTLINE

I *Introduction*

  a. Definition of the domain
  b. Framework for examining initiatives within the domain
  c. Brief explanation of analytic approach

II *Framework: Way of Thinking About This Domain and How to Affect It*

  a. Thinking strategically about the field
  b. Intervention opportunities
  c. Groups and individuals involved in the improvement of the domain

III *NSF's (SEE's) Presence and Overall Approach in the Domain*

  a. Overall approach in the domain
  b. Patterns of investment
  c. Operating strategies in the domain (as embodied in current and projected SEE programs/initiatives)

IV *Analysis and Critique of Current Strategies*

  a. Critique of overall set of current strategies
  b. Strengths and weaknesses of each strategy

V *Opportunities for Strengthening NSF's Strategies in the Domain*

  a. Overall strategic shifts
  b. Ways to strengthen, modify current strategies
  c. New strategies

VI *Concluding Observations*

individuals from some of the different media of informal education (television, radio, print), as well as from other organizations (foundations, museums) involved in this area. Most of the participants had had some previous involvement with NSF, although their knowledge of NSF activities was not a requirement for participation in the meetings.

Meeting participants reviewed the working group's assessment of the overall state of the field and of the relative strengths and weaknesses of NSF's current individual initiatives in the domain. Participants provided feedback, and our preliminary findings were modified in response to the perceptions of this extended group of experts in the five domains.

The first stage of the study drew to a close when we presented these findings to the staff of SEE. At this presentation it became clear that, although the working-group process had elaborated on the needs in science education and drawn lessons from past successful initiatives, provided the Directorate with perspective on its approaches to science education problems, showed the advantages and disadvantages of particular targets and approaches, and thus suggested variations on or alternatives to the current initiatives, it did not fully satisfy the Directorate's needs. Staff of SEE wanted more specific guidance for their actions.

A list of multiple targets and initiatives addressed to them did provide program officers, division directors, or the Assistant Director (AD) with a set of priorities or next steps. In interviews with congressional and OMB audiences, it was clear that they had been continually dissatisfied with NSF's merely listing the education programs it was sponsoring. They wanted to know what general objectives SEE was aiming to achieve and what its overall strategic plan for attaining these objectives was. Both SEE and its audiences (NSF leaders, Congress) were requesting that we move toward fulfilling the congressional mandate for a science education plan and management structure. So far, we had only inferred from current investments what the larger strategies might be and suggested variations on them for next initiatives. Much less evaluation of previous successes and failures, current needs, and potential initiatives was needed, and more planning within a framework of general options was needed. Also, a more Directorate-wide or top-down conception was needed.

Second Stage: Identifying Opportunities and Strategic Options

The assessment of current initiatives from five working-group perspectives helped us identify where SEE was currently investing in high- and low-payoff projects, but it did not prioritize investment options at the level of the individual programs nor did it suggest overall directions for the divisions or the Directorate as a whole. The initiatives developed by the working groups addressed problems of concern to particular segments of the science education community and suggested funding mechanisms that were appropriate from the point of view of selected potential grantees, but did not necessarily represent the perspective of an agency trying to bring about changes in science education through strategic investment.

The working-group findings needed to be synthesized across domains and presented as a coherent set of problems to which NSF might address its initiatives. Also, the initiatives that NSF could support had to be developed from the point of view of what was most opportune for the Foundation, given the current trends in science education and given the other players whose efforts could be leveraged. Finally, because NSF cannot afford to pursue every opportunity or support all the initiatives for which it is well suited, careful consideration had to be given to the Foundation's chosen mission in K-12 science education and to its overall stance or investment approach to achieving objectives within that mission.

There were four major events in the chronology of the project's second stage:

- A presentation of the project's analytic framework and preliminary findings to the Advisory Committee of the Science and Engineering Education Directorate.
- A meeting with 30 representatives of professional science and mathematics education associations and scientific societies concerned with K-12 science education.
- Writing a draft final report (in two volumes) and conducting an extensive and elaborate review process.
- Rewriting and preparing the final report (including a summary report and two backup volumes).

We have organized the remainder of this section around the analytic steps that are reflected in the organization of all three report volumes. There were five distinct analytic steps in the project's second stage:

- Establishing a K-12 educational mission for the Foundation.
- Identifying problems and opportunities in relation to that mission and potential initiatives aimed at each opportunity.
- Assessing current NSF (SEE) programs and alternative initiatives in terms of the opportunities before the Foundation.
- Developing overarching strategies for the Foundation's investments in K-12 science education.
- Examining the Foundation's strategic capacity for investing in K-12 science education.

We describe each step in turn.

Establishing a K-12 Educational Mission for the Foundation

During the first stage of the project, it rapidly became clear that we, SEE staff, and others interested in science education could generate a practically infinite number of good initiatives and project-level ideas for attacking problems in science education. The only sensible way to guide NSF toward some investments, rather than others, was to clarify the superordinate goals toward which the initiatives were, or could be, aimed. Once we could define the goal or mission of NSF in K-12 science education, we could break it into objectives achievable within a certain time period (i.e., 5 years to correspond with the congressional requirement for SEE to provide its strategic plan).

Working from the only explicitly stated mission for NSF in K-12 education, which appeared in the NSB Commission report on precollege education, *Educating Americans for the 21st Century*, we launched an effort to frame a mission statement that could be endorsed across the Foundation and followed by SEE. After reviewing the legal charter, written plans, and public statements about NSF's role in education at all levels (graduate, undergraduate, precollege), interviewing additional members of the scientific establishment (inside and outside NSF), and reanalyzing the information from the K-12 science education community (inside and outside SEE), we stated a mission for NSF's involvement in K-12 education (inside and outside of schools). Our statement struck a balance between the "pipeline" development rationale and the "mainline" rationale that are commonly adopted in debate about NSF's mission (see discussion in the *Summary Report* and the introduction to *Volume 1*). The mission proposed was "to broaden the pool of interested and competent science learners to the age of 18."

Identifying Problems and Opportunities

Given a statement of the Foundation's mission, it was then possible to focus on a set of national problems that related to NSF's overall mission, and to frame opportunities for NSF to address these problems.

Problems in K-12 science education--Accordingly, we organized what we had learned in working groups about critical national needs in science education in terms of the "problems that limit the pool of competent and interested science learners." As discussed in *Volume 1* (and briefly in the *Summary Report*), these problems were conceptually organized into three categories:

- Content and instructional approach.
- The quality of teachers and strength of the professional community.
- The infrastructure for science education.

In assembling a picture of national problems by these categories, important differences were apparent by educational level, though more in some working groups than others. We clustered problems that emerged from working group analyses by three educational levels (elementary, middle, high school) to the extent that distinct issues existed at each level; otherwise, problems were stated globally, pertaining to all educational levels.

Opportunities and initiatives--The framework of problems generated an organizing rubric for opportunities. As explained in *Volume 1*, we identified opportunities within each of the three categories of problems wherever national needs and the Foundation's unique capabilities converge, in situations when trends or the positioning of other actors make it timely for NSF to play a role (see Introduction to *Volume 1* for a discussion of NSF's unique capabilities and the indicators of timeliness).

The opportunities we identified served as a device for clustering and sorting among the various ideas for initiatives that had emerged from working group analyses. In the course of doing so, we discarded many initiatives, broadened others, merged initiatives, and sometimes invented new ones to arrive at a set of initiatives that met our operational requirements for a strategic initiative (see discussion of designing initiatives in Part Two of this volume).

Core functions--In the course of identifying, sorting, and revising our list of opportunities, a certain subset of SEE investment activities emerged (which we had originally described as opportunities) that were qualitatively different from the goal-directed initiatives related to each opportunity. These activities--aimed at promoting professional interchange, building the base of knowledge and information about science education, and supporting innovation--represented, instead, ongoing responsibilities of NSF that were always needed, both by the Foundation and the science education community. In fact, these "core functions" were an important underpinning for any strategic effort by the Foundation, as an input to its planning and as a way of preparing the science education community to respond appropriately to NSF initiatives. To carry out these core functions, NSF (SEE) could mount initiatives of a different sort, in addition to continuing current investments of several kinds (e.g., funding for research in science education). The core functions are described in detail at the beginning of this volume (see Part One).

Assessing Current NSF (SEE) Programs and Alternatives in Relation to the Opportunities

The set of 10 opportunities we identified (and 3 core functions) provided a frame of reference for judging the impact of current NSF (SEE) investments and of alternative initiatives for the achievement of the long-term goal (broadening the science learner pool). Synthesizing what we had learned from working-group perspectives about current NSF (SEE) activities, we developed a rough appraisal of the degree to which each opportunity was likely to be achieved given current (and projected) NSF (SEE) investment strategies, assuming these were carried out over 5 years (or more) in their current form.

Our judgments regarding NSF's likely contributions to achieving goals implied by each opportunity were based on:

- Historical precedent: lessons from NSF's past investments.
- Emerging evidence from recent and current investments.
- Logical analysis (e.g., examining the assumptions within the initiative's "hypothesis").

Where possible, we sought to corroborate our judgments by checking with NSF (SEE) staff and diverse members of the science education community, chiefly through the draft report review process.

Various alternatives to current approaches were considered, and those that held the greatest promise for improving on current SEE approaches were retained as "promising initiatives." In many cases, promising initiatives included the continuation or expansion of an existing SEE activity, where this appeared to be making an effective contribution to particular opportunities (or core functions).

Developing Overarching Strategies

But a higher level of analysis was necessary to provide an organizing rationale for NSF's choice among opportunities, and with respect to any particular opportunity, choice among possible initiatives. The core team reanalyzed literature, interview notes, and working group findings to frame appropriate overarching strategies that would serve the purposes of guiding NSF's (SEE's) choice of investments, explaining the Foundation's directions to the outside world, and maximizing the impact of the Foundation's limited resources. Various candidates for appropriate strategy were considered; these were narrowed to three by the time of the draft report (which took "powerful ideas," "professional resources," and "diversity of learning alternatives," respectively, as alternative primary foci for SEE investments). These were subsequently redefined and collapsed into two--the incremental improvement and fundamental change strategies--as explained in the *Summary Report* and Part Two of this volume.

Examining the Foundation's Capacity for Strategic Investment in Science Education

Finally, we analyzed some of the basic operational requirements for strategic investment. Because the focus of our study was on the assessment of opportunities, initiatives, and strategies, our review of the operational implications for the Education Directorate and the Foundation as a whole was somewhat cursory. Nonetheless, from reviewing interviews with NSF staff and working group analyses, certain themes recurred regarding NSF's organizational home base for educational investment, staffing for SEE, continuity of resources, policies and procedures affecting proactivity, and the degree of support from NSF's top leadership. These themes served as a way to organize our observations about NSF's current capacity for strategic investment in K-12 science education and to identify ways this capacity could be strengthened. (The results of that analysis are described in the *Summary Report* and Part Two of this volume.)

APPENDIX A:

INITIATIVES TO IMPLEMENT OVERARCHING STRATEGIES

Appendix A

INITIATIVES TO IMPLEMENT OVERARCHING STRATEGIES

The following tables list initiatives we developed for NSF (SEE) to improve K-12 science education under two different strategies. The first emphasizes investments aimed at incremental improvements through widespread impacts on current educational systems, and the other emphasizes efforts to promote more fundamental changes in the structure of science education over the long term. Each strategy includes a comprehensive set of initiatives that collectively address the 10 opportunities described in the report. In a few cases, the same initiative appears in both strategies; more often, different initiatives related to each opportunity appear in each strategy that reflect the underlying strategic philosophy. (We have noted within the tables the opportunity or core function category to which each initiative corresponds.)

Resource estimates indicate the scale of investment that would be necessary to achieve the targets of opportunity. These estimates are based on analyses discussed in *Volume 1 - Problems and Opportunities* and *Volume 2 - Groundwork for Strategic Investment*. Resource estimates reflect the following assumptions:

(1) Estimates indicate the level of SEE investment over the next 5 years, even though some initiatives would require a longer time frame for completion.

(2) Estimates do not include current SEE obligations for future fiscal years. The amounts in the table would be allocated to existing SEE programs, or in some cases to newly created ones, over and above what these programs require to meet existing obligations.

(3) The figures indicated in the tables do not show the amount for each initiative where a set of initiatives relates to a particular opportunity or core function. See Volumes 1 and 2 for details about each initiative's resource requirements and the basis for these estimates.

Table A-1

INITIATIVES THAT IMPLEMENT AN INCREMENTAL IMPROVEMENT STRATEGY

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
*Investments aimed at improving content and approach**	
a. Develop software tools for learning mathematics; expand support for current efforts to develop standards (Opportunity 1).**	$25-33 million
b. Fund limited program of field-based experiments with new conceptions of middle and high school science content (Opportunity 2b).	$25-30 million
c. Support efforts to promote exemplary models for reaching underrepresented groups; develop curriculum materials targeted to underrepresented groups; support talented members of underrepresented groups in intensive science experiences (Opportunity 3).	$30-43 million
Investments aimed at strengthening professional resources	
a. Put in place an extensive "support cadre" (lead teachers, curriculum specialists, and others) that will provide inservice training, advice, and other forms of assistance to current or newly entering mathematics and science teachers--especially at the middle and high school levels; support development of leaders and change agents at the elementary school level (Opportunity 4).	$220-244 million

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* Efforts to improve content and approach through collaborative projects with publishers are listed on page 49 under "Investments aimed at systems upgrading."

** Investments in software listed here do not include technology development that occurs as part of collaborative publisher projects, research on learning and learning environments, or the development of advanced technologies for the future.

Table A-1 (Continued)

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Investments aimed at strengthening professional resources (continued)	
b. Develop alternative preparation and retraining programs; support and upgrade science and mathematics teacher educators; some investment in new approaches to teacher education and teacher incentives (Opportunity 5).	$55-75 million
c. Study the current state of the informal science education field (Opportunity 6).	$4-5 million
Investments aimed at systems upgrading	
a. Engage publishers in ambitious efforts to improve mathematics and science materials at the elementary and middle school levels, to be followed by high school level; seed the science and mathematics tradebook market for young audiences (Opportunity 7).	$50-60 million
b. Stimulate national dialogue on testing policy and support efforts to improve prominent tests and assessments now in use (Opportunity 8).	$10-15 million
c. Stimulate national dialogue on state science education reform; provide technical assistance to state-level planners and policymakers; support cross-state research to help states learn from each other's reform efforts (Opportunity 9).	$15-21 million
d. Expand informal science learning resources in broadcast, museum, and recreational association arenas; support experiments with making these resources more available to schools (Opportunity 10).	$100-130 million

Table A-1 (Concluded)

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Related core function investments	
a. Professional interchange: support network development within the professional community, with emphasis on practicing science educators; develop effective archiving and dissemination mechanisms; incentives for scientists' participation; research on demand for currently available high-quality materials.	$39-50 million
b. Knowledge building: support research, monitoring, and policy studies emphasizing the functioning of formal and informal systems; fund research on learning and learning environments that is closely related to development projects and to new technologies that are widespread in the schools; increase efforts to evaluate and document NSF-funded projects; support research syntheses and interpretations to encourage use of research by front-line practitioners.	$55-64 million
c. Support for innovative ideas, unanticipated opportunities (as part of each K-12 science education program).	$26-30 million
TOTAL:	$654-800 million

Table A-2

INITIATIVES TO IMPLEMENT A FUNDAMENTAL CHANGE STRATEGY

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Investments aimed at content and approach	
a. Support efforts to reconceptualize K-12 mathematics through curriculum prototype creation and standard-setting (Opportunity 1).*	$40-50 million
b. Fund basic and conceptual research on alternative approaches to elementary science along with large-scale field trials of these approaches (Opportunity 2a).	$48-62 million
c. Stimulate a national reexamination of what is taught in middle and high school science through national task forces and field-based experimentation (Opportunity 2b).	$50-65 million
d. Support research on underrepresentation in K-12 science education and ways to combat it; promote exploratory development of materials and methods especially designed to serve these groups better (Opportunity 3).	$12-18 million
Investments aimed at strengthening professional resources	
a. Fund the development of a teacher support cadre, as in preceding strategy, although less extensively (Opportunity 4).	$60-70 million

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* To some extent, reconceptualization of K-12 mathematics content and approaches will happen as part of rethinking science content and approach in Opportunities 2a and 2b.

Table A-2 (Continued)

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Investments aimed at strengthening professional resources (continued)	
b. Expand and experiment with incentives for attracting new teachers, especially those with strong scientific backgrounds; further the investigation of teachers' pedagogical knowledge; fund extensive experiments with trouble spots in the teacher preparation process and alternative ways to prepare teachers; support leadership development among science and mathematics teacher educators (Opportunity 5).	$72-92 million
c. Fund leadership development among informal science educators; study the informal science education field and fund research on, and evaluation of, informal science education efforts of various kinds (Opportunity 6).	$27-30 million
Investments aimed at systems upgrading	
a. Form consortium to explore alternative publication routes; support R&D on the "textbook of the future" (Opportunity 7).	$33-45 million
b. Support national dialogue on science testing policy; fund R&D leading to prototypes that test or assess science skills and knowledge more effectively (Opportunity 8).	$12-18 million
c. Fund cross-state research on effects of state reforms (Opportunity 9).	$5-7 million
d. Fund experimentation with new forms of informal science education and ways to link informal science education more effectively with the schools (Opportunity 10).	$42-55 million

Table A-2 (Concluded)

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Related core function investments	
a. Professional interchange: Create collaborative arenas (science education centers or the equivalent; collaborative arrangements in institutions of higher education) in which educators, scientists, and others pursue work related to science education improvement goals; increase incentives for participation of scientists and engineers in science education improvement; support network development, especially among groups not currently in the mainstream of science education; create an NSF-based journal for the science education community (parallel to *Mosaic*).	$62-80 million
b. Knowledge-building: Fund extensive research on learning and learning environments, both to extend basic understanding and to complement content reexamination; pursue heavy exploratory investment in advanced educational technologies; support monitoring and analyses of the science education system emphasizing projected future conditions; fund evaluative research, concentrating on sets of projects that experiment most with content and approach.	$75-97 million
c. Support for innovative ideas, unanticipated opportunities (as part of each K-12 science education program).	$42-50 million
TOTAL:	$580-739 million