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AUTHOR	Knapp, Michael S.; And Others
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ABSTRACT

Presented in this volume is the final report of the first phase of a study designed to assess initiatives available to the National Science Foundation (NSF) to address problems and opportunities in K-12 science education. The report begins with a discussion of NSF's mission in K-12 science education, followed by a review of the problems that limit the pool of competent, interested science learners up to the age of 18. The remainder of the document is organized as a series of stand-alone essays, providing detailed discussions of ten opportunities for NSF investment. These opportunities are categorized as: (1) opportunities related to appropriate content and approaches; (2) opportunities related to the community of professionals concerned with education in the sciences; and (3) opportunities related to the infrastructure for education in the sciences. Each essay reviews the nature of the opportunity and rationale for NSF's involvement, NSF's programs in relation to this opportunity, and promising initiatives for NSF's investment. Appended is a table listing these promising initiatives according to the opportunity to which it relates, and showing estimated measures 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 1: Problems and Opportunities

June 1987

Prepared for:

THE NATIONAL SCIENCE FOUNDATION

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

Prepared by :

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

with the assistance of:
Wayne Harvey

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 (this volume) 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 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).

THE NATIONAL SCIENCE FOUNDATION IN K-12 SCIENCE EDUCATION:

OPPORTUNITIES FOR STRATEGIC INVESTMENT

Summary Report

May 1987

By: Michael S. Knapp
Marian S. Stearns
Mark St. John
Andrew Zucker

Prepared for:

The National Science Foundation

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

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SYNOPSIS OF VOLUME 2
GROUNDWORK FOR STRATEGIC INVESTMENT

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 national problems in K-12 science education and current opportunities for the National Science Foundation to address these problems. 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.

We introduce the volume with a discussion of NSF's mission in K-12 science education, followed by a review of the problems that limit the pool of competent, interested science learners up to the age of 18. The remainder of the volume has been organized as a series of stand-alone essays, providing detailed discussions of 10 opportunities for NSF investment. Each essay reviews:

- The nature of the opportunity and rationale for NSF's involvement.
- NSF's programs (past, present, and projected) in relation to this opportunity.
- Promising initiatives for NSF's investment.

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 2 - Groundwork for Strategic Investment* (extended discussion of NSF's core functions in science education and the basis for investing strategically; background materials for the study).

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
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- Milton Chen, Harvard University
- Judy Diamond, San Diego Natural History Museum
- Kristina Hooper, Apple Computer
- Paul DeHart Hurd, Stanford University (emeritus)
- Jeremy Kilpatrick, University of Georgia
- Glenn Kleiman, Education Development Center
- Barbara Pence, San Jose State University
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- Robert Semper, The San Francisco Exploratorium
- 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:

Ludwig Braun, New York Institute of Technology
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Daniel Watt, independent consultant.

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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
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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
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Patricia McWethy, National Association of Biology Teachers
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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.

INTRODUCTION

This report presents the results of a prospective assessment of initiatives available to the National Science Foundation (NSF) to address problems and opportunities in science education* at the K-12 level. These results are based on broadly solicited expert opinion and a wide range of evidence, including a thorough review of NSF's current and past education programs. The assessment has generated a set of opportunities for NSF to consider as the Foundation plans future efforts aimed at improving science education for the nation's children and youth. A detailed discussion of those opportunities is the subject of this volume. (The assessment has also produced a set of strategic considerations and possible "core function" investments, which are detailed in *Volume 2 - Groundwork for Strategic Investment*. A brief *Summary Report* presents an overview of all of our findings.)

Neither SRI nor NSF can define problems or identify opportunities effectively without first clarifying NSF's mission in science education. This mission derives from the Foundation's interpretation of its original mandate to "strengthen science education at all levels," its unique character, and the roles it can play relative to other actors in science education. Determining the nature of NSF's responsibility in K-12 science education gives us a base from which to view the problems in this area. Summarizing the findings of recent national reports and analyses, in addition to our own, we briefly highlight the problems with student performance and motivation and review the sources of these problems in instructional content and approaches, the quality of teachers and the professional community, the infrastructure for formal (and informal) education in the sciences, and the societal context.

In this introduction, we accomplish three things:

- Discuss how NSF's mandate for strengthening K-12 science education can be most productively interpreted and argue that NSF's most reasonable long-term goal is to broaden the pool of competent and interested science learners through the age of 18.

- Review the national problems in K-12 science education that limit the pool of competent and interested science learners.

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* Throughout this report, we use the term "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 science learning activities for children and youth from 5 through 18 years of age, both inside and outside of school.

- Describe in general terms what constitutes an "opportunity" for NSF to address these problems in K-12 science education, including our criteria for identifying opportunities.

The remainder of the volume consists of essays describing in detail each of the 10 opportunities we have identified.

Clarifying NSF'S Educational Mandate at the K-12 Level

The National Science Foundation's charter reads:

> The Foundation is authorized and directed to initiate and support basic scientific research and programs to *strengthen* scientific research potential and *science education programs at all levels* in the mathematical, physical, medical, biological, engineering, social, and other sciences by making...arrangements to support such scientific and educational activities. (42, U.S.C. 1862, Sec. 3 as amended; emphasis is ours)

Although any agency continually reinterprets its mandate, particularly during changes in administration and leadership, the interpretation of NSF's charter to support science education has been under especially heavy consideration recently. A number of factors make that reconsideration a pressing issue:

- *Findings of National Science Board (NSB) Commissions*. The findings of the National Science Board's Commission on Precollege Education in Mathematics, Science and Technology (NSB, 1982, 1983) and its Committee on Undergraduate Science and Engineering Education (NSB, 1986) both have encouraged the Foundation to reconsider what it means to strengthen science education at several levels.

- *Overall strategic planning in NSF*. The fact that the Foundation is currently revising its strategic plans to reflect the possibility of a doubling of its budget in the next 5 years has intensified the debate about the appropriate purview of the Foundation in science education. "Education and human resources" has become a major theme in the Foundation's overall planning process and proposed budget for FY 1988 (NSF, 1987). NSF staff are in the process of working out the implications of this theme for the Reagan administration's emphasis on ensuring U.S. economic competitiveness.

- *Broad support for fundamental reform of science education*. At the same time, there is continuing pressure from the constituencies concerned about reforming the public school system to treat science as a "new basic" so that students are well prepared to participate in U.S. economic and social life (National Commission on Excellence in Education, 1983). This theme was reiterated in the findings of the NSB Commission report *Educating Americans for the 21st Century* (1983). Most of the basics referred to--such as comparative observation, critical analysis, and problem solving--are the intellectual tools on which science is based.

- *Congressional concern.* There is somewhat heavy pressure from outside the Foundation to clarify its education mission, as reflected in the congressional requirement for this study of NSF's options in education, the congressional requirement for a 5-year strategic plan in education to be updated annually, and a recent suggestion by the Congressional Science Policy Task Force Chairman that Congress consider transferring K-12 science education programs from NSF to the U.S. Department of Education (Fuqua, 1986).

The implications of pressures from these forces are particularly significant at the K-12 level. When NSF is considering career preparation of pre- and postdoctoral researchers, the mandate to strengthen education programs hardly differs from the mandate to strengthen scientific research. At these levels, NSF supports individuals who have already selected a scientific discipline and who need to continue learning in their field by doing scientific research to receive their credentials and to become fully fledged in the profession. The strengthening of science and science education are one. It is when undergraduate and precollegiate levels of education are discussed that the meaning of "strengthening science education programs" and its relationship to NSF's mandate to strengthen scientific research becomes controversial. The issues are especially problematic at the K-12 level because there it is least easy to discern who is and isn't on the scientific and engineering career track (often referred to as the scientific "pipeline") and because science education can serve so many societal goals.

An Interpretation of NSF's Educational Mandate

For reasons that we will discuss shortly, we take the following position regarding NSF's educational mandate at the K-12 level: NSF can best serve the scientific and engineering enterprise, and the society as a whole, by promoting the development of a broad pool of competent and interested science learners through the age of 18. This long-range goal for the investment of NSF's funds derives from three sources.

First, the goal rests on the assumption that, whatever else it does, NSF must always serve the scientific and engineering enterprise. The pool of competent and interested science learners is, among other things, the source of future scientific and engineering talent. There are different conceptions of how the Foundation's educational investments can best encourage such a pool. Our analysis suggests that conceptions that emphasize broadening the pool of individuals with both scientific competence and positive attitudes about science are more likely to produce an adequate supply of scientists and engineers than conceptions that stress early talent identification.

Second, there is growing national consensus about the importance of other science learning goals, related to developing scientific literacy in the society as a whole. Numerous recent analyses and commission reports, combined with the results of our own investigations, suggest that NSF has an essential role to play in promoting these learning goals, both to build a strong foundation for the scientific and engineering enterprise and to contribute to the health of a scientifically and technologically oriented society. Once again, by emphasizing the breadth of the science learner pool and underscoring the importance of maximizing interest and competence at the same time, NSF can help direct science education toward scientific literacy for the majority of students.

Third, the current pool of competent and interested science learners emerging from the nation's high schools is small to begin with and is likely to shrink in the foreseeable future, for reasons ranging from the functioning of the school system to basic demographics. This fact provides further justification for NSF to invest in efforts to reverse these trends.

We base these assertions on the following analyses:

Contrasting Views of NSF's Contribution to the Scientific and Engineering Pipeline

Two conceptions, one narrow and the other broad, are the principal contenders in the debate over interpretation of the Foundation's educational mandate at the K-12 level. The differences between the two hinge on the distinction between education as preparation for the scientific "pipeline" (future scientists, mathematicians, and engineers) versus preparation for the "mainline" (everyone else) for scientifically informed participation in other occupations and society. Figure I-1 displays these two occupational streams, as individuals move from age 5 to adulthood across levels of education and, at different levels, exit from formal schooling to assume different occupations. The two conceptions imply that NSF fulfills its responsibility to prepare individuals for the scientific and engineering pipeline through different approaches to science education at the K-12 level. However, as the figure implies, the debate over NSF's mandate in science education concerns more than just preparation for occupations.

The narrower view, focused solely on scientific pipeline preparation, contends that NSF's mandate is to be concerned with the development of advanced scientific and engineering personnel to ensure continued world leadership by the United States in science and technology. This view has most recently been justified in terms of the need to maintain the competitiveness of our nation's economy. The implications of this view are that NSF would give priority to preparation of Ph.D.-level science and engineering students; programs for those lower on the formal education ladder would get lower priority. This approach would ensure that the highest-level human resources were developed for academic research and industrial R&D. Support for others in science and engineering education would be primarily for the purpose of fostering support for the scientific and engineering enterprise and appreciating its importance to our economy.

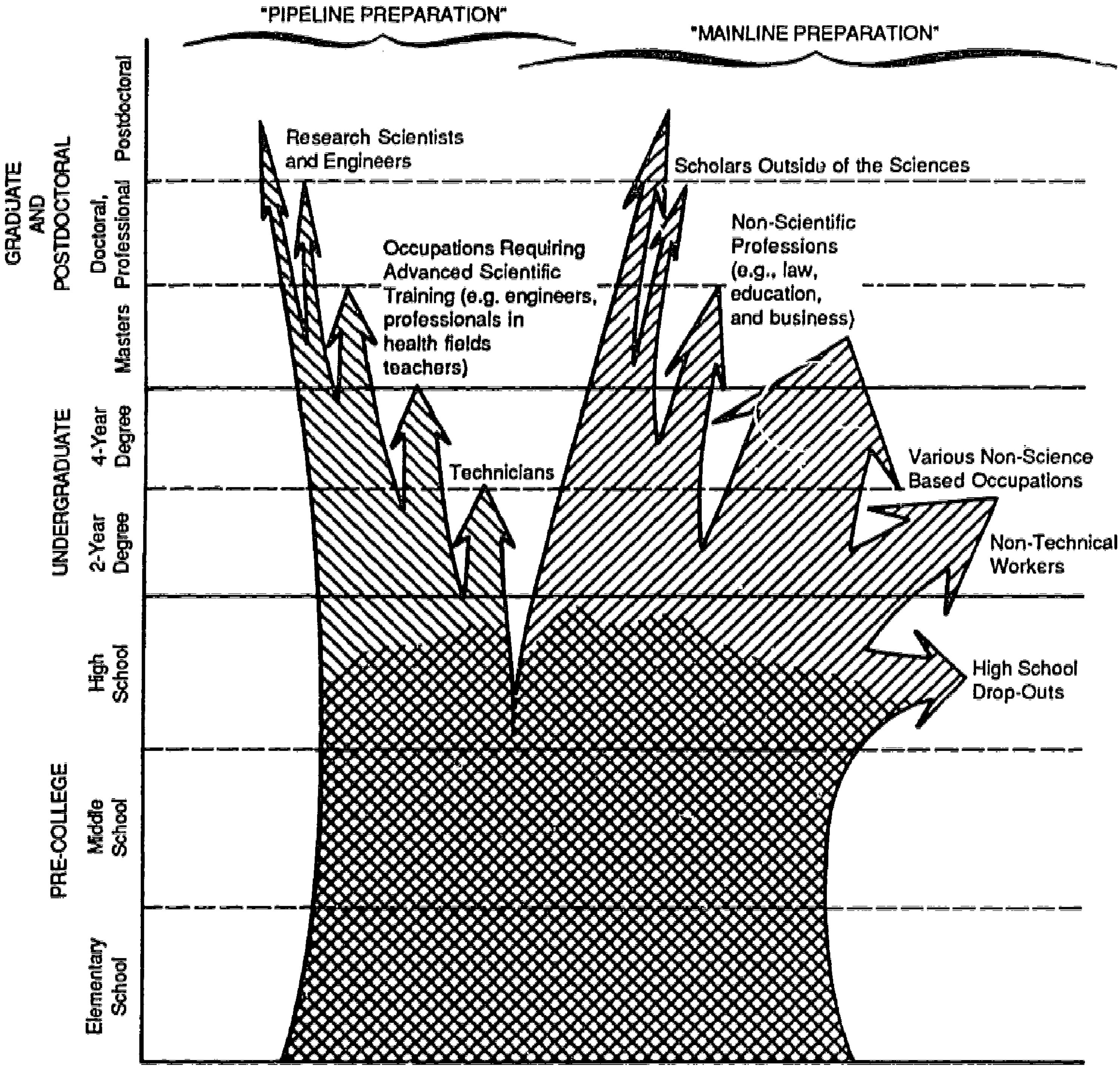

FIGURE I-1 EDUCATION IN THE SCIENCES ACROSS EDUCATIONAL LEVELS, FOR DIFFERING OCCUPATION PREPARATION STREAMS

The broader view, emphasizing preparation for informed participation in society (including preparation for scientific careers), emphasizes preparation for both the pipeline and the mainline.* In this view, NSF's concern should be the development of mathematical and scientific thinking in all individuals so that they are competent learners throughout their lives and can thrive and contribute as members of the work force, family members, and citizens. It assumes that the social and economic welfare of our nation depends on a work force and citizenry that are not just literate (i.e., able to read), but scientifically literate (i.e., able to abstract concepts from observation, hypothesize relationships, seek evidence, draw valid conclusions, and act on them in context). Not only are the facts and theories of certain fields of knowledge required, but the intellectual tools and habits of mind underlying the sciences and engineering are needed to learn and relearn on the job and in personal and social contexts.

At the K-12 level, each of these conceptions implies a different approach to developing students for the pipeline to advanced scientific research and engineering professions. One approach emphasizes "skimming the cream" off the top, i.e., identifying the scientifically and mathematically most talented students and providing them with the best learning experiences in preparation for a professional scientific career. The other approach focuses on "broadening the pool" of students who will be interested and skilled in science and who may (or may not) enter scientific and technical occupations, including research science and engineering careers. The first view assumes a "narrow and early" pipeline to scientific occupations; the second assumes a "broad and late" pipeline. The two ways of thinking about the Foundation's mission at the lower levels of education have very different implications for the kinds of initiatives NSF would support.

Skimming the cream--The first approach is selective. NSF would support the improvement of science education programs for students who demonstrate interest and capability in their early exposure to science and/or mathematics experiences. NSF's support would be aimed primarily at maintaining the interest and increasing the achievement of students who are identified early as having high potential for science and engineering careers. The Foundation would become more selective in who was provided with opportunities for enrichment or improved programs from elementary through the middle grades and high school (and ultimately throughout higher educational levels as well) until the 3% required for the highest levels of training in the professions were skimmed from the students who had risen to the top at each level. The new generations of scientists and engineers thus would arise from a group of the best students selected and provided with special science education in this way.

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* It is also possible to adopt a third view, that NSF should focus solely on mainline preparation, on the assumption that the scientific and engineering pipeline can take care of itself. We assume, however, that NSF's purview inescapably involves the development of future scientists and engineers, among other goals. There is some evidence, which we review later, that education for this occupational stream is not as sound as it could be.

The kinds of programmatic support implied include:

- Curriculum development aimed at the most able segment of the student population, as was the case during much of the NSF-sponsored curriculum development of the 1960s.

- Magnet programs that would draw students interested in science, mathematics, and engineering to schools where exemplary programs in these areas were offered.

- Programs for gifted and talented youth, e.g., science enrichment experiences offered to elementary or middle-school students who showed particular interest or capabilities in these subject-matter domains; improved advanced-placement courses for high school students.

- Research exposure programs, such as NSF's Student Science Training Program of the past or the Junior Scholars Program proposed in NSF's FY 1988 budget, whereby high school students are sponsored to participate in research projects.

Broadening the pool--The alternative approach is inclusive, rather than selective. Under this approach, NSF would be helping to prepare students for a broad range of occupational choices, from dental assistant to manager of pesticide marketing to research biochemist (K-12 science education would also provide useful background for many mainline occupations, as well). The pipeline would be broad, and the preparation for a specific career would be postponed as long as possible. Thus, NSF would be strengthening the way science and mathematics are taught to and learned by all children and youth, so that more students would be enabled to choose advanced scientific and technical careers; most students would not yet have been excluded from the pipeline by 18 years of age.

The implications for NSF's programmatic initiatives would be to support the improvement of the learning environments and the teaching methods that all students experience in elementary and secondary schooling and outside of formal schooling. This support might include such initiatives as:

- Supporting programs in which science and mathematics teachers are provided with the content and pedagogical skills to maintain students' interest and acquisition of mathematical and scientific knowledge and approaches.

- Supporting development of technologies, textbooks, and laboratory or hands-on experiences for upgrading the entire curriculum from kindergarten through 12th grade.

- Supporting out-of-school experiences in science and mathematics that motivate a mass audience of children and youth to learn more and do more and that invigorate the formal learning environment.

From the point of view of ensuring an adequate scientific and engineering pipeline, there are reasons for NSF to select this second approach at the K-12 level. By skimming the cream, NSF may not be able to ensure an adequate supply of scientific and engineering researchers in the next several decades (except through increased use of foreign nationals). First, and most important, it is difficult and often impossible to tell which students at the elementary and secondary levels will remain in the pipeline. Selective approaches to science education may miss as much talent as they identify. Second, the general level of motivation for science and mathematics is low, even at an early age (Hueftle et al., 1983). Interest in the formal study of science and mathematics drops off rapidly, starting at the upper elementary levels, perhaps including students who would have shown talent if the experiences offered had been more motivating. Third, as we explain in more detail subsequently, the size of the high school pool of students from which the cream must rise will decline over the next decade (Hodgkinson, 1985). Hence, selective approaches risk making the pool progressively smaller.

Other Important Science Learning Goals

Besides pipeline preparation, there are other important science learning goals at the K-12 level. The nationwide movement over the last 5 years to reform science education (and education generally) has put a great deal of emphasis on learning goals, as implied by the following synthesis of reform recommendations for secondary school students (Hurd, 1985):

- An overall purpose of secondary school education in the sciences is to develop scientifically, technologically, and culturally literate students for active participation in a science/technology-oriented democracy.

- The science curriculum should be a balance of science and technological concepts and modes of thinking presented as an integrative system and in the context of personal and social themes.

- The subject matter for science courses should be selected with regard to the nation's social system--its shared goals, values, and common life experiences--and for its practical usefulness in human affairs.

- The teaching of science should foster an awareness of one's personal obligations to the human community and the well-being of the nation, and provide an understanding of oneself.

- The skills to be developed in science teaching are those essential for acquiring, processing, and using information in the contexts of thinking critically, making decisions, and forming ethical judgments. These are also the skills needed for sustaining independent and lifelong learning.

These are obviously aimed at the mainline student as much as, or more than, the potential pipeline student.

The degree of consensus that has developed around these goals is remarkably strong and broad-based. These kinds of views have been expressed by broadly based national reform commissions (e.g., National Commission on Excellence in Education, 1983), professional educational associations (e.g., American Association of School Administrators [AASA], 1985), scientific societies (e.g., American Chemical Society [ACS], 1984), state governments (e.g., Education Commission of the States, 1983), private-sector groups at national and state levels (e.g., Exxon Foundation, 1984; California Roundtable, 1985), and the National Science Board of the National Science Foundation itself (NSB, 1982, 1983).

An inclusive approach to broadening the pool of competent and interested science learners at the K-12 level is much more likely to accomplish these goals than a more narrowly focused approach, for obvious reasons. By emphasizing the breadth of the pool and by attempting to maintain learners' interest in science, NSF would be addressing the needs, motivations, and occupational trajectories of the majority of students, most of whom will not become scientists and engineers. Conversely, by seeking to design and promote science education that accomplishes these other science learning goals, NSF will simultaneously contribute to a broadening of the learner pool. There are compelling reasons for NSF to assume that these goals should be part of its effort to broaden the pool:

- *Enhanced public support for the scientific and engineering enterprise.* The large numbers of learners in a broadened pool who do *not* go on to scientific or engineering careers will nonetheless have both a better understanding and appreciation of the scientific activities of the research community. This is likely to translate into public support (funding, enlightened policies governing scientific activities, etc.) without which the scientific enterprise cannot function.

- *Preparation for a broader range of scientific and technical occupations.* Broadening the pool prepares students for a wide range of occupations, more and more of which will require the intellectual tools of science and mathematics, knowledge of theories and findings, and certain attitudes and approaches to work tasks. It takes into account that engineering professionals include those who have graduated from school at bachelor's and master's degree levels as well as at the Ph.D. level. It is consistent with NSF's education and human resources thrust and the preparation of the entire technical work force--not simply those making the breakthroughs. Broadening the pool takes into consideration that the supporting cast of technicians and information processors is as essential as top scientists and engineers in maintaining economic competitiveness in the United States.

- *Contribution to the functioning and health of a scientifically and technologically oriented society.* All individuals in the pool of competent and interested science learners carry with them the ability to reason, analyze, solve problems, understand social issues, and manage technology--an ability that will become increasingly needed in all occupations as well as for personal fulfillment and participation in a democracy. By emphasizing these other important learning goals, scientists and nonscientists alike will be better equipped to cope with and contribute to the society in which they live.

Motivation and Performance of Today's Science Learners

The current (and projected) patterns of student motivation and performance in science education provide a third, and especially powerful, argument for concentrating on a broader pool of competent and interested science learners at the K-12 level.

Although there are signs of an upward trend, motivation for science and mathematics learning among the vast majority of students is generally low, especially at higher levels in the K-12 educational system (e.g., Hueftle et al., 1983; Armstrong et al., 1986). Their performance in school-based science education does not compare favorably with that of students in many other industrialized nations (e.g., McKnight et al., 1987). American students are not learning higher-order thinking or problem-solving skills to any great extent, as attested to by many employers (e.g., Cullinan and Needels, 1982). Students' aspirations for scientific and engineering careers are more limited than they might be; and their parents' expectations for their performance in these areas are surprisingly modest (e.g., Stevenson et al., 1986).

These patterns obscure the variability in interest, enrollment, and performance between girls and boys, minority and nonminority youth, or children in high vs. low socioeconomic status communities. The picture for young people with supportive families, available opportunities, and other advantages--that is, those currently most likely to pursue scientific careers--is brighter, at least in the short term. American schools, on the whole, are doing a creditable job of educating this segment of the student population, judging by the six-fold increase since 1965 in the number of Advanced Placement science and math exams taken by high school students, and their high performance on those exams (Lapointe, 1984; College Board, 1986). Attendance at science museums is up, and television programs on science have large numbers of watchers. However, representation of certain minority groups (black, Hispanic) in the stream of children and youth who are motivated and performing well in mathematics and science is noticeably low. Also, despite the fact that there is a stream of able students who are performing well on mathematics and science tests, questions have been raised about whether they are receiving the best preparation for college-level science and engineering and beyond (McKnight et al., 1987; NSB, 1986).

The challenge of improving science and mathematics education in and outside of the schools is accentuated by the profound demographic changes in the student population projected for the next two decades (Darling-Hammond, 1984; Hodgkinson, 1985). That is, a decline in the number of students at the high school and undergraduate levels through the mid-1990s will mean a decline in the supply of entrants into the work force. From the smaller entering work force, a larger proportion will be needed for scientific work. In addition, workers and professionals in all kinds of occupations will need better scientific and technical education to function effectively.

The growing diversity in socioeconomic status and increasing proportion of minority members within the student population compounds the situation: these are the kinds of students for whom science education has worked least well in the past (e.g., Berryman, 1983).

National Problems That Limit the Pool of Science Learners

Assuming that NSF takes a broad view of its education mandate, we can describe national problems and critical needs in K-12 science education. National reports and analyses, in conjunction with our own investigation, help to describe the problems in K-12 science education that limit the pool of science learners and identify where improvement is most critical. For the most part, the findings presented here represent a national challenge around which considerable consensus has developed. The nature of this challenge is by now familiar to many readers of this report; consequently, we present only a brief summary of main themes. (More detailed discussions of these problems appear, where relevant, in the essays on opportunities later in the volume.)

Before reviewing the highlights of these analyses, a few general words about the national challenge and NSF's relationship to it:

- *The scale of the problems confronting science education for children and youth is enormous.* To do something about the problem of underqualified science and mathematics teachers alone, for example, will require concerted efforts by local and state agencies and others and will require substantial resources.

- *The problems are highly interconnected and imply, for the most part, systemic solutions.* This fact implies that the energies of many groups with different relationships to formal and informal science education must converge for significant progress to be made.

- *No funder or policy actor would be well suited to address all of the problems we discuss.* No matter how many resources it has for addressing these problems, NSF still plays a "federal" role, one that reflects the Foundation's unique character and capacities. The nature of the nation's needs in science education is one, but only one, of the factors that determine what NSF's investments should look like.

The patterns of motivation and performance just described can be traced, in part, to three aspects of the formal and informal educational systems and the institutions that surround them: (1) what is taught and how it is taught, (2) the strength of the teacher force and the larger community of professionals concerned with education in the sciences, and (3) the influence of the institutions that surround and support the educational systems. The problems in these three areas differ somewhat by level within the educational system (elementary, middle, and high school) and also reflect the influence of larger societal forces.

Content and Educational Approaches

Analyses of the current situation in school-based science and mathematics education point out major problems with the content of what is taught and how it is conveyed to students. "Content" is broadly construed to include knowledge, skills, and attitudes, as embodied in curricula and conveyed by instruction or other kinds of experience. Whereas the quality of out-of-school learning experiences is improving, analysts find that the content of instruction in schools is often inappropriate with regard to (1) students' interests and cognitive development (e.g., Hurd et al., 1981; Linn, 1986); (2) contemporary ideas and theories in mathematics and the scientific disciplines; (3) the sequence, intensity, and duration of major topics in the curriculum (e.g., too much time on arithmetic, too little and too late on geometry); and (4) the nature of science and mathematics, which include ways of understanding and processes for investigating as well as "facts" (Hurd, 1985) and new terminology (Yager, 1983). Thus, for example, mathematicians and educators lament the fact that students are taught merely how to perform the steps in calculating an answer for a predefined problem. They generally do not learn such other principles and steps involved in "doing mathematics" as "abstraction," formulation," and "applications to new problems" (American Association for the Advancement of Science [AAAS], in progress).

In both mathematics and science, reformers hope for curricula that are more interesting to students, capable of serving a wider range of students, cumulative, investigatory, technologically sophisticated, cooperative, contemporary, and sensitive to social issues and applications (e.g., Hurd, 1985; Conference Board of the Mathematical Sciences [CBMS], 1983; National Science Teachers Association [NSTA], 1985; AASA, 1985; NSB, 1983; National Council of Teachers of Mathematics [NCTM], 1980).

Because of enormous variation in background, motivation, and abilities of students, the challenge of selecting the approaches to use in teaching science and mathematics to children and youth is enormous. Of course, content and approach in the teaching and learning of science and mathematics are inextricably intertwined and also reflect practical constraints in the school situation.

Strong forces inhibit substantial changes in content and approaches, among them, the dynamics of textbook adoption (Capper, 1986; Holden, 1987) and the content and process of testing, which tends to stultify the curriculum and instruction (AAAS, 1986; Raizen, 1986). New content and approaches are also difficult to implement because of the enormous number of teachers at each level who must learn new methods and change their ways. They, in turn, are influenced by state requirements regarding what must be taught. These requirements have been increasing in number (e.g., a statistics unit might be added in 10th grade mathematics), making it sometimes more difficult to try innovative approaches while "covering" more subjects.

The education reform movement has done more than raise the requirements for students to take more science and mathematics courses; it has also influenced science and mathematics curriculum planners and teachers to be more oriented to developing students' thinking and problem-solving skills (e.g., Sternberg, 1985). The fact that educators are aware of these needs does not reduce the challenge, however. The difficult job of determining how to translate "critical thinking" objectives into content and instructional approaches to teaching and learning for each age group is just in its earliest stages (Sadler and Whimbey, 1985; Segal et al., 1985).

Qualified Teachers and a Strong Profession

Arguably the most critical--and weakest--link in the science education of children and youth is the supply of well-qualified science and mathematics teachers. At the lower levels, teachers who have not themselves pursued any scientific disciplines are partly responsible for the low level of attention devoted to such subjects or methods (e.g., Weiss, 1986). At higher levels, science teachers are typically handling one or more science disciplines other than the one in which they were trained (e.g., Aldridge, 1986). Science and mathematics teachers are in short supply and promise to be more so in the coming decade, although estimates of the size of the problem differ substantially (e.g., Darling-Hammond, 1984; Feistritzer, 1986; Pelavin et al., 1984; Plisko, 1983; Romberg, 1984; Bureau of Labor Statistics [BLS], 1986; Shymansky and Aldridge, 1982).

Whereas some causes of the quantitative and qualitative problems of the school-teaching work force are deeply rooted in larger social and economic forces (e.g., demand from other industries, low status of teaching, low pay), others lie within the state and local school systems. Long-term patterns of declining enrollment (now just beginning to change at the lower grades) have meant fewer job openings for new science and mathematics teachers; in many school districts, a large pool of tenured teachers in other subject areas and in need of work have been assigned to mathematics and science teaching. Massive reassignment of teachers (teaching out of their area of specialization) appears to exist at the middle and high school levels.

It is easy to view the challenge to the science education profession too narrowly as a "teacher problem," without regard to the wider group of professionals outside the school environment concerned about the education of young people: academic or industry-based scientists, mathematicians, and engineers (e.g., cognitive scientists/engineers designing interactive computer-based learning environments; the growing cadre of non-school-based science educators in museums and in the media; and, particularly, the university-based communities of scholars and educators specializing in education in mathematics or the sciences). Science and mathematics teachers lack a strong connection with a larger and intellectually vital professional community that could provide greater intrinsic rewards and ameliorate some of the negative factors.

The community of professionals concerned with education in the sciences lacks cohesiveness and direction, by comparison with its past and its potential. A generation of leaders (many of them nurtured by NSF-supported training in the 1960s) are coming close to retirement, without good prospects for a new generation to replace them. The academic community concerned with science education lacks a central ongoing forum for sharing curricula, teaching approaches, and research results with one another. The National Science Teachers Association and National Council of Teachers of Mathematics meet this need to some extent, more through annual conferences than otherwise. Existing journals, for example, tend not to bring into effective dialogue the findings of cognitive scientists, learning theorists, and science education faculty. University-based science educators are too often isolated from the scientific disciplinary departments.

The "Infrastructure" of Science and Mathematics Education

As with education in the sciences at postsecondary levels or the scientific research enterprise itself, K-12 science education in public and private schools and the informal educational institutions has an "infrastructure," an institutional underpinning and associated support structures.

The teaching and learning of science and mathematics in formal settings happens within the 15,300 public school districts, as well as 21,000 private schools, in the 50 states. The 51,000 public elementary schools, 12,500 middle schools, and 15,500 high schools in the United States have an enormous number of tasks to perform--from teaching reading, writing, and arithmetic to sponsoring athletics and preventing drug abuse and teenage pregnancy. These systemic factors constrain what science education settings and experiences can be.

Efforts to improve science education in elementary and secondary school systems must acknowledge the role and effect of the school district administration and local school board, but also of institutions beyond school district boundaries that surround and support school science and mathematics programs: textbook publishers, computer hardware and software firms, the testing industry, the state teacher certification bureaucracy, institutions preparing future teachers, and various other education subsystems and associations. The challenge of mobilizing these groups and institutions to act in a supportive capacity--and in a common direction--for improvement is formidable.

The wave of reform initiatives has suggested new roles for publishers, public media, scientific societies, private-sector employers, the testing industry, state legislatures, and education agencies, among others, in shaping the environment within which science teaching and learning take place (e.g., National Commission on Excellence in Education, 1983; NSB, 1982; ACS, 1984; California Roundtable, 1985). Significant collaboration and experimentation has occurred among these groups and in a number of locales around the country, resulting in increased resources, involvement, and information sharing with new partners, and promising experiments in the support of science education for children and youth (Worthy, 1986). The challenge is to maintain momentum in a direction that will support the improvement of good mathematics learning and enriching science experiences for children and youth.

Differences by Educational Level

The scale and nature of the problems in each of the domains described above differ by educational level. Thus, the task of improving science education for children aged 5 to 12 is significantly different from that faced with adolescents and secondary schools. We note below some salient differences that need to be addressed.

Young children (elementary school level)--At this level, the nature of the problems depends greatly on whether we are talking about mathematics or the sciences. In the case of mathematics, whole numbers, fractions, and arithmetic computations are a major focus of the elementary curriculum for all children, through all the grade levels. The central issue in this case is the curriculum and the traditional instructional approaches associated with it, i.e., the appropriateness of the content and approach. Observers have criticized the neglect of problem-solving skills and applications; the rigid, repetitive sequence of experiences emphasizing computation and little else is another source of concern, partly because it is not good preparation for the study of mathematics in secondary school and beyond and partly because technologies (calculators and computers) make an excessive focus on computational skills obsolete (McKnight et al., 1987; NCTM, 1980; CBMS, 1983).

In the case of science, relatively little is taught--less than 1.6 hours per week on average by some estimates (e.g., NSB, 1983; Weiss, 1978). This situation is due to the generally low priority placed on science in the curriculum, the logistical problems associated with "hands on" science activities, and teachers' training in science education (many are anxious about science teaching and feel incapable of doing it effectively). More of the out-of-school experiences to which children are exposed focus on science than on mathematics, but such opportunities as museum visits, science programs on TV, and scouting or camping are very unevenly distributed among young learners.

In both mathematics and science, efforts to implement change via the school system face the problem of enormous numbers: 51,000 elementary schools and 1.2 million elementary teachers, only a few of whom (approximately 54,000) *specialize* in science teaching.

Early adolescents (middle and junior high school level)--Students at this level are extremely diverse in physical, social, and cognitive development (Hurd, 1978; Blosser, 1986). Thus, their motivation for learning and their interest in mathematics and science range from the lottery and cash register jobs to pregnancy or nuclear war to abstract principles of mathematics and science.

However, at this level, schooling tends to be organized more along the departmental lines of the senior high schools. Both the teaching staff and the curricula are often a weak--and inappropriate--imitation of the high school (Weiss, 1986). The challenge is to tune the curricula and the teachers (114,000 in science and a slightly higher number in mathematics*) in to the nature and diverse needs of this age range, including their needs for future education and occupational choice.

Older adolescents (senior high school level)--Here, the recent increases in graduation requirements being mandated by most states dramatize long-standing curricular and teaching needs while the demographic changes in the student population make it more difficult to arrive at standardized solutions.

Because of their previous negative experiences with science and mathematics in school, lack of family or community understanding or support for learning the subjects, or barriers to taking high school mathematics and science, many students choose to discontinue taking these subjects at this level as soon as the state requirements allow them to. The usual fare in high school includes biology, chemistry, physics, and sometimes earth sciences. After 10th grade biology, students begin to drop out in large numbers; chemistry and physics are "too hard," and students do not have adequate preparation in mathematics. One recent report showed that fewer than 30% of 1982 high school graduates took 3 or more years each of both science and mathematics (NCES, 1984).

Up to half, if not more, of the 94,000 science teaching staff at this level are underqualified for their jobs (based on Aldridge, 1986; Rumberger, 1984), a situation that is rendered acute by the fact that teaching assignments require them to be competent in two or more disciplines. In addition, the curriculum does not work well for most of the students who take it, and even the most able are not receiving what they might. The mathematics curriculum--with algebra and geometry taught much as it was 20 years ago--is organized ineffectively (McKnight et al., 1987). The content of both mathematics and science courses at this level underemphasizes recent knowledge, certain important skills, experiential learning (as in laboratories), and applications of knowledge to a variety of academic and real-life problems.

Undergraduate level--Although the focus of our study is on science education for students 18 years old and younger, what happens at the collegiate level has an important bearing on these issues. The structure and expectations for undergraduate-level science and mathematics set the tone for much of what goes on at lower levels, especially in the high schools. The term "precollege" science education, used at NSF for many years, makes this traditional relationship quite clear. Partly because colleges and, especially, universities generally fail to provide thoughtful introductory science courses and courses for the nonmajor, high schools emphasize physics and chemistry that are aimed at the preparation of future majors. Simultaneously, the introductory-level science and mathematics courses--if not the entire sequencing of college-level disciplinary education--profoundly shape what candidates for future teaching jobs know and how they visualize teaching it. The way in which teachers

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* Estimates of the number of middle and junior high school mathematics teachers are not available. However, estimates for all secondary school grades place the ratio of mathematics to science teachers between 1.10 (Pelavin et al., 1984) and 1.35 (OERI, 1986).

themselves were taught a subject is, quite often, the way in which they teach it to others.

The Larger Context for National Problems in Science Education

As alluded to in the discussion above, both the patterns of motivation and performance and the problems of the educational system stem from larger societal forces that shape the relative status of the professions and that influence the expectations of the public. Although these influences on the science learning of children and youth are indirect, they are powerful. Many of these factors are embedded so deeply in the nation's economy and culture that they fall outside the reach of the National Science Foundation or others concerned with educational improvement; nonetheless, they must be acknowledged, both to approach planning for improvement realistically and to identify broader targets for NSF's intervention.

We note the following patterns in the larger context for precollege science education:

- By comparison with many other industrialized nations, the American public--more precisely, parents--have relatively low expectations for their children's achievement, especially in science and mathematics (e.g., Stevenson et al., 1986).

- Although there appears to be a high degree of interest in science and technology on the part of the American public, the great majority of respondents to public opinion polls do not feel well informed about public policy issues involving science and technology (NSB, 1985).

- There are signs of an increasing sense of powerlessness in the face of technologically based issues. For example, there has been a sharp increase in the proportion of secondary-level students--tomorrow's "public"--who feel that science cannot help resolve the world's problems of energy, pollution, food shortages, and limited resources (Hueftle et al., 1983).

These cultural currents are not immutable, although they obviously do not respond straightforwardly to any particular intervention or program. Rather, they reflect the many intangibles of the national "mood" and its historical circumstances. Nonetheless, there are ways to engage the home and the public at large in activities related to the science education of children and youth that may contribute simultaneously to changes in the direction of these larger forces.

Identifying Opportunities for NSF

Given an overall goal and sense of its educational mission, NSF can search for (or create) opportunities for improving K-12 science education wherever the national needs and the Foundation's unique capabilities converge. Promising opportunities can be identified in such situations when trends or the positioning of other actors make it timely for NSF to play a role, as displayed schematically in Figure I-2 below:

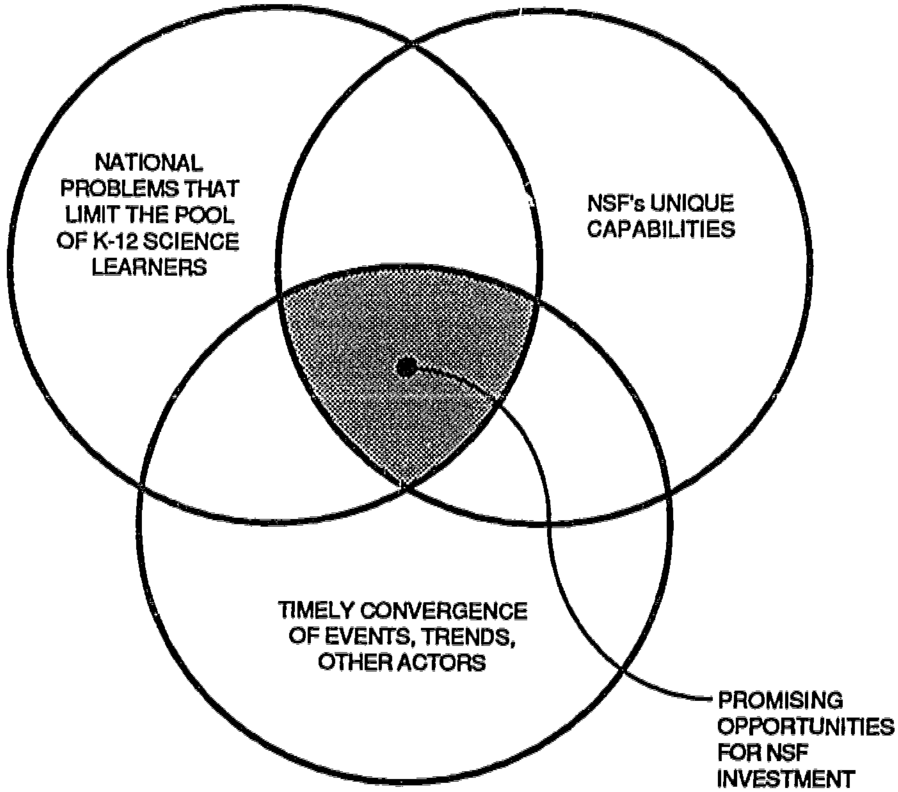

FIGURE I-2 IDENTIFYING OPPORTUNITIES FOR NSF

We have already reviewed the problems that limit the pool of competent and interested science learners through the age of 18, which are represented by one of the circles in Figure I-2. The other two circles in the figure need to be operationally defined before we can identify opportunities properly. What are NSF's unique capabilities? What makes it timely or "opportune" for NSF to address a particular problem or need?

NSF's Unique Capabilities in Science Education

In relation to other actors in this arena, the Foundation has unique capabilities in K-12 science education, which derive from general characteristics of the agency as a whole and from the capacity it has developed over the years in educational improvement activities. However, there are important differences between strengthening science and strengthening science education; consequently, NSF's capabilities in the two areas are not necessarily the same. First, NSF supports educational improvement indirectly but scientific and engineering research directly. As a consequence, NSF's presence is central to the enterprise of scientific and engineering research, but not to the enterprise of formal education at precollege levels. Second, the multidisciplinary nature of problems and solutions in science education requires NSF to be more proactive, unlike the situation in scientific research, where NSF staff typically respond to proposals from the field within a disciplinary domain. Third, expectations for NSF's investments in science education differ from expectations for scientific and engineering research support. There is little demand from Congress, OMB, and other audiences outside the Foundation for NSF to demonstrate that its support for research and engineering has paid off in terms of economic or social benefits. NSF's investments in K-12 science education, on the other hand, are expected to make observable improvements--not just in the knowledge base, but in the state of the art, in educational practice, and ultimately in student performance.

Except for the brief period when it was disestablished in the early 1980s, NSF's Directorate for Science and Engineering Education (SEE) has historically been the locus of NSF's education support programs and, as such, represents the Foundation's capability for addressing the problems and opportunities in K-12 science education. The particular features of the Education Directorate need to be taken into account in determining what roles NSF can play in addressing current problems and opportunities in K-12 education. We describe six features below, noting significant strengths and limitations they imply for the Foundation's K-12 educational capability at present.

National perspective and responsibility--The Education Directorate is the principal national-level agency with a mission of strengthening K-12 science education. This permits the Foundation to address concerns confronting schools nationwide. At the same time, because it has the ability and responsibility to adopt a national perspective, SEE cannot support programs for improving science education locally unless such projects serve as models or have ramifications for a larger segment of the population.

Flexibility as an independent federal foundation--As a federal agency, NSF has considerable flexibility in the way it carries out its mission. It can direct its funding toward the science education needs it identifies as most important. It can support grants or contracts; individuals, academic institutions, or corporate entities; conferences; research and development; training; recognition awards; or other activities. By operating directly through grants, SEE allows qualified grant recipients wide latitude to exercise their creativity. At the same time, it does not have authority to require anything of schools or school districts. SEE cannot, as the U.S. Department of Education can, regulate science education practices on the basis of funds distributed by the federal government.

As an independent grantsmaking agency, NSF does not answer to any other department of government. It has the freedom--with the consent of the National Science Board--to pursue its own agenda and develop its own programs. In K-12 science education, SEE can act almost as a private foundation does to specify its primary objectives and plan a strategic approach to achieving them. Congress has encouraged NSF (and SEE) to behave in this way, for example, by requiring a 5-year strategic plan for investments in education. Of course, in planning its own programs, NSF is not as free from political constraints as a private foundation. SEE is subject to policies of the executive branch, public and congressional demands, and the interests of its own immediate "constituency" (the community of professionals concerned with education in the sciences).

Home base in the mathematics, science, and engineering communities--SEE is part of an agency that supports research in all the sciences and engineering and, as such, it is "based" in the scientific community rather than the educational establishment (funding for SEE and any other NSF educational activities comes from a congressional appropriation for science, for example). SEE is thus close, in principle, to the source of disciplinary knowledge. This fact and the prestige associated with the Foundation's reputation for high standards based on merit-based peer review give SEE and the projects it supports a great deal of visibility and clout. On the other hand, conditions within the Foundation in recent years have not encouraged research directorates to support the Education Directorate. SEE's proximity to the other directorates helps less than it could in enlisting the support of scientists, mathematicians, and engineers outside NSF who are concerned with K-12 education.

Large amounts of discretionary funding--Relative to others in science education (including federal and state agencies, private foundations, professional societies, etc.), NSF has large amounts of discretionary funding at its disposal. In the current fiscal year, approximately $62 million in the Education Directorate's budget is allocated to programs serving the K-12 level. Although this figure is small relative to the scale of the problems in science education, it exceeds the combined annual funding for science education improvement from *all* major private foundations currently active in this area, and far surpasses the resources of other actors such as professional societies or state governments. Only the U.S. Department of Education (ED) comes close (and in the coming fiscal year may exceed) SEE's resources for science education improvement; however, ED's funds are, for the most part, disbursed through formula-allocation block grants to states and localities and are earmarked for a particular type of activity (teacher training). ED thus has little capability to direct its resources strategically in this area.

Central position relative to other groups interested in science education improvement-NSF is situated midway between disparate groups that take (or could take) an interest in science education improvement: in addition to the scientific community, NSF (SEE) has an active relationship with the private sector (especially foundations and technologically based industries), certain elements of the educational establishment, informal science education institutions of various kinds (museums, television broadcast groups, etc.), university-based mathematics and science educators, groups and individuals involved in educational research and development, and the educational publishing industry. These and other groups naturally turn to NSF (SEE) because of its national perspective, its existing relationships with members of these communities, and its role as a funding source.

The Education Directorate's track record at the K-12 level--NSF, through its Education Directorate, has a long and rich history of investment in science education at the K-12 level. To some extent, the priorities of past investments--in curriculum or materials development, teacher training, and informal science education, for example--define the areas of the Foundation's greatest capability for further investments at this level: SEE has developed its greatest know-how in these areas and its funding has helped stimulate the formation of a "constituency" that carries out such work. For obvious reasons, SEE's pattern of investments over time represents inertia as well as a capability: proposals may continue to be submitted to SEE that are, in effect, replications of past work and not responsive to new directions for SEE funding.

For reasons that stem from its recent history as much as anything else, NSF has yet to take full advantage of the capabilities represented by these six features. Put another way, the Foundation has yet to establish the extent and nature of its niche within the community of groups and institutions engaged in science education improvement.

By contrast with some earlier periods of its history, NSF finds itself in an active "field" when it attempts to address the national challenge in K-12 science education. In recent years, other actors have dominated the agenda for strengthening science education--each in its own way. State policy groups have been especially active, for example, by increasing science and mathematics course requirements for high school graduation. Private foundations and scientific societies have fostered dialogue on standards and expectations, pointing toward new directions for content and supporting exemplary science and mathematics programs for youth. The colleges of education and professional associations have been trying to fill the tremendous demand from the school systems for advice and assistance, as well as contributing to ideas about professionalizing the teaching force.

The roles NSF can play in improving education in the sciences inside and outside of schools are largely a function of how the Foundation relates to other interested or potentially interested players in the game. To determine which tasks NSF can do well by itself, which tasks it can productively pursue with others, and which tasks are best addressed by others alone, NSF must be aware of the roles others are playing vis-a-vis its own goals.

What Makes NSF's Involvement Opportune?

Awareness of the capabilities and interests of other actors is only part of the story. To address key problems for which it is well suited, the Foundation must identify trends, events, and circumstances that make its involvement timely. NSF's investment must have a high probability of payoff relative to the dollars the Foundation invests in a specifiable time frame (say, the next 5 years). The opportunity may not remain as "ripe" 5 years from now, and it may not have been so in the recent past.

Our sketch of each opportunity later in this volume will demonstrate that NSF's intervention is opportune in one or more of the following ways:

- *A critical mass of participants exists, but lacks the stimulus or resources to coalesce and move forward.* For example, a sufficient number of science learning centers and museums are in place in major urban areas to provide the potential for a permanent extension of the schools' science learning and training resources, with a potential to reach a significant portion of the nation's students and/or teachers.

- *Important ideas or issues are emerging, but are not yet widely understood, appreciated, or thoroughly explored.* For example, scientists and mathematicians have recently agreed on the importance of statistical and probabilistic thinking in science, engineering, and everyday life. This realization has yet to be integrated into science and mathematics curricula at the elementary and secondary levels.

- *Momentum is building toward reform, but is unlikely to be sustained or applied to science education without an additional push.* For example, the recent Holmes Group (1986) and Carnegie Forum on Education and the Economy (1986) reports have generated considerable momentum toward a reform of teacher education, which paves the way for NSF to consider the specific implications of these movements for science and mathematics teachers.

- *Trends or a change in trends makes a particular unaddressed issue or course of action more salient.* For example, the demographic trends in the student population over the next 10 years--e.g., toward a smaller, more diverse student body at the high school level--make the search for science curricula that work well for this kind of student body especially opportune.

- *New knowledge or technology has recently became available, but is unlikely to be applied effectively without focused support.* The present capability and spread of microcomputers and the software for them in elementary schools, for example, make it possible to integrate mathematics and science in ways that were heretofore difficult because of the limited computational skills of young students.

Defining an area of opportunity relies on expert opinion and intuition as well as analysis. No crystal ball exists that can protect against the possibility of a poor judgment regarding likely effectiveness. But there are clues to poor choices. One such clue is evident when the absence of the above factors suggests a lack of readiness for action. For example, heavy investments in the development of videodisc-based science courses for the purpose of achieving widespread immediate impact on schools may be ill-timed at present because, unlike the microcomputer, this technology has not yet dispersed among schools or homes to a point of critical mass, nor has an industry-wide standard for the disc itself been established. This fact does not preclude NSF from considering exploratory research in this area, however, to determine the capabilities of the technology or to stimulate further the hardware base in the schools. Five years from now, however, the situation may be radically different; then, investment in videodisc courseware development might realize wide impact in science classrooms.

The Universe of Opportunities

Although the 10 opportunities we discuss cover a great deal of ground, they do not exhaust the possibilities for NSF action. We have concentrated our efforts on a realm of opportunities that emphasize schooling, from kindergarten through 12th grade, and the informal science learning experiences that parallel the schooling process. Where appropriate, we include connections between students' science learning in schools and their experiences at home or what takes place at the collegiate level.

There are other realms of opportunity that are more indirectly related to the science learning of children and youth, but that are no less powerful. In particular, the societal, cultural, and economic forces alluded to earlier are strong influences on public images of science, which in turn shape young people's preferences and occupational choices, including the decision to enter the teaching profession. We have not considered the full range of possibilities in this larger realm, for several reasons. First, many of NSF's options involve primarily an effort to address the adult world; although a worthy goal, this lies beyond the scope of our investigation. (It has also been addressed by NSF through its former Public Understanding of Science Program, and to a lesser extent through its current Informal Science Education Program.) Second, influencing societal values is an extremely ambitious, and politically risky, business.

Within the realm of opportunities that are more specifically focused on young learners, we have tended to define opportunities in terms of both a specific target (e.g., the content of middle and high school mathematics curricula, state science education reforms) and the generic action available to NSF (e.g., to support a reconceptualization process, to provide technical leadership). We have not used categories of activity (teacher education, technology, research) as the rubric for defining opportunities, although these are an integral part of many of the opportunities we describe. We prefer to view these activities as means to an end, rather than as ends in themselves.

Categories of Opportunity

NSF's opportunities can be described in three groupings, each corresponding to one of the three problem areas in science education described earlier. Each grouping represents a different role for the Foundation to play.

(1) *To guide the search for appropriate content and approaches.* Here NSF's role emphasizes intellectual leadership in the science education community by supporting work that extends the state of the art and examines and extends the fundamental assumptions that underlie current practice. The long-range goal is to set the standard for excellence in science education, define alternative conceptions of curricular content, and generate intellectual excitement among the various collaborators who contribute to the process.

(2) *To build the professional community concerned with education in the sciences.* Here NSF's role is to concentrate on the people who form the diverse community of professionals concerned with science education and on the interactions among them. The long-term goal is to build a more coherent and vital professional community, including individuals on the front line of instruction, research scientists and engineers, and individuals in intermediary positions.

(3) *To provide content-related professional leadership among groups and institutions in the educational infrastructure.* Here NSF acts as a leader, for particular matters within its realm of expertise, among the institutions (publishers, state education agencies, etc.) that form the support systems for formal and informal educational institutions. The long-range goal is to improve the advice, information, flow of resources, etc., directed at those who work directly with children in formal or informal educational settings.

A list of the 10 opportunities we have identified, organized into these categories, appears in Table I-1.

Opportunities in Strategic Perspective

Identifying suitable opportunities and initiatives related to them for NSF investment is only part of the process for the Foundation to develop an effective strategic presence in K-12 science education. As we explain in the *Summary Report* and in greater detail in *Volume 2 - Groundwork for Strategic Investment*, NSF (SEE) has other important tasks that it must consider:

- *Supporting "core functions" in science education*--that is, non-goal-directed investments aimed at promoting professional interchange, building the base of information and knowledge about K-12 science education, and maintaining support for open-ended innovation. NSF (SEE) must do these things both to guide its own planning and as a resource to the science education community.

- *Developing an overarching strategy* that orchestrates and rationalizes investments related to content and approach, the strength of the professional community, and support for the science education infrastructure. Such a strategy (not yet clearly formulated or articulated by SEE or NSF as a whole) will help guide the choice of initiative, send clear signals to the professional community and political groups, make the best use of limited resources, and help to coordinate SEE's internal operations.

The reader is referred to the *Summary Report* and *Volume 2 - Groundwork for Strategic Investment* for more extended discussions of these matters.

Table I-1

PROMISING AREAS OF OPPORTUNITY FOR NSF'S INVESTMENT IN K-12 SCIENCE EDUCATION

Guiding the Search for Appropriate Content and Approaches

1. To reconceptualize K-12 mathematics curricula and associated instructional approaches

2a. To rethink the approach to, and settings for, elementary science education

2b. To recast the content of middle and high school science curricula

3. To match science and mathematics education to different groups in a diverse student population

Building the Professional Community Concerned with Education in the Sciences

4. To bolster the support cadre serving science and mathematics teachers

5. To help attract and prepare the next generation of qualified mathematics and science teachers (high, middle, and elementary specialists)

6. To strengthen the informal science education community

Providing Content-Related Leadership in the Science Education "Infrastructure"

7. To improve and expand science and mathematics education publishing capabilities

8. To improve science and mathematics testing and assessment

9. To provide content-related professional leadership for state science and mathematics education reform

10. To expand informal science learning resources and enhance their contribution to school-based programs

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PART ONE: OPPORTUNITIES RELATED TO APPROPRIATE CONTENT AND APPROACHES

What is taught and how it is taught are central problems in science education, and NSF has a great deal to contribute to their solution. "Content" must be broadly construed to include knowledge, skills, and attitudes, both as embodied in materials and as displayed in instruction. NSF can guide the nation toward conceptions of science education and teaching that are more responsive to current and future needs, and that reflect more accurately the processes and ideas of science.

The most attractive funding initiatives for addressing content-related opportunities tend to emphasize long-term, fundamental restructuring of curricular content and approach rather than short-term incremental improvements. As a consequence, there tends to be a heavy emphasis on research, exploratory development, and experimentation.

Appropriate Content and Approaches

Too easily and too often, the "content" of science education is equated with the knowledge that the school curriculum explicitly intends to convey. We prefer to consider questions of content more broadly, so that the following are included: (1) *knowledge*, e.g., facts, concepts, principles, theorems; (2) *skills*, e.g., the ability to think scientifically, to observe, record, and interpret data, to evaluate information critically; and (3) *attitudes*, e.g., the value learners associate with science and mathematics, their interest in pursuing activities that are mathematical or scientific in nature, their beliefs about the utility of science or technology and their own ability to control it.

We also resist equating issues of content with those that arise in curriculum design, although the two are obviously related, because questions about the fundamental assumptions underlying curricula are too easily ignored. Without belittling the importance of translating scientific content into practical experiences, we see more pressing opportunities for NSF and the nation as a whole involving fundamental content issues, including those related to the subject disciplines and the connections among them, and the way scientific skills and attitudes are built into the curriculum, as explained in the opportunity essays that follow.

These kinds of issues raise difficult questions about the content of science and mathematics education that beg to be resolved. The challenge to NSF is to guide the search for *appropriate* content. The content must be suited to the purpose of science and mathematics instruction, as discussed earlier in this report, which is to develop the broadest possible pool of youths who are interested in science and mathematics and able to apply scientific and mathematical thinking to a wide range of applications, including the consideration of issues that are not limited to the pursuit of a scientific career. The content must also be appropriate to the nature of the learners. Assuming a goal of developing the widest possible pool of learners, the content must be framed in terms that are understandable and appealing to the majority of students. At the same time, content must be conceptualized so that learners with different degrees of sophistication can learn it.

The Opportunities at a Glance

Our analyses point to three opportunities in this area. The first involves rethinking what it is students are to learn in K-12 mathematics:

- *Opportunity 1: To reconceptualize K-12 mathematics curricula and associated instructional approaches*. Starting in the earliest grades, mathematics education acts as a critical filter for students who might develop scientific interests and skills. To broaden the pool, K-12 mathematics curricula (and instruction) need to be reconceived to reduce the repetitive focus on computation, to broaden the attention to other skills and topics (mathematical problem solving, probability and statistics, computer science, etc.), and to explore more thoroughly the various applications of mathematics. NSF (SEE) has made a good start at supporting efforts by the mathematics education community to reconceptualize mathematics (e.g., in relation to the computer and the calculator at the elementary level). Further investment is necessary, however, if this kind of thinking is to be extended to all grade levels and translated into workable curricular prototypes. The Foundation should consider comprehensive curriculum development, further support for efforts to set standards for the mathematics education community, and development of new software for mathematics instruction.

A parallel opportunity exists for the natural sciences (because of the less sequential nature of this subject area and substantial differences between educational levels, we present the opportunity in two parts):

- *Opportunity 2a: To rethink the approach to, and settings for, elementary science education*. This level of education is especially critical, given the mission of broadening the pool of competent and interested science learners and the fact that the population of students in the elementary schools is beginning to grow once again. These students' exposure to science has remained limited, despite NSF's earlier attempts to develop effective "hands-on" curricula. The massive systemic barriers to effective science instruction at this level call for further experimentation, with new approaches that build on what has been learned from "hands-on" science education and, at the same time, question the fundamental assumptions of these and other approaches. NSF (SEE) has recognized the need by making the elementary level a funding priority and is currently supporting work that explores several aspects of the problem. However, these projects are unlikely to achieve the bold rethinking that seems called for. The Foundation can expand its investments through appropriate research and large-scale field experiments on particular types of promising solutions (technology-based solutions, specialist systems, curricular integration, etc.).

- *Opportunity 2b: To reconceptualize the content of middle and high school science education.* In line with the overall goal of broadening the pool, the science education reform movement of the past half dozen years sets the stage for a thorough reconstruing of the content (knowledge, skills, attitudes toward science) of the science curricula taught to middle and high school students. Specifically, reform manifestos have called for greater effectiveness in teaching science to the majority of students, but this goal has yet to be translated into guiding conceptions (e.g., frameworks, course sequences). NSF's (SEE's) current and projected investments related to this opportunity concentrate on pieces of the problem: modules, new technological applications, experiments with "science, technology, and society" courses, etc. Investments aimed at the problem as a whole are needed to promote powerful new visions of learning in the natural sciences across these levels of education. NSF (SEE) should consider supporting high-profile national task forces to generate alternative curricular conceptions and initiate a process of developing professional consensus. At the same time NSF should support "bottom-up" experimentation with curricular prototypes by individuals and groups in the professional community.

A third opportunity reflects the fact that science and mathematics education must work for an increasingly diverse student population--in particular, for female and minority learners, who have not been well served by most past and present programs in these subject areas:

- *Opportunity 3: To match science and mathematics education to diversity in the student population.* Demographic changes in the student population, among other things, underscore the importance of renewing the quest for more satisfactory K-12 science and mathematics experiences for underrepresented groups, especially female and minority students. NSF's (SEE's) policy of the past 4 years--encouraging all proposals to consider the needs of these groups--has proved ineffectual so far: only a few projects address these needs. The answer is probably not a wholesale return to targeted, equity-oriented programs as in the 1970s; nonetheless, SEE should consider a variety of approaches, including student support programs, research on particular groups of students in relation to science learning, curriculum development targeted for the non-college-bound, and aggressive promotion of currently operating exemplary models.

Opportunity 1

TO RECONCEPTUALIZE K-12 MATHEMATICS CONTENT AND ASSOCIATED INSTRUCTIONAL APPROACHES

Starting in the earliest grades, mathematics education acts as a critical filter for students who might develop their interests and scientific skills. To broaden the pool of science and mathematics learners, mathematics curricula (and instruction) at grades K-12 need to be reconceived to reduce the repetitive focus on computation, to broaden the attention to other skills and topics (mathematical problem solving, probability and statistics, computer science, etc.), and to explore more thoroughly the various applications of mathematics. NSF has an important opportunity to bring about this reconceptualization by supporting efforts to rethink and restructure what is taught in mathematics (knowledge, skills, and, to the extent possible, appreciation of mathematical thinking) and associated instructional approaches. The target group is the full range of students, not only those likely to pursue mathematics, engineering, or the sciences in postsecondary institutions or in their careers.

This opportunity is similar to one that NSF faced in the late 1950s, when it initiated a 15-year program of curriculum and course improvement that also involved rethinking the approach to mathematics in grades K-12. At that time, a wide range of exploratory development and research was supported in mathematics education (e.g., Unified Science and Mathematics for Elementary Schools, or USMES; the Madison Mathematics Project, or MAD-M), producing curriculum units, films for teachers, and other materials, but not complete curricula. The earlier NSF-sponsored efforts also generated several complete, high-quality mathematics curricula (e.g., the School Mathematics Study Group, or SMSG, grades K-12; the Secondary School Mathematics Curriculum Improvement Study, or SSMCIS, grades 9-12) that were influential and worked well with the more able students and teachers, but that were less successful with the others, for whom they were not designed (Howson et al., 1981).

The current situation presents a somewhat different challenge: to rethink the content and approach of mathematics curricula that work well for a wide variety of students and also provide an adequate foundation for those most likely to pursue scientific and engineering careers. Not only has the target population changed, but, more importantly, so have the goals for the teaching of mathematics (Kulm, 1986), reflecting new technologies (notably the calculator and the computer), new topics (e.g., statistics, algorithmic thinking), and new approaches (e.g., mathematical modeling).

Rethinking K-12 Mathematics

The typical mathematics curriculum for American students is not satisfactory at present. It needs to be reconceived and restructured for at least three reasons:

- Unsatisfactory student achievement
- Lack of attention to new mathematical tools and applications outside of school
- Declining interest and enrollments.

In mathematics, even the best American students stack up surprisingly poorly on national and international tests of achievement. For example:

- Nine-year-olds, who perform well on items testing arithmetic computation skills, do relatively poorly in thinking through and setting up problems, even problems whose numerical solution requires only computation. Indeed, this finding from the first two National Assessments was so striking that it helped lead the National Council of Teachers of Mathematics (NCTM) to make problem solving the centerpiece of its recommendations for school mathematics in the 1980s (Carpenter et al., 1983; NCTM, 1980).
- In addition, there are a number of mathematical topics on which, unlike arithmetic, elementary students do poorly. Notable among these is geometry; measurement, uses of data, and other topics also show low performance.
- Research supported by NSF shows that American students are behind Japanese students beginning in 1st grade, and the gap grows larger at higher grades (Stevenson et al., 1986). In comparing a large number of American, Chinese, and Japanese 5th-grade classrooms, the lowest-scoring Japanese classroom scored *above* the highest-scoring American classroom.

Results from the Second International Mathematics Study (also supported by NSF) allow comparisons of American students with those from more than a dozen other industrialized nations (McKnight et al., 1987). Findings include these:

- Although American 8th graders score slightly above the international average on arithmetic, they score well below the international average on problem solving and geometry, among other topics, and in their overall score.
- American students taking calculus were about at the international average on the topics tested; however, a considerably smaller percentage of the total age cohort in the United States (about 3%) take calculus than in most other countries.
- American students taking precalculus fell substantially below the international average, in some cases below the 25th percentile.

Such low achievement in mathematics, even by our best high school seniors, would be considered a problem in most eras, but there are particular reasons why a great many people are concerned today about low achievement in mathematics. These include concern about educational achievement and reform generally, growing worries about international economic competition, and a widespread belief that mathematics education is especially important in achieving state and national economic goals, as well as personal goals. Given the disappointing overall achievement of American students in mathematics and these other concerns, it is not surprising that more states have raised high school graduation requirements for mathematics than for any other subject (Pipho, 1986).

In addition to patterns of student performance, the lack of attention in current mathematics education to new mathematical tools and applications is a major cause for concern. The National Science Board Commission on Precollege Education in Mathematics, Science and Technology expressed its belief that new educational goals in mathematics would require new and better curricula emphasizing broadly applicable "thinking tools" (NSB, 1983). Providing students a greater familiarity with and understanding of data and statistics, increasing the emphasis on problem solving, giving more attention to discrete mathematics (the mathematics of the computer), as well as teaching the use of calculators and computers are all among the new educational goals that are frequently discussed (e.g., NSB, 1983; CBMS, 1983, 1984).

Despite the fact that these and other topics (e.g., measurement, spatial or geometric thinking) are considered important by mathematics educators, most elementary teachers appear to believe, as they did a decade ago, that their sole responsibility in mathematics teaching is to develop student facility in arithmetic computation (Fey, 1981). Because these attitudes do not match the needs of society or of the students who will live in it, the attitudes of teachers and their instructional practices need to change, as well as curriculum materials.

The calculator and the computer need to be included in mathematics classes not only because they will be useful tools for students to use outside the classroom, as important as that is. In addition, the calculator and the computer create a new environment for learning and are the basis for new ways to teach that have dramatic implications for both course content and approach (Romberg and Stewart, 1984). The visual nature of computer graphics permits dynamic representations of graphs, two-dimensional views of solids, and many other things. These allow students to learn some concepts faster and/or better, and they also permit the order of presentation of topics to be changed substantially, so that some "advanced" topics become accessible at a much earlier age (e.g., the concepts of calculus may be much easier to understand, years earlier, with computer graphics).

The calculator and the computer also pose still another challenge to the traditional curriculum. According to one mathematician's tongue-in-cheek remark, "two-thirds of all elementary school mathematics is taught in order to make calculators and microprocessors obsolete" (Romberg and Stewart, 1984). How much time should be devoted in elementary school to drill and practice of multi-digit long division, when few people outside the classroom do such problems by hand? The question of how much rote or mechanical mathematics should be taught will be increasingly relevant at higher levels of education, too; for example, microcomputer-based software can now solve many standard calculus problems (*Mathematics Teacher*, 1983).

An additional reason for concern about the current mathematics curriculum is that American 17-year-olds list mathematics as their least-liked subject. At the same time, school districts, reformers, parents, and others wish they would voluntarily enroll in more high school and college mathematics courses. Voluntary enrollment is not likely to happen unless the incentives for learning mathematics change.

It is true that more than 40 states have increased high school graduation requirements in mathematics in recent years (Pipho, 1986), and that this has increased the average number of mathematics courses that students take. However, students' motivation or incentive to take mathematics may not have changed at all. It is not clear whether the average number of high school mathematics courses taken has gone up simply in step with the new minimums, nor is it clear to what extent students are voluntarily enrolling in additional college mathematics courses. As a baseline, we know (using the most recent available data) that in 1982, fewer than half the graduating seniors had taken 3 or more years of high school mathematics (NCES, 1984), a figure that the National Commission on Excellence in Education and many other influential groups have suggested is far too low (National Commission on Educational Excellence, 1983).

Content and Approach: Some Guiding Themes

In speaking about education, people often try to distinguish between the content of instruction and the way that content is presented to students, the approach. This separation is useful--for example, one can separately fund curriculum development and, say, studies of instruction. At the same time, the separation has its limitations, which is one reason why the phrase "curriculum and instruction" is so often used instead of just one term or the other.

Content and approach are necessarily interdependent. The *content* of some of the innovative high school science courses of the 1950s and '60s, for example, included, a change in *approach*, emphasizing inquiry and open-endedness. Conversely, teachers who sharply changed their approach to an innovative course could change its character completely, by "using it in traditional ways never intended by the originators" (Pallrand and Lindenfeld, 1985).

Notwithstanding these caveats, which show how closely linked content and approach are, the two elements can be used to distinguish between the changes needed at the elementary school level and those needed at the middle and high school levels. Broadly speaking, the pressing need at the elementary school level is to change the approach to mathematics, whereas at the high school level there is a greater need to change and reorder content.

Elementary School

By almost anyone's reckoning, mastery of basic arithmetic will remain a very important goal of the mathematics program at the elementary level. However, additional goals are also important, notably problem solving and learning to "think mathematically" (NSB, 1983). Even if proposals to focus more attention on measurement, data analysis, computers, and other topics are implemented, for the most part the mathematical content that is considered important at this level will not be unfamiliar to teachers. Rather, the problem is, as Dr. Edward Begle, a mathematician and director of the School Mathematics Study Group, used to say,

> We have learned to teach better mathematics; now, we need to learn how to teach mathematics better. (Sobel, 1986)

The fact that American elementary school students fall behind in problem solving based on arithmetic underlines this remark. It does not seem to be content they are lacking, but understanding. Some specific aspects of the problems with content and approach at the elementary level follow.

Repetition and lack of intensity are the norm--Within recent years, it has become increasingly clear that a major problem with the elementary mathematics curriculum is its "lack of intensity" (McKnight et al., 1987). The report of results on the American portion of the Second International Mathematics Study, entitled *The Underachieving Curriculum,* describes the "spiral" curriculum in the United States, which reintroduces subject matter from year to year, as inefficient and unnecessarily repetitive. It "needs to be reconsidered, and alternative arrangements explored" (McKnight et al., 1987).

Another way of looking at the problem of unnecessary repetition is to turn it around and ask how much new material is introduced each year. A researcher at the University of Chicago examined each page in several popular mathematics series and categorized a page as "new" if *any* material on the page would be new to the student, even a bonus problem. The results show that in grades 4-8 the overall average of new pages in popular textbooks is well under 50%, and in grade 8 only 30% of the pages have new material. The author writes:

> The new content students [in grade 8] do encounter is covered primarily at the end of the year *if* the class covers most of the book.... We say we want students to be active and creative problem solvers, yet we set up an environment which seems designed to discourage them from thinking about new ideas--in short, an environment designed to put them to sleep. (Flanders, in press)

The calculator and computer need to be integrated--For many years, leading mathematics educators have recommended that the calculator and, more recently, the computer be an integral part of the mathematics curriculum (CBMS, 1975; NCTM, 1980). Actual implementation in the schools has lagged behind the ideals recommended. Although some locales are making definite progress (e.g., the state of Connecticut will be making a calculator available to every student in the 8th grade, and the "Mathematics Framework for California Public Schools" states that calculators should be used from the primary grades onward), availability of the equipment does not ensure its appropriate use, and there is still much to be done toward preparing teachers to use these technologies wisely (California State Department of Education, 1985).

Calculators and computers have a very wide variety of applications, as has been mentioned. One important one is permitting the use of real-world, "messy" numbers (not whole numbers or simple fractions) from a wide variety of applications, allowing students to engage in more work with interesting problems that have not been prepared to "come out right." The overlap of science with mathematics, such as in data analysis, becomes much easier to take advantage of, rather than being a barrier (e.g., multiplying many sets of decimals can be done by the computer).

The rigid structure needs to be changed--Students in elementary school rate mathematics as one of their favorite subjects, but by high school that rating has changed dramatically. The reasons are not altogether clear, but a certain rigidity in the way mathematics is taught seems to be a major factor. Last year a researcher from the University of Chicago studied 5th-grade mathematics and social studies classes, and found:

> In math, one way of teaching and learning dominated: students watched a teacher demonstrate a procedure--such as how to multiply fractions--then practiced it alone at their desks.... Except for rulers in a few classrooms, students used only pencils, paper, and textbooks.... Although taught by the same teachers, social studies lessons varied much more--from day to day within classrooms and from one classroom to the next. Group work complemented whole class instruction, and children spent less time laboring alone at their desks. The curriculum explicitly stressed independent learning and the development of research skills, so students consulted maps, encyclopedias, and newspapers, as well as textbooks. (Featherstone, 1986)

This is a problem that continues throughout middle school and high school mathematics, but students' expectations are formed in elementary school.

Agreement on revised goals and topics is needed--Eventually, to rethink content and approach on a national scale, some consensus will be necessary concerning new goals, specific topics, and the levels at which they should be taught. Without a consensus, publishers will find it difficult to develop and market significantly different textbooks. There will never be a single national curriculum, but neither is it practical to have 50 or 16,000 significantly different curricula.

The need for including new topics and new instructional approaches in elementary mathematics has been identified by a variety of individuals and groups. Mathematicians, on the whole, would be delighted to see less emphasis placed on paper-and-pencil arithmetic. In its report to the NSB Commission on Precollege Education in Mathematics, Science and Technology, the Conference Board of the Mathematical Sciences advocated more experience with collection and analysis of data, early use of calculators and computers, and more emphasis on mental arithmetic, estimation, and approximation; less paper-and-pencil arithmetic would make more time available for these topics (CBMS, 1983). A later report by the same group, *New Goals for*

Mathematical Sciences Education, states that "the fundamentals of mathematics desirable for students at elementary, secondary and college levels have, in the view of many mathematics educators, changed radically, yet the changes are not reflected in core curricula" (CBMS, 1984).

This latter report advocated creation of a new Mathematical Sciences Education Board (MSEB), under the National Academy of Sciences' National Research Council, to help facilitate change in mathematics education. The Board was subsequently formed and has a diverse membership. It has been able to publish strong, unified statements about changes the members believe are needed, and plans to publish a *Report to the Nation* in 1988 as part of its effort to speed up the process of change.

Agreement now seems widespread on the importance in the curriculum of problem-solving skills, applications of mathematics to a wide variety of situations, and use of the calculator and computer as tools for teaching and learning mathematics. There is also a consensus on the importance of introducing probability, statistics, estimation, and at least some geometry at earlier ages than has been traditional in the United States.

There are signs that the base of consensus can be broad, including more than the mathematics education community. The views of business and industry, for example, are increasingly important in rethinking education (e.g., in the growing number of school-business partnerships). In 1985, business leaders at the highest levels issued a report on education, entitled *Investing in Our Children.* This unusual document in one section reported that a survey of many firms found that employers put a high premium on a high-quality education at the elementary level and on problem-solving skills, in particular; however, like the groups cited above, they do not think that the schools are doing a good job of developing such skills (Committee for Economic Development, 1985).

Consensus is important because it not only helps identify what needs to be done, it also helps get it done. Many of the barriers to improving elementary mathematics education will require widespread cooperation if they are to be overcome.

Middle and Secondary Schools

Mathematics is widely regarded as a "critical filter"--that is success in mathematics opens entry to many fields, from accounting to zoology. Failure, or dropping out, blocks entry. The filtering seems to intensify in middle school and high school, especially for females and minorities (Berryman, 1983).

Changes in content and approach at these levels cannot happen in isolation. Even more than the sciences, mathematics is a sequential and cumulative discipline in which prerequisites need to be fulfilled before moving along to a new topic or a new course. Widespread change in the content and approach to mathematics at the elementary level will therefore have consequences at the middle and high school levels. Some ongoing curriculum revisions are aimed at the entire K-12 enterprise (such as the University of Chicago's School Mathematics Project, funded by a private foundation). Other projects will need to be mindful that changes at one level have impacts on other levels. The following are some specific aspects of the problems of content and of approach at the middle and high school levels.

New tools need to be integrated, and new needs reflected in the curriculum--Even more than at the elementary school level, the calculator and especially the computer are likely to have a significant impact on content and approach. As discussed above, these devices are tools; they are instructional aids, and they raise important questions about which topics are important and which are not. Greater attention to discrete mathematics and to probability and statistics are recommendations whose feasibility is due partly to the widespread availability of the computer (NSB, 1983).

One analyst, looking only at the school algebra curriculum, suggested that additional emphasis be placed on a number of topics: "programming, attention to recursion and iteration, inclusion of flow diagrams and approximate solution procedures, and attention to errors in approximate calculations" (Coxford, 1985). That is, in a sense, the "conservative" view, which also holds that much of the current algebra curriculum needs to remain in place. A college mathematician who has been involved in curriculum reform at the college level (where much high school mathematics is needed), believes that emerging hand-held symbol manipulators (super calculators) will make most of the algebra curriculum obsolete. He believes there is:

> No sound argument...claims that high school students must be very skillful at polynomial algebra, trigonometric identities, the solution of linear or quadratic equations or systems of equations, or *any* of the myriad manipulative tasks that are part of the current high school mathematics curriculum. (Ralston, 1985)

It is not yet clear what changes will finally be wrought on the secondary mathematics curriculum, but they are bound to be substantial.

For more than a decade, mathematics educators have been calling for more opportunities in the curriculum to apply mathematics in as wide a realm as possible (CBMS, 1975). The calculator and the computer make this goal much more feasible, through the application to many topics of mathematical models, dynamic pictorial representations, etc. (NSB, 1983).

Also, although prominent mathematics educators have generally objected to the categorization of computer science courses as mathematics courses, algorithmic thinking "as an essential part of problem-solving" is accepted as an important aspect of secondary school mathematics (NSB, 1983).* Aspects of computer science may well become part of

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* A separate commissioned paper prepared for this study (Soloway, 1986) examines computer science in K-12 education as a possible area of investment for NSF (SEE). The paper does not treat computer science as part of the mathematics or science curriculum per se, but rather as a set of learning goals that may be part of the overall school curriculum in various ways. See *Volume 2 - Groundwork for Strategic Investment.*

a reconceptualized mathematics curriculum as a device for teaching problem-solving skills or the "synthesis" skills that are basic to design-oriented activities such as engineering (Soloway, 1986). In practice, instruction in algorithmic thinking will often involve use of computers in the mathematics program.

Reorganization of content is needed--The placement, sequence, and duration of topics in the typical middle and high school curriculum are a big part of the problem. For example, the year-long high school course in geometry, unique to American schools, has doubtful efficacy (NSB, 1983). A number of groups have recommended that it be spread across several years. In contrast to the "diluted" elementary curriculum, the geometry course often packs too much into one year, making mastery very difficult for many students. At the end of a full-year course in geometry in which proof writing is studied, about 25% of the students have virtually no competence writing proofs; another 25% can do only the simplest proofs (Senk, 1985). Earlier attention to some basic geometric concepts is one suggested remedy.

Reorganization of content extends beyond geometry, and can affect a very substantial portion of the mathematics curriculum. New York State has gone so far as to eliminate the traditional algebra 1, geometry, and algebra 2 courses. Instead, a 3-year sequence of integrated mathematics has been substituted for college-bound youngsters (Paul, 1986). Even if few other states take this particular approach, it appears certain that reorganization is needed and will eventually be reflected in many high school mathematics textbooks. Inclusion of aspects of computer science, some statistics, and a wide variety of applications of mathematics can be made possible in part by reorganization and streamlining.

Motivation is not great and needs to be changed--Problems of students "stopping out" of mathematics at the high school level have already been discussed. So has the dramatic decline in interest in mathematics that takes place between elementary school and high school.

Lack of interest at the high school level is not restricted to mathematics classrooms, of course. In fact, student disengagement and passivity have been noted in many of the education reports of the last 5 years. A Study of High Schools (partly sponsored by the National Association of Secondary School Principals), looked especially at the middle range of students and found:

> These self-proclaimed average students...expected courses to be boring, but they did not complain. And they never complained that too little was expected of them. 'Why should we? We just want to get out....' Little was expected of them, apart from orderly attendance, and they gave nothing beyond the minimum. (Powell, 1985)

Other research, based on more than 1,000 schools, identifies a profound passivity among students:

> Few activities call for or even permit active student planning, follow through, and evaluation. Students listened; they responded when called on to do so; they

read short sections of textbooks; they wrote short responses to questions or chose from among alternative responses in quizzes. But they rarely planned or initiated anything, read or wrote anything of some length, or created their own products. (Goodlad, 1983)

These problems are apparent for all subjects taught, and changing the situation dramatically may require cross-cutting changes (e.g., one reformer recommends that much less time be spent in regular classroom instruction). Nonetheless, rethinking the mathematics curriculum in grades 7-12 leads to questions about how the average mathematics classroom can be made more interesting. Overemphasis on the rote mechanics of the subject is not likely to encourage student engagement (College Board, 1985). Yet, at least 30% of first-year algebra is spent on mechanical techniques, like factoring polynomials, which were "useless for most students even before the computer" (Usiskin, 1985). A change in content seems appropriate.

Some headway may be made by including in the curriculum a wider variety of applications relating to different aspects of the student's world and the larger world. Similarly, the use of a variety of tools (e.g., computers, calculators) and approaches (numerical models, etc.) may help. Students want to see a connection between what they are learning and various ways that this will be of use to them. (This is a starting point for many activities of the Ford Foundation's Urban Mathematics Collaboratives project involving secondary mathematics teachers.) Since many college majors, many jobs, and many activities require mathematics, the connections are certainly there to be found. The middle and high school curricula need to be brought up to date and made more stimulating.

NSF and the Search for Appropriate Content and Approaches in K-12 Mathematics Education

These kinds of issues raise difficult questions about the content of mathematics education that need to be resolved. The challenge to NSF is to guide the search for diverse curricular approaches that take advantage of revisions in both content and approach. The content and the approach need to be suited to the purpose of developing a broader pool of young people who are interested in science and mathematics and able to apply scientific and mathematical thinking in their future lives and occupations (including but not limited to scientific careers). The curricula must also be appropriate to the students for whom they are intended, and be presented in ways that are understandable and appealing to them. At the same time, content must be presented so that learners with different degrees of sophistication can learn it.

NSF is very well positioned to stimulate the rethinking of curriculum along the lines we have discussed by supporting a combination of exploratory work (research, development, teacher training, etc.) and networking among the groups that must collaborate to arrive at satisfactory solutions. General awareness of the need and the issues is increasing. Examples and challenges from overseas are beginning to make themselves evident, contributing to the ferment around this issue.

Some experiments have been undertaken, such as the University of Chicago project to revamp K-12 mathematics curricula. AAAS's Project 2061, in which multidisciplinary panels are attempting to define what 18-year-olds in the future should know, provides one basis rooted in the mathematics community for exploring these issues (Rutherford et al., 1986). These and other related projects deserve additional efforts to form a broadly based and continuing set of projects for expanding the dialogue and contributing to curriculum improvement. Activities such as these suggest that the stage is set for a wide-ranging reconsideration of what is taught in mathematics education. As one observer comments:

> 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.... In addition to the emphasis on computers, [current large-scale curriculum] 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 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. (Kulm, 1986)

Additionally, the federal role in education is continuing to evolve, so that the "locus of action for reform has switched from the national level to local and state levels.... The administration's efforts are now channeled toward encouraging the states and exhorting them to push its substantive agenda" (Clark and Astuto, 1986). As discussed in the *Summary Report* of this study, the role of supporting content-related leadership is a natural one for NSF, and of all the pieces of the science education puzzle, the content of mathematics curricula presents NSF with problems of a type it can best help with. Its history in curriculum reform (not all of which was successful, to be sure) contributes to general acceptance of this kind of role, provided that it is leveraged--not completely carried--by NSF, and that lessons learned earlier (e.g., mathematicians working in isolation are unlikely to create successful materials) are applied to current operations. NSF is uniquely positioned to bring together the kinds of coalitions of mathematicians, scientists, educators, publishers, and others necessary to undertake this ambitious task, and thereby to assist states and localities in their own efforts.

However, the limitations of pursuing curriculum reform must be acknowledged. Addressing content (e.g., how much arithmetic is necessary in the elementary school curriculum) risks public scrutiny (which NSF is not eager for); dealing with the content of "science for all" risks resistance from the scientific community, much of which takes a narrower view of curricular priorities and hence of NSF's mission as a whole.

Past and Present NSF Investments in Rethinking the Mathematics Curriculum

It will be useful to put current NSF investments in rethinking the content and approach of K-12 mathematics education in the context of SEE's experiences in the field, stretching back more than 30 years. For even longer than that period of time, the history of mathematics education shows an ebb and flow between an emphasis on practical versus theoretical topics and approaches.

NSF's Past Investments in Historical Perspective

Immediately after the Second World War, the mathematics community (principally mathematicians in colleges and universities) felt that there was:

> ...undue emphasis being placed on skills, an unnecessary preoccupation with the immediate usefulness of what was taught, and an unfortunate distortion of the students' ideas as to the nature of mathematics. (Wooton, 1965)

Reacting to this situation, which they believed was "actually dangerous to the future welfare of the country," mathematicians formed a number of organizations, including the University of Illinois Committee on School Mathematics (UICSM) in 1951. Directed by Max Beberman, UICSM became the first of the postwar, university-based developers of new courses for K-12 mathematics and science. UICSM emphasized precision of language and deemphasized applications.

NSF carried the process of mathematics education reform further by funding the School Mathematics Study Group (SMSG), based at Yale (and then later at Stanford), which was formed in 1958 and, under E. G. Begle, received a series of grants from the National Science Foundation. SMSG remained active until 1972, producing a large number of textbooks for grades 1-12, many supplementary materials, films for teachers, mathematical monographs, and research data on its very large-scale National Longitudinal Study of Mathematical Abilities. With few exceptions, this extensive curricular activity was pointed consistently toward an emphasis on abstract and higher-level topics and was based on college entrance as the central goal of "precollege" mathematics education. (Kulm, 1986)

From the beginning, SMSG hoped to influence commercial publishers, and this appears to have happened, although not primarily through direct publication of NSF-funded curricula. To a much greater extent than the science materials developers, the mathematics groups relied on indirect influence to accomplish their goals rather than on having their work directly picked up by publishers. This fact may account for the lower penetration of schools' curricula by federally funded mathematics materials than by science materials (Buccino et al., 1982).

Indirect impacts on commercially published materials, and through them the schools, took various forms. Many people, however, believe that the impacts on curriculum were significant. Among other impacts, SMSG provided training and experience for a generation of leaders in mathematics education (Kulm, 1986); for example, SMSG was translated into 15 languages and provided a model to innovators throughout the world (Howson et al., 1981). In the schools, this influence shows up most clearly in the geometry text written later by E. Moise and F. Downs for Addison-Wesley--a text that is based largely on the same work done (by Moise and others) under the auspices of SMSG. A review of publishers' responses to NSF curriculum improvement funding points out:

> The development of instructional materials in mathematics by federal funds and private funds...indicates the influence of the [NSF-supported] curriculum studies in encouraging publishers to publish materials with the new approach. (BCMA Associates, 1975)

One of the best current examples of the indirect impact of federally funded mathematics materials development is found in the new integrated mathematics curriculum in New York State, a 3-year sequence for college-bound students to replace (within this year) algebra 1 and 2 and geometry. According to one of the staff at the state's Bureau of Mathematics responsible for developing and testing the course, the NSF-funded Secondary School Mathematics Curriculum Improvement Project (SSMCIS) "was a great model for us, although it was too high powered." SSMCIS had been developed in the early 1970s at Teachers College, Columbia, so that people in New York were especially aware of it.

There are many other examples of the impact that NSF-supported development projects in mathematics had on education. Mathematics-related computer software developed with support from NSF (SEE) has, in a number of cases, had extensive commercial distribution. Most influential and ubiquitous have been the computer languages BASIC and LOGO, each developed with NSF support. (BASIC has appeared in schools both as a language to study and, in many cases, as the language in which computer-assisted instruction has been written.)

Nonetheless, in spite of numerous successful innovations in mathematics education, NSF-supported and otherwise, many of which remain in place in the schools after many years, few would argue that the system of K-12 mathematics education is in good health today. In the area of curriculum, what is needed is not "old math" (say, pre-Sputnik) or "new math" (which, despite negative public perceptions and an overemphasis on abstractions, has had some lasting positive effects on the secondary curriculum), but something that takes into account the needs of today, including the calculator, the computer, and greater emphasis on the "average" student (Usiskin, 1985).

In fact, opinions of what is needed for mathematics education in the schools today differ greatly from views widely held in the 1950s and 60s. Compared with the immediate postwar pedagogical emphasis on theory and abstraction, mathematicians' current strong interest in applications represents a remarkable swing of the pendulum. According to some knowledgeable observers, the new pedagogical interest in applications reflects changes in mathematics itself. One mathematician providing a brief history of mathematics education since World War II told us:

"In abstract mathematics, many branches developed independently after the war, and mathematicians focused on learning more about these areas.... Now, those branches have converged once again. There is greater emphasis on problem solving and applications, and less on theory, so that there is now a natural affinity of pure mathematicians for applications."

The practical aspects of mathematics were also emphasized by mathematicians in a recent National Academy of Sciences report, *Renewing U.S. Mathematics: Critical Resource for the Future* (the David report), which stressed the connection of mathematics to both the sciences and to technology (Ad Hoc Committee on Resources for the Mathematical Sciences, 1984). Mathematicians are now less likely to discuss their work in terms of n-dimensional spaces, and more likely to point out that new mathematical tools lie behind particular applications such as technological advances, supersonic aircraft wings, and medical scanners.

Applications make excellent vehicles for teaching mathematics, of course. Many projects supported by SEE in recent years have heavily emphasized the teaching of applications, notably those undertaken by COMAP (the Consortium for Mathematics and its Applications), and also many of the diverse computer-based projects for pre-college education supported at a wide variety of institutions.

Current and Projected NSF (SEE) Investments

Since the reestablishment of the Directorate in 1983, many of SEE's efforts (notably in materials development, but in other program areas as well) have supported projects that tackle pieces of the broad goal of rethinking the mathematics curriculum without addressing the goal head on, that is, without producing K-12 syllabi, new texts embodying significantly new approaches to problem solving, or the like. There are several major thrusts to SEE's work as it pertains to rethinking the K-12 curriculum, as discussed in the following paragraphs.

Current efforts to develop new curricular "modules"--This approach aims at filling gaps in the K-12 mathematics curriculum as well as developing tools (e.g., software) that can be used in various places within the curriculum. This approach is carried out primarily by the Instructional Materials Development and Applications of Advanced Technology programs. (The Development in Science Education program, or DISE, which ran from 1977 to 1981, did the same.)

The topics addressed by module development vary widely. SEE neither places limits on applicants nor encourages them to focus on specified topics. Examples of modules include a grant to Washington State University for "Secondary School Mathematics Modules in the Social Sciences" and a grant to the New York Institute of Technology for "Developing Discovery-Learning Materials in Mathematics."

Some materials developed as "modules" will be widely used. This is most often the case if the modules are part of a series that can be distributed commercially in a common form (e.g., as workbooks or computer programs). Publishers may pick up ideas from modules, so that those particular ideas circulate widely. For the most part, however, it is difficult to disseminate modular materials on a large scale. The original developer may not be the best-qualified person to market or disseminate the material, or may not have sufficient incentive, either in terms of activities permitted under the grant or for other reasons. Publishers often see little financial incentive in producing modular materials.

On the whole, module development is not controversial, providing opportunities for many applicants, and results each year in a few, generally modest products that are widely distributed or otherwise influential. A broad impact on rethinking mathematics education, or on textbooks, cannot be expected from this type of approach.

Current investment in whole-course development--If they are successful, whole courses can have a much more extensive impact on the curriculum than modules. For example, at one time more than half of all secondary science teachers were using federally funded materials, primarily courses (Buccino et al., 1982). However, development of whole courses became controversial, largely because of congressional displeasure with the "Man: A Course of Study" (MACOS) curriculum in the mid-1970s. Mainly for this reason, very few projects have been funded since the late 1970s (including the years since SEE's reinstatement in 1983) that aim at producing an entire year-long mathematics course for the K-12 level. Since the large-scale materials development projects of the early and mid-1970s, in fact, there have been few such efforts in the United States, except by the publishers themselves (Usiskin, 1985). SEE, however, has provided support to the University of Chicago School Mathematics Project to test the elementary portion of its curriculum; this is one of only a few projects related to whole-course development.

In the sciences, SEE is moving toward providing more support for whole courses. Collaborative development ventures with publishers have been encouraged, and are likely to result in widespread dissemination. In mathematics, this approach has not yet been used. Whether that approach is appropriate for mathematics depends in large measure on the goal: if the goal is incremental change and fairly rapid dissemination and use of new whole-year (text) materials, the publisher-collaborative approach makes good sense.

...lar reconceptualization--Short of developing a whole course or a set of ... ...cular grade span (e.g., K-6), a variety of approaches can be used to ... ...ioners, publishers, and others to rethink the content and approach ... ...atics. SEE has used many of these.

...o targeted grants competition requested applicants to focus on development of "prototypical" materials exploring ways students and teachers can take advantage of the calculator and computer. (Prototypes may include units, software tools, "strands" of a curriculum, or other pieces short of an entire course. Even if an entire prototype course were developed, it might be much more of a rough cut than a finished product.) There is no requirement that the projects involve publishers. Six grants were made for periods up to 4 years, costing a total of $5 million. The largest of the six grants was made to the Education Development Center to develop a framework for a whole new elementary mathematics curriculum that will emphasize problem solving, applications of mathematics, and the integration of the calculator and computer as tools.

By virtue of their size and duration, projects of this sort have a visibility that most module development projects cannot achieve. How well or how soon they will be able to translate efforts at experimentation into large-scale use is difficult to know. This approach seems a reasonable one if there is a general direction to go in, but at the same time it is too soon to expect finished textbooks to be produced. In this way, the approach differs from whole-course development.

Another important project that is being partly supported by SEE is the review of the goals and objectives of K-12 mathematics curricula now under way by the Mathematical Sciences Education Board. This project should produce results that are significant to those wishing to make revisions in mathematics curricula. As noted earlier, development of widespread agreement about the goals of mathematics education, by level, is extremely important.

Research and related activities--Building on a base of NSF-supported research in mathematics education during the late 1970s (Kulm, 1986), SEE has also supported (under the Research in Teaching and Learning program) a large number of projects to generate new knowledge relevant to rethinking mathematics education. Much of what is learned may help in developing better ways to teach or learn mathematics or to organize instruction.

Support has also been provided (through the Studies and Analyses program) to develop and to gather indicators of the condition of mathematics education. This effort includes international comparisons, such as partial support for SIMS, and national comparisons, such as partial support for work on NAEP, and a planning grant for the University of Wisconsin Mathematics Monitoring Center.

A large variety of research and development work is being supported related to the use of computers and other advanced technologies. Some of the projects have arranged for commercial distribution of their products; others are more exploratory. Some of the knowledge created through the research program is being used in SEE-supported projects to establish viable computer-based tutors. Those projects are supported by AAT, such as a grant to the University of Pittsburgh for development of "intelligent tutors" for elementary and middle school mathematics.

Other projects--SEE has also supported various other mathematics education projects in recent years. For example, the Informal Science Education program has provided partial support for the new children's television series introducing mathematical ideas, "Square One," which seems to be headed toward success in the ratings. "Square One" addresses the question of student motivation more than it does the content and approach of the curriculum, but these are obviously intertwined.

What will these investments in development, research, and related activities yield as far as the rethinking of mathematics content and approach is concerned? NSF

(SEE) has made a good start at supporting efforts by the mathematics education community to reconceptualize mathematics, such as in relation to the calculator and computer at the elementary level. But the preponderance of funding in the past 3 years has gone to projects that will solve only pieces of the problem. Further investments, focused more centrally on the overall goal (of reconceived K-12 mathematics aimed at broadening the pool of competent, interested learners), will be necessary if NSF (SEE) is to take full advantage of the opportunity before it. We describe below initiatives that will be likely to realize that goal.

Promising Initiatives

In this area of opportunity, the most promising approaches include development of new prototype curricula (demonstrating changes in content and approach) at the middle and high school levels (following recent funding for prototypes at the elementary level), and also the development of goals and objectives in K-12 mathematics to aim for nationally, grade by grade. We believe that the field of education is ready for a demonstration of new possibilities, and NSF is well positioned to support their development and feasibility testing.* Educators are looking for solutions, but most are not yet ready to implement substantially new curricula. One thing that would help increase readiness is widespread agreement on new standards for mathematics education at the K-12 level. On this point, too, NSF may be able to help in ways that others cannot.

New ways of thinking about the mathematics curriculum include those in which the calculator, computer, and other technologies play a vital, if not central, role. Currently, publishers need to assume (in almost all cases) that the availability of machines is limited; therefore, the role machines have played in new or revised textbooks has been limited. Model curricula in which small group activity is more prevalent, or in which students have greater ability to learn through independent work/research, would also be helpful in breaking out of the current mold of whole-group, teacher exposition, student response classrooms that dominate mathematics instruction in schools. Teachers and principals need proof that such models will work in typical situations, and not just with the most gifted teachers. Until the current lockstep model is replaced, it is difficult to foresee a widespread turnaround in students' steadily declining interest in mathematics as they grow older.

An additional area of promise for NSF lies in the development of new or better software tools for teaching and learning mathematics. This is already an area of strength for NSF, based on its past history, but new needs as well as new possibilities call for further work in this area.

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* The emphasis in this opportunity is on the development of new visions of K-12 mathematics education, not necessarily on their immediate adoption by schools nationwide. Alternatively, as described under Opportunity 7, NSF may try to contribute more directly to incremental improvements in published mathematics curricula with immediate market appeal.

1.1 Develop Comprehensive Prototypes for Middle and High School Mathematics

SEE has already supported a competition for prototype materials for teaching elementary school mathematics using calculators and computers. To follow this competition, NSF could soon sponsor competitions for materials at the middle and high school levels. Those teaching or developing materials for 7th grade and above cannot assume that students know much beyond mastery of arithmetic (and perhaps some familiarity with calculators and computers), so that completion of NSF-supported elementary school curricular work in mathematics (which in any case is for prototypes) is not a necessary prerequisite to starting middle and high school work.

Conceivably, some middle and high school mathematics curriculum development projects could be supported as part of open grants announcements (i.e., those without a fixed focus). However, it would be more appropriate for support to come from a targeted grants competition, similar to those in 1986 for elementary mathematics and elementary science. A targeted competition increases the likelihood of receiving the types of applications desired from the most qualified applicants.

Concentrating on the middle school level is logical for a number of reasons. This initiative would follow the elementary mathematics solicitation, extending the search for new models to higher levels. The middle school is already given special emphasis by SEE, largely because early adolescence is a critical time in developing attitudes and consolidating skills. As we pointed out earlier, students often are screened out or select themselves out of mathematics in early adolescence. Finally, existing curricula at the middle school level are often especially "thin" and insufficiently challenging, particularly for those not studying algebra at the 7th or 8th grade level (McKnight et al., 1987; Flanders, in press).

The high school level is closely linked with the middle or junior high level. For example, whereas algebra is now typically taught in high schools, there are proposals to make it a middle school course (Usiskin, 1985). This change would have the effect, among others, of forcing the high school curriculum to be reconsidered at the same time. In general, the problems in mathematics in grades 7-12 (where the subject is taught by specialists, and where student choice becomes a major factor) are best addressed simultaneously, or at least in a coordinated manner.

A choice would need to be made by NSF as to whether these projects were aimed at producing prototypes--as with the elementary math solicitation--or whether the goal should be for developing commercially viable products (and including plans for distribution at an early stage), as is the case with the elementary science competition (which is linked with publishers). Given the current uncertainties at the middle and high school levels on what mathematics education is and should be, prototype development seems most appropriate at this stage. In a few years, an increase in the number of calculators and computers and the further development of standards will make commercialization less risky and therefore more likely.

Special emphasis should be placed on students other than the top 10% to 25%. As discussed in the introduction to this volume, the most appropriate mission for NSF at this time is to "broaden the pool of science learners," rather than merely to "skim the cream" (i.e., to try to identify future scientists and mathematicians very early and develop materials for them).

Among the disadvantages of this initiative are that large materials development projects are considered by some as too sensitive politically for support by NSF, given the important role of state and local government and the private sector. Several projects (NCTM, MSEB, Project 2061) to reexamine K-12 curricula in mathematics will not be completed for a year or more, and materials development might logically await their completion. In addition, developing a middle and high school curriculum builds on elementary school experiences (and leads, for some, to college curricula) that, it is widely agreed, are themselves in need of revision.

The elementary science solicitations are projected to cost $50 million, with half coming from NSF and half from publishers. This is probably more than is needed in middle or high school mathematics, each of which covers fewer grades; also, prototypes rather than more finished curricula would be produced. However, about $20 million to $25 million should be set aside for a middle school development effort in mathematics, to adequately fund comprehensive, multiyear projects in sufficient numbers (e.g., four to six projects), and a comparable amount should be set aside for high school projects. This brings the 5-year total to $40 million to $50 million for middle and high school level projects.

1.2 Develop National Standards for Mathematics Education, K-12

A number of groups are actively reviewing K-12 curricula in mathematics. Some of these organizations will propose frameworks to help guide the development of future curricula. At least one effort under way, that of the NCTM, is aimed at developing standards for mathematics education, that is, what students at a given grade level should know and be able to do. The AAAS's Project 2061 has somewhat similar goals (with reference to what 18-year-olds of the future should know), including the specification of educational goals, means of reaching them, and strategies and leadership for the reform process. As mentioned earlier, the MSEB is also reviewing the curriculum.

NSF should take advantage of these efforts and use them (as others will) as part of its overall strategy for getting mathematicians, educators, and others to rethink the mathematics curriculum. It is possible, but unlikely, that all three of these efforts will soon agree about goals and objectives. It is more likely that various uncertainties will remain after these and other similar projects have completed their work. Momentum may flag; large ambiguities may remain concerning specifics of what should be taught to whom and when; outright disagreements may become apparent. For any of a number of reasons, more than one round of effort may be necessary to move the mathematics and education communities toward a consensus. A number of our respondents argued that there is an important role for SEE in supporting such projects that can connect new goals, objectives, and methods to the realities of the schools. SEE's support would thus contribute to a realistic blueprint for what constitutes feasible and desirable mathematics curricula.

Establishing standards (something that would be done by groups other than NSF, but with the Foundation's support) would be helpful in a number of domains. It would be one factor helping to guide state, local, and commercial efforts in curriculum development, testing, and teacher education, to name a few key activities. Publishers, for example, will find it difficult to develop and market new textbooks unless they have a sufficiently large market sharing similar goals and objectives. In addition, high but reasonable standards that might influence state requirements, achievement tests, and the like, could also go a long way toward pepping up the "underachieving curriculum" and raising students' motivation and performance.

One risk, of course, is that states, localities, mathematicians, mathematics educators, and the private sector will not find it possible to reach a consensus on standards, and projects such as these will fail. That seems a risk worth taking, particularly since the alternatives are little or no change from current, inadequate standards, or creation of dozens of different frameworks by cities and states, reflecting an inability of experts and the public to agree on what is important.

Even though ambitious, these sorts of projects are relatively inexpensive; $1 million to $1.5 million annually could support two or three standards development efforts. This translates into a 5-year total of $5 million to $7.5 million.

1.3 Develop Software Tools for Learning Mathematics, K-12

Ways to use the potential of the computer for teaching K-12 mathematics are not yet well developed, but there is widespread agreement that the potential is great (NSB, 1983; Romberg and Stewart, 1984; Lesgold and Reif, 1983). Some examples of the use of sophisticated software tools in schools are already apparent (e.g., "Geometric Supposer," published by Sunburst). A few experiments are under way--and more should be supported--that "*combine* mathematics and science using technology in exciting and potentially revolutionary ways" (Tinker, 1987). There is no longer any question that productive new tools might be created; the problem is to do it, and do it in ways that are feasible in schools. Under this initiative, SEE would support the development of a variety of new software tools for teaching and learning mathematics in grades K-12. These tools might be designed for use by students individually, or for use by a teacher in changing the content and/or approach to whole-class instruction.

SEE already supports many projects of this sort, primarily through the Applications of Advanced Technology (AAT) program; but, for the most part, these are aimed at long-term fundamental changes in instruction through sophisticated technology. For example, AAT's grantees include projects doing developmental work on a variety of "intelligent tutors" in mathematics, as well as other software aimed at particular skills or topics (e.g., arithmetic, geometry). The Instructional Materials Development program also supports development of some software tools for teaching mathematics. The difference in what is being proposed here (which would be in addition to ongoing software efforts) is that it would be focused on a particular level or set of topics, such as teaching algebra in the middle school grades, and would be aimed at widespread implementation in schools in no more than 5 years.

The example of algebra in the middle school grades is chosen because it may turn out that new standards for teaching mathematics emphasize earlier instruction in algebra. Appropriate materials (and tools) would be necessary to implement any such recommendations (Usiskin, 1985). (In addition, such tools and materials could first be used to test the feasibility of teaching subjects, such as algebra, at earlier-than-usual grade levels.) Software tools for teaching probability and statistics, geometry, calculus, and many other topics could conceivably make learning faster, easier, and feasible at earlier ages than in the past. Because the market for such tools has been very small, there has been little commercial activity in many of these areas.

To increase the potential for commercial distribution (i.e., immediate and widespread dissemination), matching funds (or other contributed resources) from publishers might be required for applicants. As in the case of the elementary science solicitation involving publishers, commitment of funds "up front" would help ensure a later commitment to market the products. This seems especially appropriate in areas where commercial potential is so uncertain that publishers are unwilling to underwrite the full cost of development. Examples include "thin" high school markets, like calculus and other advanced courses in mathematics having relatively low enrollments.

Development of new software can be expensive; the testing and revision phases need to be funded, as well as initial research and development. To support eight projects annually at $0.5 million per project (plus matching funds) would cost NSF $4 million annually. Over 5 years a total of $20 million would be needed.

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Opportunity 2a

TO RETHINK THE APPROACH TO, AND SETTINGS FOR, ELEMENTARY SCIENCE EDUCATION

This opportunity focuses on discovering ways around the massive barriers to science instruction in the elementary grades. Providing young children with positive and frequent experiences with science is an essential component of achieving a broad pool of interested and competent learners in science education. Experiments with both conventional and highly innovative alternatives (especially those emphasizing new technologies and the use of informal education settings) for improving young children's access to and interest in science might yield a range of exciting possibilities.

The Importance of Science Exposure at an Early Age

An ironic outcome of the rapid advances in science and technology is that today's youth may be more technologically isolated from real-world phenomena than were their parents. In both the home and school environments, children live in a world that is rich with information, images, and symbols, but is poor in its opportunities for direct experience with real phenomena and substance. Growing a garden, fixing a car, building a cabinet, heating a house, and sailing a boat are all examples of the science-like activities that can provide young people with an increased familiarity with and intuition about everyday phenomena. Such experiences provide a base of physical experience on which later academic training can build. Equally important, they engender active habits of inquiry, a confidence in one's ability to probe and understand, and an interest in "messing about" (doing informal experiments). It is not surprising that many successful scientists had home environments that exposed them early in their lives to a wide range of science-like experiences (Bloom, 1985). In contrast, many American children today face a science-impoverished environment, with few opportunities for firsthand intellectual and physical experiences with investigating the world around them.

A physicist and educator put the problem of experience deprivation this way:

> As short a time ago as a hundred years, most people spent most of their time dealing with nonsymbolic problems that presented themselves as physical problems.... The easy example is the child growing up on the farm. That child had experience with heating the house...knowing how much wood had to come in.... Today this out-of-school experience with physical reality is no longer true of most people.... We see that the schools have come upon a new problem that they have not brought forward or faced squarely--the problem of enlarging the task of education in school beyond the teaching of symbolic material....

> There needs to be an experiential and challenging connection between individuals today and the natural world...this task should be taken up by the schools as institutions as well as by less formal institutions like museums, clubs, and so on.... The school should give the children what the children need today, which is different from what the farmer's children needed. It is our indictment that the schools do not see this as a central problem....
>
> But as the schools come to science, they typically reach for science as part of the symbol system. We see again and again that the symbol is used to replace the substance, the experience of the reality of things. (Morrison and Morrison, 1984)

The National Science Board's Precollege Commission on Science, Mathematics, and Technology Education (NSB, 1983) echoed the same admonitions more concretely, by indicating that instruction should be designed to achieve the following outcomes:

- Knowledge of phenomena in the natural environment.
- Growth in the natural curiosity of children about their physical and biological surroundings.
- Personal experiences with appropriate level hands-on science activities for both biological and physical phenomena.

The failure to provide young children with a chance to engage in diverse science-like experiences also initiates a split between those children who do and those who do not think of themselves as interested and capable in science. By the middle school years, this split all but determines who will and will not pursue technical hobbies, scientific study, and science-related careers (Wolf, 1979; Welch, 1985).

The educational potential of hands-on exploratory science activities at the elementary level has been recognized for a long time. Piaget has pointed out the crucial role of physical exploration in the intellectual development of the young child. National studies have indicated the critical importance of a child's early experience of science and mathematics and how just a few experiences may predetermine later career choices (Bloom, 1985; NSB, 1983). If, indeed, active open-ended exploration in one's early years is critically important to developing a lifelong interest in science, then NSF might well invest in opportunities that make such experiences more available to young people. The challenge for NSF is to find and support a range of new alternatives that offer to many students what now is the privilege of a few. This opportunity examines NSF's options within the schools; Opportunity 10 examines NSF's best out-of-school alternatives.

Barriers to Science Experience in the Schools

Elementary schools, by and large, give children little exposure to science activities. On the average, there is roughly an hour per week of science instruction in each classroom at the elementary level (NSB, 1983). Furthermore, the science instruction that exists is largely centered around the study of a textbook, empha-sizing the learning of symbols, concepts, and vocabulary:

> As for the science curriculum in elementary schools, it hardly exists, and where it does, it is more often a reading program about science or an eclectic selection of "science projects" rather than an organized science program.... (March et al., 1987)

Why do the schools not offer students rich and diverse experiences in science? It is not that teachers, administrators, or parents feel that science is not important. In recent surveys (Weiss, 1986; St. John, 1987), most teachers thought that elementary science instruction was a very important part of the curriculum, that more of it needed to be taught, and that it needed to be taught better. The problems and constraints that they face, however, in doing material-based, hands-on science in the elementary schools are large, complex, and interrelated. It is important to understand the nature of the barriers in the schools if one wishes to pursue the strengthening of science teaching in the elementary schools.

Teachers find purely practical constraints almost overwhelming in their efforts to teach activity-based science. In particular, a lack of time to acquire, organize, set up, and store materials is probably the largest barrier. Related problems include the lack of classroom support (in the form of aides who could help with mate-rials and instruction) and a pressure to give other subjects higher priority (St. John, 1987; Weiss, 1978).

Time--Time pressure is a major constraint on the teaching of science. Time is needed for teachers to learn about science and science activities and for them to develop activities, prepare classroom materials, and set up and take down activities. Teachers told us:

> "Science takes more preparation time and set-up time than anything else you do. But there is no way of getting around that...."

> "Even though I liked science a lot, I found I wasn't teaching very much of it. It is easy to do reading, for example, because there is a good book and materials.... There is no doubt about it--a good science program takes more time...."

Support--Recent analyses of the teaching profession point out how professionals in other fields have a wide array of support personnel to assist them so that they can reserve their time for the professionally most demanding tasks. The lack of sup-port personnel for teachers means that they "spend between 10 and 50% of their time on noninstructional duties" because "skilled support help is rarely available, nor the time to do the job right" (Carnegie Forum, 1986). With the heavy logistical demands of elementary science, these conditions are particularly devastating. One teacher we interviewed noted, "Elementary teachers...simply won't do science activities unless they have someone coming in to help them...."

Pressure to teach other subjects--Competition with other subjects is another major reason for the general lack of emphasis on science at the elementary level (among "generalist" teachers; elementary science specialists do not face this difficulty). One teacher said, "We have to spend an hour a day on math, on reading, and on the language arts...and I do an hour of social studies every day...and then there is always a bite out of your time from somewhere else...."

Although teachers are quick to point out the practical difficulties they face, there are other, more fundamental difficulties they must overcome if they are to become skilled conductors of activity-based science classes.

Lack of science background--The great majority of elementary teachers do not have appropriate backgrounds, especially in the physical sciences; many lack confidence and/or interest in teaching the topics specified by school district curricular guidelines. Most elementary teachers rate their training in science as weaker than their training in other areas. Many consider a weak background in science an impediment to teaching more science in their classes (Weiss, 1978). Only one in five teachers say they feel well qualified to teach elementary science (Weiss, 1986). Teachers are the gatekeepers to their classrooms. What they don't like, and what they are not comfortable with, they won't teach.

> By and large, the elementary teachers did not feel confident about their knowledge of science, especially about their understanding of science concepts. Even those who did like science and felt confident in their understanding of at least a few aspects of it often felt that they did not have time nor material resources to develop what they thought would be a meaningful program. As a consequence, science has been deemphasized at the elementary level, with some teachers ignoring it completely.... (Stake and Easley, 1978)

The authors of the NSB report *Educating Americans for the 21st Century* stated the point more strongly:

> Many of the teachers in the elementary schools are not qualified to teach mathematics and science for even 30 minutes a day.... (NSB, 1983)

The pedagogical demands of inquiry-based teaching--In addition to not knowing science content, many teachers do not understand its nature as a disciplined approach to inquiry. Elementary-level science is a natural arena in which students can gain more general skills of inquiry--skills that are valuable far beyond the science domain itself. From the perspective of developing even more general cognitive processes, elementary-level science activities are an ideal arena for providing students with rich interactive experiences. For most teachers, however, the aim of elementary science instruction is to teach students the *vocabulary* of science. For these teachers, the "hands-on" or "discovery" approach is a way of making the teaching of facts and concepts more interesting. The deeper goals--not only to teach students what others have discovered, but to give them confidence, skill, and interest in figuring things out on their own--remain largely ignored.

Studies have noted the lack of experience teachers have in doing real inquiry:

> Science was something teachers "took" in college, but it was not something they experienced as a process of inquiry, certainly seldom a participation in inquiry. It was not surprising, then, to find that creative inquiry was not what we found--except in rare instances.... (Stake and Easley, 1978)

The teaching of general inquiry skills is difficult and requires a dramatic shift by the teacher; the goal becomes the empowering of the students' ability for self-exploration, not the reinforcement of the teacher's explanations. A teacher trainer at the Boston Children's Museum described it this way:

> "You have to work for a total change in the teacher's psyche.... You have to go after deeper stuff. You need to change the way that people think about themselves and their roles as learners and teachers. We try to teach a different mode of teaching--we are teaching people how to use materials, not books. Thus, we are not teaching science as much as we are teaching material-based learning.... Forget the subject matter--it is secondary...."

Observers have noted that the culture of the classroom is slanted toward the efficient mastery of lower-level knowledge. There are few rewards, incentives, or role models for pursuing the longer-term, more difficult goals of inquiry in the elementary classroom:

> It occurred to us that there was more reason to expect that real inquiry would occur in elementary school science classes.... But we found little inquiry, little of the aesthetic view, little messing about in the elementary schools either. The problem here apparently was that many teachers, particularly in the upper elementary grades, did not feel they could afford to allow children to engage in such undisciplined, unproductive behavior. They were not somehow protected by the scientists, historians, and philosophers who testified that--even ideally--science was actually not so rigorous and disciplined.... Perhaps against the pressure of parents and teachers up the line, these teachers felt obligated to do more work-like activities....
>
> Where and when science was formally taught, the instructional material was usually taken directly from a textbook series. The method of presentation was: assign - recite - test - discuss.... (Stake and Easley, 1978)

Because of both practical constraints and deeper pedagogical problems, creating a self-sustaining, high-quality, material-based science program within the elementary schools is very difficult (Gilmar, 1985). The pressure for efficiency, the need to test student achievement, the teacher's own experience of science, and the culture of the schools conspire against the deeper goals of exploratory learning.

The prospects for improving this situation without developing fundamentally new approaches appear slim. Current local and state efforts to increase and improve elementary science teaching are unlikely to increase the chance for students to have high-quality motivating science experiences. Legislating that more science be taught, in the absence of major new resources and capabilities to teach it well, may even be counterproductive.

The Nature of the Opportunity for NSF

NSF can play an important role in finding new ways to make high-quality science experiences accessible to young people, and the Foundation has already begun to explore the possibilities for doing so. NSF is the appropriate agency to undertake the task of developing a diversity of new approaches, for it alone has the experience and connections to bring together the required collaboration of scientists, science educators, experts in educational technology, cognitive psychologists, and media experts.

This is an opportunity for NSF to offer leadership in developing new approaches (as opposed, for example, to undertaking large efforts to train teachers). The elementary school system is huge; science is a very small part of the curricula that the system offers. NSF cannot hope to train the 1.2 million elementary school teachers, nor does it have the mission to change the culture and priorities of the educational system. Rather, NSF can use its resources to investigate and promote alternative approaches to providing young people with positive science-like experiences.

Fortunately, there is currently a demand as well as a need for new approaches. Many states and localities, recognizing the importance and potential of elementary science, are increasing science requirements for the early grades. However, legislated requirements, state curricula frameworks, and enthusiasm are not sufficient. In fact, under the pressure of state reform, many districts have reduced process-oriented curricular goals to a scope and sequence of topics to be covered. A curriculum developer and researcher associated with a nationally recognized project told us:

> "Many schools have few viable options for improvement beyond the adoption of 'modern' textbooks published by the major publishers.... Some more capable districts are developing their own curricula...but in terms of local development of new materials there are real problems. They are proceeding in a haphazard way; they lack expertise and knowledge of what is available; usually they patchwork together materials in a way that does not reflect a deeper framework...."

The NSB Precollege Commission (1983) not only defined the problems with science education but also outlined a general framework for the solution. The Commission made the following five key points:

(1) Elementary science instruction must be made a national educational priority.

(2) Elementary science programs must emphasize the child's personal exploration of, and physical interaction with, the natural phenomena of everyday life.

(3) The quality of the teacher is the key to creating high-quality science programs.

(4) Teachers must have sufficient time inside and outside of class to educate themselves, to prepare their classes, and to teach science on a regular basis.

(5) Teachers must be supported so that they can teach in favorable rather than unfavorable conditions.

Each of these suggestions comes from a deep understanding of the nature of science, the nature of children's development, and the nature of our school systems. However, not all of the above guidelines offer NSF equally opportune intervention possibilities.

NSF certainly can help to make the teaching of elementary science a national priority. Through large national studies as well as smaller more focused research efforts, it can illuminate for the nation the current state of elementary science instruction. NSF can identify and target critical problems within the system (e.g., tests, textbooks, teacher preparation) and outline approaches for their solution.

The other guidelines pose greater challenges for NSF. The systemic constraints--lack of time, the pressure to teach other subjects, and the lack of classroom materials and support--are so deeply interrelated and so deeply rooted in the values and priorities of the school system that piecemeal approaches (e.g., development of a new curriculum of hands-on activities, a summer workshop for teachers) are not likely to make a difference. The systemic nature of the problem makes it difficult to identify ways that NSF, with its limited resources and constrained federal role, can intervene in the elementary schools and have a significant impact on practice at a feasible cost.

There are examples of elementary science programs around the country that have overcome many of these constraints and that offer high-quality elementary science experiences as a basic part of the elementary curriculum (Rothman, 1986). Support for exemplary programs like these is one mechanism available to NSF to demonstrate what is possible at the elementary level. Perhaps more importantly, however, these exemplary programs (which are almost invariably the product of a motivated individual serving as an elementary science advocate) suggest that skilled district-level leadership may have real potential for inducing systemic changes. The role that NSF might take in developing leaders and change advocates at the district level is discussed in detail in Opportunity 4.

The quality of the nation's 1.2 million elementary teachers, while critically important, can be influenced by NSF in indirect ways at best. NSF can, however, support more and better science teaching by providing teachers with a greater range of options. To establish in the schools science programs that foster inquiry, active experience, and direct contact with real phenomena will require an expanded repertoire of approaches and means. If NSF were successful in developing new approaches to providing elementary-age children with science-like experiences and in creating viable, innovative ways to get good science to happen in and out of the classroom, it could have great impact on the thinking of educators who work with elementary-age children. The result could be a new paradigm of science education for the young, generating a wave of reform that resembles yet surpasses the hands-on science movement of 20 years ago.

As context for examining NSF's most attractive investments in this area, we review and assess the Foundation's current and past initiatives for improving elementary science education.

NSF's Past and Current Investments in Elementary Science Education

Twenty years ago, NSF addressed this problem by designing and testing several fine elementary science curricula (*Science Curriculum Improvement Study; Elementary Science Study; Science: A Process Approach*). These projects paralleled the work of others--e.g., the Nuffield program in England, which provided open-ended exploratory activities for young children. Illustrating the potential of hands-on science, these curricula have shown that young children can engage successfully in hands-on, inquiry-based science in the classroom (City College, 1985). They have served as an ideal and provided a model for elementary science for more than 20 years.

These programs failed, however, to become widely established in the schools. Later studies (Gilmar, 1985; March et al., 1987) showed several reasons for this failure:

- The teachers took introductory workshops in how to use the curricula, but they lacked follow-up support as they tried to use the materials in their own classes.

- The implementation issues--the continuing training of teachers, the maintenance of kits and materials--were not successfully addressed.

- The teachers never understood the underlying science very well.

- The teachers never made the psychological transition to a process approach. They tried to use the ESS and SCIS materials to teach facts and concepts and did not know how to recognize or value the goal of fostering exploration for its own sake.

- The educational mainstream (administrators, principals, publishers, testers) did not embrace the innovations.

Consequently, in spite of NSF's high-quality curricula, the reality of science instruction in most elementary school classrooms has changed little over the years. A leader in the movement to improve science instruction at this level observed at a recent elementary science conference:

> It is wonderful to see these exemplary programs doing wonderful work. But it is also more than a little discouraging to see that innovative programs we instituted in ESS and African Primary Science 20 years ago are still thought of as innovative.... In fact, since it is taking all that you have got (with all of our expertise and experience) to initiate and sustain your own programs, it seems unlikely that the hands-on movement is going to make much headway in the next 10 years without a major new level of commitment and resources.... (Goldstein, 1986)

Only 6% of science classes in grades 4-6 have access to laboratories or special science rooms. Nearly 40% of classes use no materials at all in teaching science. Teachers and principals across the country rank inadequate facilities, lack of funds for equipment, and inadequate materials for individualizing instruction as very serious problems (Weiss, 1986). As a result, few of the elementary students today participate in a significant activity-based science program during their elementary years. Certainly, very few students experience a consistent diet of exciting science activities throughout their elementary years.

For 20 years, then, both the ideal of hands-on science and the reality of textbook-centered science have remained remarkably fixed. This standoff is not likely to change soon, for, as we have seen, the barriers to the widespread classroom adoption of activity-based science programs are deeply embedded in the conditions, priorities, and culture of the schools themselves.

NSF (SEE) is currently funding several experiments that attempt to get around the impasse. Most recently, SEE has initiated and promoted a targeted solicitation aimed at influencing what publishers bring into the typical elementary classroom. Based on the assumption that commercially published programs will continue to be the dominant source of materials and curricula at the elementary level, this initiative seeks to work in partnership with major publishers to get high-quality materials widely distributed throughout the massive elementary system. Rather than provide grants to private developers and "hope" that materials end up getting published, SEE has used this solicitation to explore the possibility of providing the equivalent of private venture capital to publishers to induce a new wave of innovative published approaches to elementary science. By establishing partnerships between publishers, developers, and school systems, SEE is hoping that the best curriculum innovators can gain access to, and have an incremental effect on, the mainstream materials and curriculum.

In the out-of-school arena, SEE is supporting "3-2-1 Contact," a daily science television show that is reaching a significant portion of American children aged 2 to 11 (Chen, 1984). In collaboration with the Department of Education, SEE has funded the development of "The Voyage of the Mimi"--a sophisticated multimedia, interdisciplinary curriculum (for use both in and out of the classroom) that aims at breaking the mold of text and recitation elementary science. SEE also provides funds for museum and youth group experiments that seek to provide hands-on experiences for young children (see Opportunity 10).

In addition, SEE funding supports a few training institutes for elementary school teachers, projects aimed at developing curriculum modules oriented to elementary-level children, and some research on problem-solving in young children.

From the point of view of generating new approaches to elementary science instruction, several aspects of NSF's current efforts are promising. Publicly declaring a new priority for elementary-level science and visibly arguing for the need to provide young children with more and better science experiences is already attracting some of the nation's best talent. The new thrust emphasizing partnerships with publishers (who must commit resources up front) substantially increases the total resources available for this work. Also, if successful, the publisher experiments will begin to influence the mainstream of elementary science education, rather than remain on the fringe as notable "model curricula," which may or may not be noticed or adopted. On the other hand, publishable materials are less likely to be innovative and may in the end fail to offer radically new approaches to what already exists.

Current NSF experiments with broadcasts, museums, and clubs are also promising and need to be thoroughly studied (see Opportunity 10 for a more extended discussion of these investments).

Both the publisher and the broadcast initiatives can have widespread impacts, but the quality of the science experience they offer young people deserves careful examination. In the case of the publishers, it may be difficult to maintain the more innovative features of the new programs when they must prove themselves commercially viable in the publishing marketplace. In the case of science broadcasts for young children, the media demand that the shows be highly motivating and entertaining, and it is often difficult to include very much scientific content. Thus, in both cases, NSF faces a very difficult dilemma: if the development efforts emphasize radically new approaches (relative to their own media and marketplace), they run the risk of not being acceptable as part of the mainstream; if, on the other hand, they are made to be viable for their own media and marketplace, they may lose the educational integrity and merit that makes them worth funding in the first place. There are no easy solutions to the dilemma; NSF must walk a tightrope in each case. SEE staff acknowledge that these initiatives are experiments, and they are gaining the needed experience and judgment to engineer successful compromises. Current projects appear to represent good starting efforts, but it is not clear that NSF has designed effective ways to learn from them and build on them.

Promising Initiatives

As pointed out already, NSF's long-range goal in supporting projects at the elementary level should be to foster the invention and development of a wide range of activities (both in and out of school) that give children positive experiences with science and mathematics. We see two related initiatives that directly support this goal. (Out-of-school opportunities are described in Opportunity 10, and a separate initiative that aims at developing leaders of elementary science is described in Opportunity 4.)

2a.1 Support Studies and Research on the Mission for, Constraints on, and Possibilities for Enhancing the Science Learning of Younger Children

This initiative emphasizes the general need for understanding better: (1) how young children are drawn toward (or away from) science and develop interest and confidence in carrying out their own explorations; (2) how the elementary school system serves as a context for various forms of science education; and (3) the informal science learning environment of young children and how it can be influenced. The research funded under this initiative could either be carried out as "add-on" grants to large NSF elementary science projects (such as the present publisher solicitation) or it could be funded as independent investigations. The principal criteria for projects would be their potential for generating new knowledge about the barriers to learning science at the elementary level, and/or for probing ways to overcome them.

As we have pointed out, the problems in elementary science education are systemic in nature. Only intelligent, well-engineered interventions stand a chance of altering current practice. Thus, this initiative addresses the prerequisite need to gain a good understanding of the constraints and freedoms inherent in the system, the nature of motivation and learning in young people, and the successes and failures of present and past efforts. In short, this initiative would allow NSF to do its homework thoroughly, before and during a major attack on the problem. Ultimately, by changing conventional wisdom about the appropriateness of goals and the efficacy of methods in carrying out elementary science instruction, this research could have significant leverage on practice.

SEE would probably get the best thinking under this initiative by combining relatively open-ended research support with some focused topical conferences on different aspects of the elementary science problem. To make a reasonable impact in this area, we estimate that $1.6 million to $2.4 million would be needed per year to fund approximately 8 to 12 research projects (at approximately $200,000 per project), combined with a small amount of funding for conferences, for a total of between $8 million and $12 million over 5 years.

2a.2 Support Large-Scale Field Experiments with Alternative Approaches to School-Based Elementary Science Education

NSF could support several multiyear, large-scale experiments to learn how science experiences can be made a basic part of the elementary curriculum and can be made attractive and accessible to a broad range of young people. Unlike the previous initiative, which focuses on national studies and basic research, these experiments would involve significant efforts at developing and testing innovative approaches. Unlike current support for collaborative development projects involving publishers, these experiments would not aim at a particular commercial product; rather, they would constitute a demonstration of alternative instructional systems at work. Such experiments would explore different dimensions and directions that allow for new possibilities (e.g., the potential of computer technologies, visual media, printed materials, telecommunications, informal institutions, and integration with the rest of the school curriculum). These experiments would develop a new concept of science education for young people, embody that concept in prototype programs (including curricula, training, tests), and point out the potential and drawbacks of the approach.

In particular, we see the following areas as candidates for experimentation.

Technologically rich environments for elementary science--The use of technology needs to be explored thoroughly as to its potential and feasibility for fostering science-like experiences for young children, both within and outside the schools. In seeking to explore what this domain has to offer the elementary-age child, NSF needs to support experiments at both the cutting edge of research and at the lagging edge of practice.

In attempting to advance the state of the art, NSF must selectively support future-oriented applications that open up new possibilities. LOGO is a very good example of a development that takes advantage of the new powers of the computer and offers a great deal to the young child. Other promising areas include:

- *Micro-based laboratories*--appropriately used, they can extend what is possible in the lab and enhance intuition about the way physical phenomena behave. One teacher wrote of her experience with microcomputer-based lab: "One major advantage of this approach is the way it can receive and store data and graphically depict abstract measurements as they are being taken. I have observed that my students grasp almost immediately the temperature plateau--that is "discovered" when observing a substance going through a phase change--when the experiment is performed with a temperature probe and software to plot out the results in real time. The students can look from graph to test tube and back to graph and correlate what they see in the phenomena with a graphical interpretation of the quantitative data. Without lectures and prompting, students begin applying their common sense to understanding the phenomena they observe firsthand."

- *Microworlds*--can offer young students imaginative and challenging learning opportunities. Computer programs like "Rocky's Boots" can let students absorb the rules of formal logic and problem-solving strategies while they seek to solve problems within the unique environment of the microworld.

- *Interactive tutoring*--becoming increasingly sophisticated, tutors may soon be able to adapt themselves to the cognitive level and style of the student.

- *Simulations*--must be used judiciously with younger students. Only where experience with the real phenomena is not possible are simulations desirable. Simulations, like microworlds, can offer students a chance for rapid and repeated exploration of a complex system, allowing the kind of intellectual activity that good hands-on experimenting also provides.

The best of these applications provide good opportunities for independent investigation and inquiry (Anderson et al., 1985; Watson, 1983). Like other good science education efforts, good software requires the collaboration of educators, subject matter specialists, learning theorists, instructional designers, and programmers (Lang, 1984). NSF has a good opportunity at the elementary level to support further innovation in each of the above areas, as well as in entirely new modes of using the computer.

In addition to supporting state-of-the-art development of new educational possibilities for young people, NSF could also productively support field-based experiments aimed at fostering widespread, sustainable computer use in real-world settings. One NSF program officer described the need in this way:

> The pressing need at this time is to provide a number of major implementation experiments and demonstrations. These must be strongly focused and directed toward a pragmatic integration with the curriculum and toward problems of working teachers in typical classroom environments.... A typical project, and there should be several in each area, should mount a fully equipped and integrated demonstration throughout a small and representative school system. (Tressel, 1987)

A similar theme was also voiced by the National Academy of Sciences/National Research Council Committee on Research in Mathematics, Science, and Technology Education:

> The problem of effective use of microcomputers in schools is a variation on the problem of fostering change in organizations. Computers represent a means for presenting science in an attractive mode with broad appeal, that can emphasize abstractions, scientific reasoning, and experimentation. Computers can also be used as "intelligent tutors" to make instruction more effective. Extensive practical use of computers would, however, require very different classroom organization, new teaching materials, easily available and usable software, and different teacher skills in managing different social interaction. It is not enough to focus just on training teachers, or on developing software or on changing learning groups. All these factors must be related. Interdisciplinary

> research is needed to exploit findings on how schools can produce better learning through educational systems that might be quite different--and more effective than familiar ones. (March et al., 1987)

In the effort to both advance the state of the art and conduct major implementation experiments, the goal of the effort must be to improve elementary-age science education, not to explore the potential of technology. The danger of a "technocentric" approach has been increasingly articulated, often most eloquently by those most involved in the development of new technological approaches (Papert, 1987). There is a clear need for SEE to insist on an educational focus in the work it supports.

Other technologies, particularly videotape, also figure in this initiative. Most classrooms have access to videocassette recorders (Riccobono, 1986), and they are a familiar technology. NSF is currently sponsoring small experiments in trying to use reformatted parts of the new mathematics broadcast series, "Square One," in the classroom as a tool to supplement the teaching of a particular topic. Similarly, "The Voyage of the Mimi" has integrated other technologies with a core curriculum of videotapes to provide a new way of doing science in the classroom. We need to learn more from these experiments about how to actualize the potential of all levels of technology in the classroom.

The role of the elementary science specialist--The role of the science specialist at the elementary level is an area worthy of experimentation. There are strong arguments (Swartz, 1987; Hounshell, 1987) for and against making science a specialty subject, taught by a specialist in a space especially set up for doing science. Alternatively, specialists could focus on supporting teachers doing science in their own classrooms. A few experiments with district-level specialists in a variety of roles might provide insights into ways to overcome the barriers that currently exclude active exploratory science experiences from most classrooms.

> Specialized teaching, starting in grades 4 or 5, characterizes the education systems of many other nations, particularly those in which students outperform U.S. students. A few such specialist teachers work in selected school districts in several states but the practice is uncommon in the United States. If the use of specialist teachers were to spread in grades 4-6, what training would be appropriate for them...? What would be the role of the specialist teacher: student contact or working with the regular teachers? or both? (March et al., 1987)

NSF is the agency most suited to pursuing this possibility and to finding the answers to these questions. (A related initiative that focuses on developing elementary specialists and supervisors is presented in Opportunity 4.)

Alternative informational resources--The development and use of alternative information resources in place of a text-centered approach could be examined. Various observers argue that commercially published textbooks will never lead students to experience the true nature of science, for example:

> Science textbooks should be removed from the elementary schools. They promote teacher and student dependence and actually get in the way of good science instruction.... (Rutherford, 1987)

Other resources besides textbooks that promote science-like activities may communicate more effectively what science is all about to young children: tradebooks, magazines, and reference books are a good starting point. Conservation groups, amateur science societies, and professional associations produce very good materials. In addition to printed materials, telecommunications in concert with computers can also provide students with another source of information--one that offers students a chance to gather and share data on a large scale and in a scientific mode. Students can either collect and share their own data, or they can have access to a common and large data base. Like hands-on experiments, the use of technology in an active and appropriate way can provide a realistic and motivating context for student exploration.

Integration of science with other curricular areas--Integrating science with other subjects can overcome the pressure on teachers to give other subjects priority. An integrated curriculum is especially viable and attractive at the elementary level. Elementary mathematics and social studies are natural partners with science; the Unified Science and Mathematics in Elementary Schools (USMES) curricula funded by NSF a decade ago might offer one good starting point for this effort. Reading and writing can also revolve around science-relevant subject matter. There is considerable potential for integrating science and mathematics activities, especially through use of the computer. A more interdisciplinary approach may help science to "shoehorn" its way into an already crowded curriculum.

The kinds of experiments described above are not meant to take place in a vacuum. Research has shown that innovations must include teachers, who are obviously central to the success of new approaches or courses (French, 1986; Miles, 1983). Such experiments should also be compatible with state frameworks and reform efforts. Extensive third-party evaluation and documentation also would help to make the experiments maximally useful to others. Several small research studies could accompany and profit from these major experiments.

Such experiments call for extensive collaboration. NSF will need to draw on the connections it has within the science and education communities to ensure that the appropriate range of developers are involved in these large projects. They will need to work extensively with publishers, testing agencies, industry, other foundations, and professional associations. The goal of this program would be not only to generate new possibilities and models of elementary science instruction but to prove their desirability and feasibility in the schools. Additional follow-up support would allow successful projects to be shared through the U.S. Department of Education's National Diffusion Network and other mechanisms.

Major field experiments in science education at the elementary level will require the investment of substantial resources. We estimate that $8 million to $10 million per year, or a total of $40 million to $50 million over 5 years will be required to fully develop and explore alternative approaches. This level of funding could provide support for a number of large projects in each of the following areas:

(1) Use of technology (computers, video...)
8 to 10 projects at $500,000 per project per year

(2) Integration of science with other subjects
3 to 4 projects at $250,000 per project per year

(3) Pilot studies of alternative arrangements for science specialist teachers
3 to 4 projects at $500,000 per project per year

(4) Development and use of alternative resources (informal institutions, tradebooks...)
8 to 10 projects at $200,000 per project per year.

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Opportunity 2b

TO RECAST THE CONTENT OF MIDDLE AND HIGH SCHOOL SCIENCE CURRICULA

NSF has a major opportunity to help the nation reconceptualize and restructure what is taught--knowledge, skills, and attitudes--in science and mathematics classrooms at the middle and high school levels. This opportunity is generated by an educational crisis that is similar in intensity if not kind to that which faced NSF in the late 1950s, when it initiated a 15-year program of curriculum and course improvement. That effort generated a wide range of high-quality science and mathematics curricula that worked best with the most able and academically inclined students and teachers (French, 1986; Pallrand and Lindenfeld, 1985).

The current situation presents NSF with a somewhat different (and perhaps even more difficult) challenge: to define content and approaches for science and mathematics curricula that work well for most students and, at the same time, provide a strong foundation for those most likely to pursue scientific and engineering careers.

Recasting the Content of Middle and High School Science

As noted in the discussion of the national challenge in the introduction to this volume, the content of science education--knowledge, skills, and attitudes--embodied in curricula at the middle and high school levels is badly in need of attention. Although there are important differences between the two levels, the picture that emerges across the disciplines is remarkably similar: a heavy emphasis on encyclopedic coverage of descriptive and factual information (the base of which is burgeoning), too little attention to problem-solving and critical thinking skills, little connection of abstract concepts with everyday experience, and inadequate opportunities for active experiential learning. Also, by and large, science courses are structured tightly along the lines of the traditional scientific disciplines and reflect little of the interdisciplinary nature of actual science and engineering activities. Abstract concepts are taught in a vacuum with little connection to the student's personal interests or larger societal issues. Courses are centered on the textbook and classroom recitations; the laboratory experience is disappearing; and little advantage is being taken of the new technologies. An observer comments as follows:

> A critical problem with...the science curricula in grades 7-12 is too much emphasis on facts and too little emphasis on basic concepts and methods of mathematical and scientific reasoning.... Teachers use the textbook as their central instructional tool.... Analysis of current science textbooks has documented that the learning of special or technical vocabulary (i.e., rote

memorization) is a central feature of these texts. It should not be surprising that the recent study on the overall outcomes of schooling show gains in elementary knowledge...but that higher-level processes are being acquired less well. (March et al., 1987)

Perhaps most problematic, science curricula at the high school and middle school levels, as expressed in the predominant commercial textbooks, tend to address the interests and needs of only the most academically able students. These curricula implicitly assume that science courses should primarily serve those who are most likely to go to college and to pursue scientifically oriented careers. High school courses, in particular, appear to imitate college-level disciplinary courses. A vicious cycle has been established: those who design high school science courses (and those who teach them) have passed through rigorous curricula aimed at students headed for the scientific "pipeline"; not surprisingly, they design (and teach) curricula that are best suited for those few students who have strong science and mathematics backgrounds. As a result, the majority of students, who have little experience with science either at home or in elementary schools, are shocked as they are abruptly introduced into a highly abstract and difficult science curriculum that resembles a foreign language more closely than a study of the world they know:

> In effect, the average student receives no real science until he or she reaches high school, when we pose the question "Would you like to take physics, chemistry or botany and zoology?" And we know that four years prior to this, without real exposure to a science course, most students have already decided that science courses are difficult and dull.... In effect we select those children who are already motivated and prepared by other sources. And we discard the rest.... (Tressel, 1987b)

The pattern of student enrollment does, in fact, reflect a scenario of the disillusionment of the majority: most students then struggle through one or two required science courses and opt out as soon as possible (Weiss, 1986).

The failure of existing curricula to address the needs and interests of the majority of middle and high school students is the central theme of almost all the national reform reports and analyses (e.g., NSB, 1983; AASA, 1985; National Commission on Excellence in Education, 1983; ACS, 1984; summarized in Hurd, 1986). An observer sums up the bottom-line message in the following way:

> Though the different reactions [to national analyses of science education and efforts to improve it] are considerably diverse, almost all agree on the two goals toward which the efforts of all concerned...should be directed: more science and math in our schools and a different kind of science instruction at all levels, but especially in the upper grades and beyond.... In what way must this science instruction be different? It must be "science for all" as opposed to "science for future scientists." The desired new science instruction will not be so much "easier"--though that is certainly part of it--as it will be science brought to life, science taught in a way that will make apparent its

> relevance to daily living and to current social issues. And it will be a science through thought and action, science taught through laboratory and field experiences that stress the skills of inquiry, problem solving, and decision-making, as opposed to the mere collection and memorization of scientific terms and facts.... (Jackson, 1984)

The goal of establishing curricula appropriate for the diverse needs, interests, and abilities of all middle and high school students presents NSF with a far more ambitious challenge than it faces in trying to create curricula appropriate for the science-oriented students alone. There are, for example, several persistent systemic forces that continue to push high school curricula in the direction of being more suited to those likely to pursue science as a career. One force is the idea that school curricula should serve as a filter:

> Put in other terms, the system is one of successive filtering until only the majors and only the graduate students are left. Such a system may be necessary at the colleges and universities, where the students are being prepared for careers as research scientists. No similar arguments can be made for the high schools. Here the students are at a far different level of development in their intellectual skills. Science instruction in the schools must serve a different function. It must address a far wider range of the population and foster a far broader spectrum of interest.... (Pallrand and Lindenfeld, 1985)

A second factor that makes it difficult to develop a curriculum that provides appropriate learning experiences for a broad range of the students is the distorting culture of the schools themselves. Teachers and administrators gravitate toward teaching the measurable. Teachers feel obligated to prepare students for college courses as well as for passing state and national tests. They strive to cover the "prerequisites" for later learning:

> It is possible to come to the firm conclusion that most teachers have a narrow perception of these responsibilities.... The apparent primary goal of most science teachers appears to be that of teaching "fundamental knowledge" which is necessary to prepare students for later coursework. Goals related to preparation for using science in the personal, societal, and career-choice arenas, and goals related to inquiry appear to receive very little attention from teachers.... (Harms and Yager, 1981)

This is equally true of middle school science curricula, which seek to cover the material perceived as prerequisite to high school courses:

> There is clear consensus among scientists and science educators that the current middle/junior high school curricula are inappropriately "discipline-bound" and that they attempt to "cover" too much material. All agree that specific content is much less important than giving students an opportunity to experience science as a way of knowing. (Weiss, 1986)

The pressure of accountability distorts both the intent and implementation of even the most innovative, experientially based curriculum until it becomes just another (hopefully, more interesting) approach to "covering the material." Thus, it is important to realize that new curricula alone will not be able to bring about the desired changes:

> The little we know about how materials are actually being used in the classroom suggests that...today's students are now being exposed to content that is more factually correct, in the sense of being closer to what leading scientists claim to know, than was true in the past; yet the new material is still being taught in old ways with an emphasis on recitation and the memorization of facts. The notion of science as a process, as a mode of inquiry, seems not to have caught on, even amongst those using inquiry-oriented materials.... (Jackson, 1984)

A third and related force that drives curricula away from appealing to a wide range of students is the "trickle-down" effect from the college level. A prominent textbook author describes the process as follows:

> At RPI we wrote a book for our students, who are some of the best science and engineering students in the country. Because we assumed most of them had rather encyclopedic and broad coverage of topics in high school, we made the choice to cover far fewer topics and in much more depth.... Soon we found that textbooks at the high school level began to imitate our book, covering only the same topics.... What was designed for a few good students was now being taken as appropriate for the full range of high school students across the country.... (Resnick, 1987)

The trickle-down process affects what is taught at the middle school level in a similar way.

Finally, a fourth systemic force is the long-term decline in the fiscal capacity of most school systems (as school populations begin to grow again and as state legislatures show renewed interest in education, the funding situation may be improving once again). The role of the laboratory, considered by some scientists to be at the core of the science learning experience, has been declining in recent years. Many schools have eliminated the double lab period, and the expense of materials. the need for restocking and the time demands on the teacher all militate against experimental science.

In summary, then, all these forces pressure the middle and high school curricula toward uniformity, toward "covering" topics, toward the most academically inclined, and away from content that would interest all students. The problem is exacerbated by a force of teachers who mostly lack the extensive background and supportive conditions that allow them to teach up to the potential of new innovative curricula when they are available (French, 1986; Welch, 1979). All these considerations imply that a concentrated effort on new content, approaches, and environmental conditions will be required to modernize the system of science education.

Broadening the Curriculum: Some Guiding Themes

Future attempts to broaden and diversify the curriculum should involve fundamental and even radical rethinking of what students are to learn and how they are to learn it. There are important issues of content related to the subject disciplines and the students' experience that suggest promising directions to explore. The following eight themes provide starting points for the consideration of new curricula.

Reconsider the structure of the subject disciplines--The conventional subjects of middle school and high school science courses--chemistry, physics, biology, earth sciences--need to be reconsidered in light of new advances and basic changes in the working structure of the disciplines. Today, scientists are classified more by the types of problems they work on than by their parent disciplines. There are around 60,000 specialist journals to represent the major science and engineering problem categories. Most scientific and engineering problems are attacked by multidisciplinary teams and individuals with interdisciplinary skills. For more than a decade, the trend away from traditional disciplines has been clear:

> The growth of the sciences, particularly the natural sciences, has reached a stage where they can no longer be looked at separately. First of all, interface sciences began to develop between such subjects as chemistry and biology; for example, biochemistry, and later on more complicated linkages appeared in the form of such subjects as molecular biology.... The same phenomenon is now beginning to appear more and more with the subjects to which science and technology are applied. Nearly all the problems facing society today cannot be attacked by single disciplines.... The present static classifications of the sciences... have become essentially obsolete.... (King, 1972)

In addition to the emergence of new hybrid disciplines (e.g., computer science, genetic engineering), the role and prominence of technology are growing. Not only is technology a tool for investigation, it is also an instigator of whole new lines of inquiry (e.g., the electron microscope, not cell theory, gave rise to molecular biology) (Price, 1983). Middle and high school (as well as undergraduate) curricula lag behind these developments badly (just as they did in the 1950s). Efforts are needed to restructure the curricula so that they more accurately reflect the nature and processes of science.

Identify unifying principles across the sciences--Given the increasing fragmentation of knowledge at the frontiers of research, school-level science education more than ever needs a basis in enduring scientific ideas that appear in many disciplines (e.g., systems thinking, principles of conservation, the idea of functions) to serve as a foundation for a science curriculum that is organized around "essentials." Such essentials would selectively include disciplinary and societal knowledge, scientific attitudes, and generalizable intellectual skills that could provide an individual with a working "literacy" in science and its approaches, as well as a fundamentally strong base for advanced work in the sciences and mathematics.

Integrate technology into science and mathematics courses--Technology, especially calculators and computers, changes what can be taught and how it can be taught, in addition to being a topic of study in itself. Just as they do in science, such technologies create new realms of possibility in education. For example, computers and appropriate software make some scientific concepts accessible at earlier ages (e.g., ecology simulations for elementary school students), and they serve as powerful tools that empower new levels of inquiry in the laboratory. Computers and telecommunications can be integrated into the classroom to provide students with a chance to do scientific investigations that accurately mimic "real" science.

Technology changes the way scientific problems are solved; and, more generally, it affects the way people think about problems. Powerful ideas--numerical methods, iterative approaches, algorithms, heuristics, debugging--all become part of a more general problem-solving repertoire. Technologies in this way change the intellectual culture of the environment in which they are used (Papert, 1987). It is important that today's students learn the language and the metaphors of this culture. The potential of technology to enhance learning in the classroom has been demonstrated in many different pilot projects. Now, in addition to continuing the search for new possibilities, the challenge is to find feasible, attractive ways to integrate these technologies into actual school settings and curricula on a large scale (Tressel, 1987a).

Combine mathematics and science--Especially with the availability of technologies for handling complex calculations, the connections between mathematics and science are more possible and more important to make at all levels--e.g., making probability and statistics more prevalent in biology and life science instruction, providing dynamic graphical representation as an aid to interpretation of physical science principles. A decade ago, the NSF-funded Unified Science and Mathematics for Elementary Schools (USMES) project was a first experiment in pursuing large-scale integration of the two subjects, perhaps a little before its time. Now, with new technological capabilities, the time may be ripe for further experiments, more specifically aimed at middle and high school grades.

Attend to the applications of science and technology and their impact on society and economics--The increasing presence of science and technology in all aspects of life makes these issues an essential dimension of science learning, either as a basis for organizing an entire curriculum, or as a major emphasis in courses to provide a connection with real-world issues. Many observers argue that we need to promote a more realistic vision of science centered around technological and societal issues, and that science should be taught in a way that "fuses social purpose and human betterment with scientific research and technological innovation in ways most likely to advance the quality of life" (Hurd, 1985).

However, the professional community of scientists and educators is currently debating the emphasis that issues of science and society should play in the curricula. In teaching *about* science, rather than *doing* science, some scientists fear a fatal loss of integrity and rigor in what is presented to students as "science." A recent editorial in *Science* phrased the concern this way:

> Developing "good guys" and "civic-minded women" is all very well, but the greatest contribution...is to expose students to deep intellectual experiences and to show them how to do a job, almost any job, extremely well. (Koshland, 1987)

The challenge for the new curricula will be to develop an approach that is relevant to students and their lives and at the same time makes "the new science education a solid learning experience" (Jackson 1984).

Exploit the ease of access to information, while taking account of the potentials and problems this creates--The fact of ready access, via printed and electronic means, to an enormous quantity and variety of scientific information needs to be considered to understand the search and management skills that are required of the learner. "Technology literacy" skills need to be a part of the curricula if young learners are to be empowered to use the tools of information retrieval and processing that will be an integral part of the world in which they will live and work. New curricula must shift their purpose from predominantly providing knowledge (which is increasingly ephemeral, as well as growing exponentially) to providing individuals with more generic skills of finding and processing information. Science content is not to be ignored but should be presented on a "need to know" basis; at the same time, students must learn how to get it for themselves.

Reassess experiential learning and ways to achieve it--There is growing consensus that the content of current school-level science education places too great an emphasis on broad coverage of scientific knowledge, at the expense of more satisfactory "experiences in depth"--exploration of particular topics in detail so as to master the process of disciplined inquiry (Jackson, 1984). One scientist eloquently phrased the difference in the following way:

> I think that our instruction has been single-pathed. You're in a forest, you walk carefully along the path and reach the chest of doubloons on the other side--and solve the problem! And that is the way we--I too--teach physics. But the kids that try it get lost at each turning of the path. The trouble is that they think there is only one safe path, that they have to stick as close to that as they can, and they are afraid to go off into the deep woods. I think that the only way to teach pathfinding is to make them get lost many many times, to make all the false starts, to try out all the alternatives. Of course, you can't learn many paths that way, but you learn a way of going down a path. Then if someone gives you another start, you might be able to find your way for yourself, hopefully, some other time. (Morrison, 1964)

In light of the paucity of science-like experiences in the backgrounds of most students, and in light of the difficulties schools face in mounting adequate experience-based instruction, there needs to be a reexamination of the laboratory experience and possible complements to it. Curricula aimed at providing rich, student-centered experiential learning will have to find ways to exist in present classroom cultures and conditions, and at the same time go beyond the current limitations imposed by existing curricular expectations. In particular, new technologies need to be explored with this end in mind. Computer-based laboratories and, to a lesser extent, simulations may be able to offer classrooms cost-effective tools for student inquiry. Videos may be useful in providing a "window on the world" and presenting images of natural behavior and phenomena.

Informal science experiences can be used to complement and augment classroom activities. Particularly for adolescents, the opportunity to participate in real-world science contexts is important (Diamond et al., in press). Clubs, jobs in informal institutions, amateur science societies, crafts, and hobbies can all provide contexts that both attract middle school and high school students and can provide them with experiences that foster scientific attitudes and interests. (See Opportunity 10 for more on informal science learning as a complement to school-based programs.)

Design instruction that is appropriate to the cognitive processes of the learner-- In the past decade considerable progress has been made in understanding, in detail, the processes involved as students learn (and don't learn) science content (Linn, 1986). The perspective of those cognitive scientists who study the learning and problem-solving processes of novices and experts provides curriculum developers with insights as to the barriers they must overcome and how they might best approach the instruction of young science learners. One researcher told us:

> "I feel that one of the major reasons we have a chance to do better this time than we did in the 1960's is that we know so much more than we did then about what and how students are capable of learning. The research on misconceptions and cognitive science has profound curricular as well as instructional implications.... My first priority for the new curricula is that they should *work*. That is, they should actually lead to the student learning what they claim as their goals.... The implication of this position is that I believe that curriculum development should be based on what we know about student learning...."

NSF and the Search for Appropriate Content

These eight themes suggest general directions for recasting the content and approaches of middle school and high school science. To fulfill its mandate of "strengthening science education" at these levels, NSF faces the challenge of guiding a national search for diverse and innovative curricular approaches. Such curricula must be much more effective than present ones are at meeting the needs and interests of the broader pool of students who ultimately must fulfill the nation's growing need for a citizenry and a work force that are deeply imbued with scientific skills and attitudes. Put the other way around, NSF must search for curricular solutions at the high school and middle school levels that begin to stem the present large-scale disenfranchisement of most students from scientific careers and interests.

NSF is particularly suited to guide the search for *appropriate* content (knowledge, skills, and attitudes toward science) and associated approaches to teaching and learning. Such content must meet several criteria. The content must obviously be suited to the purpose of developing a broader pool of youths who are interested in science and mathematics and able to apply scientific and mathematical thinking in their future lives and occupations (including but not limited to scientific careers). The content must also be appropriate to the age and development level of the learners and be framed in terms that are understandable and appealing to the majority of students. It must also reflect the nature and structure of science accurately, and must include only essential knowledge, skills, and attitudes, which are carefully distilled from the practitioners of science. At the same time, content must be conceptualized so that learners with different degrees of sophistication can learn it.

The time is ripe for a "frontal assault" on this national need. NSF is positioned centrally in the field of players who need to be engaged in this reform. General awareness of the need and the issues is high; there is broad public support for this kind of curricular overhaul. State and local educational policy groups (e.g., legislators, governors, state supervisors, superintendents) are seeking assistance, especially with regard to substantive content issues. Examples and challenges from overseas are beginning to make themselves evident, adding to the ferment around this issue. And given the attention span of the nation to "crises," the window of opportunity for collaborative action on the curriculum may exist for only a few years. However, the consequences of failing to shift the general curricular emphasis, especially given the present demographic trends, will be acutely felt throughout the society for the next several decades.

Some of the groundwork has been laid for addressing this national need, e.g., NSF-funded Project Synthesis in the early 1980s. More recently, the Carnegie Corporation's support for revamping middle school life science curricula along "human biology" lines and for Project 2061 (conducted by the American Association for the Advancement of Science), in which multidisciplinary panels are attempting to define what 18-year-olds in the future should know, provide starting points for NSF-supported efforts to reconceptualize curricular content. This latter project provides one basis rooted in the scientific community for exploring these issues (Rutherford et al., 1986).

NSF has supported smaller, more modular experiments with new curricula, and with bolder new approaches in technology and out-of-school settings. These and other related efforts are a beginning; what is needed now is a broadly based, continuing, and more ambitious effort to expand the dialogue on curricular needs, to propose new curricular visions, and to support experiments in radical curriculum revision that will ultimately lead to significant national curriculum reform.

The role of substantive leader is a natural one for NSF, and of all the pieces of the science education puzzle, dealing with the content of science curricula is what NSF can do best. The Foundation's history in curriculum reform (although not without blemishes) contributes to general acceptance of this kind of role, provided that NSF's efforts do not lead to what critics perceive as a "national curriculum" imposed from the federal level. NSF is uniquely positioned to bring together the kinds of coalitions of scientists, educators, and others necessary to undertake this ambitious task, and thereby to assist states and localities in their own efforts.

There are pitfalls in addressing this opportunity. Addressing educational content risks public scrutiny (about which NSF is very shy). Dealing with the content of "science for all" risks resistance from the scientific community, much of which takes a narrower view of curricular priorities and hence of NSF's educational mission. The science education community has not confronted questions of what to teach and why, as much as questions of how to teach (Harms and Yager, 1981). These factors add to the difficulty of the task.

Finally, the limitations of curriculum reform must be acknowledged. Addressing content in isolation from the other forces that keep the curriculum the way it is will prove frustrating. Any attempt to recast the content of, and approaches to, curricula must eventually take into account the teacher's world, the publishing and testing industry, and the operating modes of schools and districts. One of the lessons of the past is that the problems of science and mathematics instruction at the high school level are so deeply embedded in larger problems of the schools that any attempt to solve them in isolation may be doomed to failure (e.g., Stake, 1977; Carnegie Forum, 1986; National Commission on Excellence in Education, 1983):

> Dull courses; instruction that bears no relation to the concerns and interests of students; emphasis on the memorization of facts and the consequent neglect of critical thought; halfhearted teachers; petty administrative practices--the history of educational criticism in this century and long before reminds us that these defects are by no means restricted to math and science alone, but are endemic throughout the system and have been for generations. (Jackson, 1984)

Thus, not all of the problem with the pool of science learners can be attributed to the content of what is taught. The level of preparation and expertise among teachers, the quality of textbooks, and the effects of poor or inappropriate testing procedures are as much a cause, if not the greater part of the story. But these aspects of the problem would be more easily improved given a clearer sense of what is to be taught to whom and compelling demonstrations of such curricula in use.

Past and Present NSF (SEE) Investments in Relation to This Opportunity

Because of NSF's extensive history of support for curriculum improvement, it will be helpful to put its current investments in historical perspective. The idea of "science for all" is as old as modern empirical science itself. In the 17th century, Bacon argued that only by engendering widespread science literacy in the population could England avoid the dangers of scientific knowledge invested in a few, which he called the "hazard of genius" (Prather, 1985). In this country, it wasn't until the end of World War II that science education at the K-12 level was thought of as a national priority. In 1950, the Bush Report led to the establishment of the National Science Foundation and its mandate "to improve science instruction at all levels of education" (Buccino, 1983).

From 1945 to 1955 there were many studies of the deplorable state of science teaching (Lacey, 1966). The parallels to today's situation are both remarkable and sobering. Consider an AAAS study that outlined three major factors involved in the poor state of science education in 1946:

> The American public, which fails to pay its teachers decently,...the American colleges, which have failed to prepare prospective teachers for the kind of teaching they should do...and the high school curriculum, which needs a thoroughgoing reorganization.... (Lacey, 1966)

The resulting revolution in curriculum development involved a shift in premises and emphases. Before the mid-1950s, textbooks used in science classes at all levels were written by educators, not scientists (Butts, 1982). From the late 1950s on, the production of new materials under the NSF initiatives was put in the hands of scientists, with teachers and educators playing an important, but often secondary role.

Before the 1950s, the emphasis of science education was on the development of intellectual faculties and on the use of science education as a vehicle to develop the whole person (Zais, 1976). By 1960 the focus had shifted to providing students with mastery of content:

> For the first time it appeared that we had moved into a period when the teaching of subject matter might become an end in itself. (Atkin, 1983)

> Today we take it for granted that science teaching at all levels should focus on the study of the substantive content of the subject matter for its own sake. Indeed, the study of the subject matter of science is a relatively new idea, for throughout the history of mass education science was used as a vehicle to achieve other, presumably loftier, purposes.... (Buccino, 1983)

Bruner (1960) articulated the need for the new curricula to be structured around the the most fundamental principles of the discipline itself. The premise underlying the new curricula was that students could be taught to think like scientists; that think process, in itself, was assumed to be inherently interesting to most students (Gagne, 1979; Yager, 1981).

NSF's Past Investments in Curriculum Improvement

Within this overarching disciplinary context, from 1956 to 1975, NSF funded more than 50 curriculum development projects (Welch, 1979). Known informally as the "alphabet" curricula (PSSC, ESS, SCIS, etc.), these curricula shared several important characteristics. As already mentioned, they were developed by teams headed by scientists and consequently sought to convey the nature and structure of the disciplines. They were structured around predominant themes within the disciplines; for example, different versions of Biological Science Curriculum Study (BSCS) materials were designed around different major ideas and approaches to biology: molecular, ecological, cellular. Most curricula emphasized student hands-on experience and provided kits, labs, field experiments, and/or supplementary reading.

How is the success or failure of NSF's heavy investment in these curricula to be determined? The record is mixed, and the level of success depends heavily on what perspective is adopted when viewing the results. In terms of impact on those in the "pipeline," some of the curricula strongly influenced a significant number of students. Twenty-five percent of all undergraduates in 1983-84 earning a bachelor's degree in physics had taken PSSC physics in high school. Of those taking the College Board Physics Achievement Test, up to 43% had taken PSSC physics (French, 1986). The BSCS texts were used by 50% of the biology classes in the United States from the mid-1960s to the mid-1970s (Tamir, 1983). As of the late 1970s, three-fifths of the nation's grade 10-12 schools had used one or more of the federally funded curricula (Weiss, 1978).

However, when viewed from a broader and longer-term perspective, the impact of the curricula appears more diffuse and less positive. One survey found that 9% of high schools offered PSSC physics; 8% offered Project Physics; while 54% offered *Modern Physics*, a standard textbook by Williams et al. (1976). Another study found little evidence of continuing use of these curricula and concluded that the classroom was little changed from 20 years previously (Stake and Easley, 1978).

The new curricula presented materials of high intellectual quality, especially when viewed from a disciplinary point of view. However, particularly in physics and chemistry, the courses proved to be too difficult. One observer commented:

> Without fully realizing it, the makers of PSSC physics were speaking mainly to their own kind. The problem of reaching the average student remained unsolved.... (French, 1986)

Why did the massive curriculum efforts not supply all students with the excitement of modern science as their authors had hoped? One reviewer concludes: "Things did not work out as planned for at least three...reasons: (1) the level of difficulty of the materials produced; (2) the complexities of their dissemination; and (3) the ambiguities surrounding federal policy with respect to curriculum development" (Jackson, 1984). The new curricula did not consciously set out to exclude students not already intellectually excited by science. In fact, it was planned that the new curricula "had in view not just the training of future scientists but also a concern for the view of science held by students in general" (Pallrand and Lindenfeld, 1985).

One difficulty may have been the curriculum developers' lack of deep understanding of the schools, teachers, and students. Steering committees and large teams of developers were often involved in developing the new curricula, but teacher feedback and realistic formative evaluation appeared to play a minimal part in setting the final form of the curricula:

> My own experience with that process suggests the results of classroom tryouts had little effect on subsequent versions. Scientists were usually hesitant to accept the criticism of their "science" from school teachers unless very convincing data were provided. (Welch, 1972)

More often than not...revisions were based on debates among project staffs....
I believe...this explains the generally high difficulty level of most, if not
all, of the newer curricula. (Welch, 1979)

The hopes for the curricula were also doused by the lack of effective mechanisms for "dissemination." Research over the last decade (e.g., Gilmar, 1985; McLaughlin, 1976; Miles, 1983), as well as SEE's own extensive experience, helps to identify a number of key variables affecting the likelihood of the widespread dissemination and adoption of an innovative curriculum:

- The nature of arrangements with commercial publishers--in particular, the timing of their involvement, the financial incentives for their participation, the long-term rights over further distribution or use of the materials.

- The compatibility of the course with existing curricular frameworks and sequences: where courses in the past (such as *The Man Made World*) had no natural niche in existing curricula, the distribution of such courses was not extensive. This factor imposes a certain conservatism on large-scale curriculum development efforts, which seek to fit into existing curricular frameworks.

- The extent of teacher exposure and training in the concepts, skills, and approach embodied in the course.

- The level of difficulty at which the content is set, both in terms of its fit with the nature of the student population being taught and the demands it places on teachers.

- The logistical demands of the course and their compatibility with the support level and overall conditions of the classroom.

The joint effect of these factors has been that many, if not most, of the large-scale curricula developed with SEE support over the years have not found a place in school curricula over the long term and hence have not had continuing widespread direct impact on students (Jackson, 1984; Welch, 1979).

At the same time, the indirect impacts of these investments were numerous and are easy to overlook:

- Imitation and carryover of practices into other development, e.g., in commercially prepared textbooks (Quick, 1977).

- Leadership development: many of the current cadre of leaders in science education got a significant start in curriculum study groups of the 1960s.

Finally, it was the ambiguous demands and constraints of the federal role that ended NSF's heavy involvement in curriculum improvement during the mid-1970s. In particular, one effort to produce a course in the social sciences--MACOS ("Man: A Course of Study")--led NSF into severe criticism from those who felt that the federal government had sponsored an effort to produce a "national curriculum" promoting secular humanism, thus overriding local religious values. The controversy that arose ultimately not only hurt NSF's curricular role but also contributed to the general demise of the Foundation's role in K-12 education in the early 1980s. Even today, 12 years later, the MACOS affair still colors NSF's (and others') perceptions of NSF's role in the curriculum area. SEE staff readily admit to being "gun shy" when it comes to efforts in social science or large-scale curricular efforts.

We summarize the principal lessons that can be learned from NSF's past involvement in curriculum development that have implications for the Foundation's future role in the search for appropriate content and approach:

(1) *NSF can respond effectively to a national curricular "crisis" in science and mathematics education.* It has the ability to make the deep-rooted curricular problems of science education visible and to mobilize intellectual talent to address them.

(2) *To be effective, curricular reform efforts need to be collaborative.* The heavy involvement of the scientific community is a necessary but not sufficient condition for success. Also required is the involvement of the diverse groups of the science education community, from those studying learning and cognition to those administering reforms at the state level (March et al., 1987).

(3) *The indirect impacts of curricular reform efforts may be as important as the adoption and use of specific curricula.* Curricula that derive from and illustrate new ideas about science and about learning can have large leverage over conventional wisdom about what should be taught and how it should be taught. Similarly, the professional development and exchange of ideas among those involved in the development process can be very significant.

(4) *NSF is well suited to the task of creating alternatives to existing practices* (e.g., embodied in the materials offered by most commercial publishers) and proliferating options that provide new perspectives and approaches. For example, in the 1960s and 1970s the new curricula embodied the intellectual flavor of the "modern" sciences and made them available to students of all ages.

(5) *Curricular reform is not separable from overall reform efforts.* To bring about changes in the content of what is taught and the way it is taught, there will have to be an integrated effort focused on the entire system of K-12 science education. New curricula will not be embedded in the schools in the absence of efforts with teachers, publishers, school administrators, state agencies, etc.

(6) *In its classical linear form, the research-development-and-dissemination model is not the process by which new curricula make their way into practice.* Curricula are not proven in model schools and then adopted on a wide scale.

(7) *NSF faces a fundamental and deeply rooted dilemma that pervades all of its efforts at affecting curricula.* If NSF focuses too much on model curricula and very new approaches, then it runs the risk of having developed unmarketable curricula that never get used. If, on the other hand, SEE chooses to develop materials within existing commercial and educational constraints, then it may compromise the integrity of any innovations and merely create a slightly higher grade of the mediocrity.

NSF's (SEE's) Current Investment Aimed at Rethinking Middle and High School Science Content

Since the "rebirth" of the Directorate in 1983, SEE's materials development efforts have supported projects that tackle pieces of the broad goal of rethinking the curricular content. Through its support for the development of materials, SEE has indirectly approached the larger task of fundamentally rethinking the content and approach of high school and middle school science. One can discern three principal strategies underlying the current (and projected) developmental thrusts of the Directorate.

Development of curriculum modules and tools--The first strategy aims at the development of curriculum modules that fill gaps in the current K-12 curriculum (and also at technological tools that can be used flexibly in various places within the curriculum). The strategy is carried out chiefly through the Instructional Materials Development program, supplemented by a few grants made by the Applications of Advanced Technology and Informal Science Education programs. The recently terminated Methods and Materials of Teacher Preparation program (1984-85) and the Development in Science Education program (DISE, 1977-1981) pursued a similar investment strategy.

The rationale for this strategy is partly political. Following the MACOS controversy, SEE was (and is) reluctant to put itself in the business of large-scale curriculum development. Curriculum modules aimed at "gaps" and "supplemental materials" avoid potential accusations of fostering a "national curriculum." In addition, these materials do not supplant existing curricula. Novel and radical approaches can be tried because they are "supplemental." Successful innovative materials, created as curricular modules, can serve as convincing models of what is possible on a larger scale.

In addition to political advantages, the strategy has other, more substantive advantages. By not specifying the particular areas of school-based science to be addressed, the open-ended solicitation used to supplement this strategy invites the widest possible range of participation from the field; the diversity of topics, types of grantees, and disciplinary areas encompassed by current projects suggest that NSF's investments have encouraged a broad response. Although the products of modular development are not necessarily very visible, there is some potential in this strategy for a "breakthrough" idea to be developed and proven feasible: perhaps microcomputer-based laboratories, now being pioneered with SEE funding, may prove be an example of this in a few years' time. Finally, modular materials and tools can--in principle--be used more flexibly in the existing course structure:

> Curriculum modules, each covering a more or less self-contained segment of a subject, can be introduced in existing courses on an experimental or continuing basis without the necessity of changing the rest of the course or the textbook. They lend themselves particularly well to...topics of current scientific interest as well as...to material with a technological or social component.... The smaller and more informal units make change and adaptation relatively easy.... (Pallrand and Lindenfeld, 1985)

However, because the emphasis of this strategy is on the development of materials for topical areas not currently covered by most curricula or on the creation of new tools for use in the curriculum, the immediate and direct impact of the strategy's products on students and instruction nationwide is likely to be small. At most, students in the pilot test schools are directly exposed to the new materials. Broader exposure occurs only as the materials are commercially published and adopted, or as the fundamental content and approach illuminated by the module ar widely imitated by others. Curriculum modules, however, are typically not attractive financially to the publishing industry.

On the whole, the strategy aimed at "filling topical gaps" is "safe"--that is, unlikely to attract negative attention from the powers that be (e.g., political groups at the national level)--but also low-yield, in the sense that the results will be unlikely to make a splash among science educators. In terms of addressing the larger opportunity of recasting the science curriculum at the middle and high school levels, the current SEE investments of this type have little potential for national impact. The modular approach to curriculum revision is a legitimate mechanism, but it is currently being carried out in the absence of a larger guiding context.

Whole course development--The Directorate has recently funded a few projects aimed at "whole course" development (e.g., life science for the middle school; a course on chemistry for the "general" high school student). Such large-scale curriculum efforts have been few in number since the controversy in the mid-1970s over the federal curriculum role (partly because resource levels are much lower now). The present strategy aims at fashioning new programs appropriate to particular age levels in school. Such efforts begin to get at the opportunity of fundamentally recasting the curricula to be appropriate for a diverse group of students.

By comparison with the development of curriculum modules, whole course (or text) development has greater potential for widespread direct impact on students and instructional practice nationwide, but this potential is realizable only to the extent that the development products are published, receive widespread attention, and are adopted by large numbers of school districts.

There are indirect benefits of sponsoring such projects. The nature of whole course or text development requires large, multidisciplinary groups. Few of these groupings exist naturally in the field, and they must be created in response to SEE funding (if the response to the elementary science materials solicitation is any indication, such groups are readily formed but may face significant start-up problems). The strategy has a great potential for bringing unlikely partners together, particularly if such requirements are built into the funding mechanisms.

As currently conceived and implemented, there are significant disadvantages to investments in whole courses. First, a course is not a curriculum. This strategy thus runs the risk of creating courses--the building blocks of a school's curricular sequence--that are incompatible with one another or not informed by a unifying vision of the conceptual ground to be traversed. Second, supporting development of one course at a time is more likely to elicit courses designed for existing slots in the current curriculum sequences--e.g., high school physics, middle school earth science.

Publisher partnerships--In part because of the dissemination difficulties of both the modular and whole course approaches, NSF has recently experimented with another strategy for supporting curriculum and materials development. By offering "venture capital" for publishing companies to work with developers on innovative curricula and by requiring publishers to put part of their profits into teacher training, NSF is attacking head-on the perennial problem of disseminating the model curriculum its grantees develop. By bringing in publishers from the beginning, NSF is trying to assure the widespread use of its materials rather than leave their dissemination to hope.

This latest strategy, now well under way with the recent announcement of three first-round awards in elementary science, represents the closest NSF has come to a "grand strategy" for improving the content of science. The strategy has the following features:

- Initial emphasis on the elementary grades, to be followed in due course by similar efforts aimed at the middle and high school grades.

- Concentration of funding in a small number of large-scale, multiyear projects, featuring equal collaboration among developers, commercial publishers, and a school system.

- Emphasis on developing materials or programs suitable for the "average child" in the "typical American school" (in contrast with earlier generations of NSF-supported curriculum development, which usually aimed at only the more able students or those most likely to pursue scientific careers).

This strategy has yet to be applied to the middle and high school levels; it has been articulated and implemented first with respect to elementary science. However, SEE planners project that a version of the strategy will be applied to higher levels of schooling in the near future.

The Likely Yield of Current and Projected Investments

Although innovative, high-quality projects are being funded (some on a sufficiently large scale to encourage broad thinking about curricula), the three development strategies described above are likely to fall short of reaching the goal of rethinking the content of and approach to K-12 science education in several ways:

- *Lack of comprehensiveness*--Current materials development approaches are unlikely to explore, formulate, or articulate the fundamental rethinking that is needed. Partnerships with publishers and modular development strategies will produce many useful units to be inserted into existing curricula, without calling into question basic curricular assumptions.

- *Lack of relationship to research*--Research currently supported by SEE's Research in Teaching and Learning (RTL) and Applications of Advanced Technology (AAT) programs is not as closely related to the developmental thrusts as it ought to be to achieve the reconceptualization described above. RTL investments tend to be oriented toward specific lines of scholarly inquiry; AAT investments aim at technological applications for the distant future. Both programs have much to contribute to rethinking content and approach in principle, but their potential to do so has not been tapped extensively.

- *Constraints on the range of ideas considered*--The current emphasis on developing major new course or program alternatives in close collaboration with publishers may jeopardize the breadth of rethinking that takes place within them. The constraints of the current marketplace will inevitably cause good ideas to be discarded or ignored. SEE currently lacks a larger strategy to ensure that these projects contribute to a bigger rethinking process.

In summary, then, NSF's current programs are supporting good people in the field who are addressing specific problems and taking advantage of emerging opportunities. Individually, the projects are generally of high quality and are well directed. Collectively, however, their potential is limited--either in the breadth of their impact or in their contribution to a comprehensive reformulation of what students are to learn--for they set out to do neither. As we have seen from NSF's earlier history, the barriers to change and the constraining forces on the curriculum are great. With the exception of the targeted publisher initiatives, there are no clearly evident mechanisms by which the three current strategies, executed on a small scale, can realistically hope to have wide impact on the practice or theory of science education.

The publisher partnership approach has the advantage of a well-articulated strategy. It places NSF in a more proactive role and allows the Foundation to target its efforts in a more concentrated way. It is too soon to judge whether in fact such funding approaches can yield high-quality materials that have widespread impact. It is certainly a worthy experiment and should be given a full trial. However, this arrangement is aimed at incremental improvements and is conducted with the early involvement of publishers, who must keep an eye on the commercial viability of what is developed. Even if successful, the strategy may not yield the most far-reaching or creative rethinking of curriculum content and approaches.

Very recently, SEE has begun to develop and articulate a larger guiding context for its curricular initiatives:

> One of the key missing pieces is a consistent and coherent science curriculum for all students. Not another physics course or chemistry course or biology course, but a consistent and coherent pattern of basic science education throughout elementary and high school. (Shakhashiri, 1987)

Such a context can provide greater direction to NSF's investments in curriculum modules, whole courses, and publisher partnerships. More ambitious initiatives, such as those outlined below, are probably necessary, however, to generate the curricular frameworks into which these investments fit.

Promising Initiatives

The approaches most attractive to NSF in this area of opportunity emphasize long-term examination of the fundamental assumptions and structure of the science curricula employed at the middle and high school levels. In this sense, we argue that an approach aimed at long-term basic changes in content and approach will bear the most fruit, although there are some more immediate ways to encourage schools to reframe their curricula. The nature of the opportunity, however, excludes most kinds of strategies emphasizing short-term incremental change. The fundamental challenge involves recasting the curricula in ways that go beyond what is now conventional. NSF needs to support a search for radically new guiding conceptions of science curriculum.

If NSF is able to take advantage of this opportunity (and it appears that it is well positioned to do so), the outcome would be several new conceptions and ways of thinking about the teaching and learning of science at the middle and high school levels. Twenty years ago a wave of reform introduced the notion of hands-on science at the elementary level, providing a new paradigm for early elementary science education (see discussion under Opportunity 2a). Such new paradigms are now needed at the middle and high school levels. It is impossible to foresee exactly the nature of the alternative visions of science education that may emerge. Probably they will creatively meld many of the important aspects of curricula discussed above (e.g., inquiry-based learning, depth over breadth, use of new technologies, diversity of approaches, integration with other subjects). Their implementation will probably entail the orchestration of technology, informal resources, laboratory materials, texts and other printed materials, and perhaps field experiences, to say nothing of teacher preparation and support.

A committee of the National Research Council (March et al., 1987) recently called for a similar large-scale initiative to rethink the nation's curricula and pointed out the need for innovative ways to accomplish this rethinking:

> Obviously, the context of 25 years ago cannot be recreated. Optimism about the ability to solve the nation's educational problems has diminished, while priorities have shifted to a concern with mathematical and scientific literacy for all, rather than emphasizing primarily preprofessional education. The new priority requires even greater emphasis on collaborative work drawing on several disciplines and professions.... Given these factors, adaptations or new social inventions are needed for conducting interdisciplinary research that focuses on current priorities....

The two initiatives that follow emphasize two different approaches to creating and focusing debate on curricular alternatives. The first initiative approaches the task "from the top down" and emphasizes NSF's ability to network the critical expertise and constituents who need to be involved in a national reconceptualization effort. The second initiative is a "bottom-up" approach and provides support for more concrete experimentation with alternative visions of science education for the high school and middle school.

2b.1 Support National Task Forces with a Mandate to Redesign High School and Middle School Science Curricula

Consisting of nationally prominent scientists and science educators, state-level educators, and prominent representatives of industry and other professional communities, several different task forces could pursue in detail different guiding conceptions for the new curricula. Each task force would approach the redesign of the curricula from a different point of view. For example, task forces could focus on:

(1) *Reflecting new structures of the disciplines*. This task force could, for example, follow up on the groundwork laid by Project 2061, and design curricular frameworks for high school and middle school that reflect a more integrated view of the traditional disciplines. These frameworks would specify knowledge and skills extracted from all the disciplines, roughly by level, that could form a curriculum core or basic education in the sciences for all students.

(2) *Integrating new information technologies into the curricula*. The use of information technologies is becoming increasingly powerful in enhancing the quality of science education. Telecommunications, computer-based labs, simulations, sophisticated tutoring systems, and microworlds all offer new vehicles for letting students do and learn science. Similarly, other technologies, particularly videotapes and other visual systems, are already in

place in most classrooms and offer yet another tool to aid the teacher in teaching science in multiple modes. This task force would envision (in some detail) what it might look like if the new technologies, both as a tool and as a subject of study, were used to their potential and occupied a more central position in the middle and high school science curricula.

(3) *Centering the science curricula on societal and personal issues.* As pointed out earlier, the curricula generated in the 1960s derived from an attempt to reflect the structure of the scientific disciplines. Another equally valid starting point, and one that might prove more successful in broadening the appeal and success of science instruction, is to develop curricula that derive from and reflect interests and issues closer to the learner. This would involve studying some issues of science and society, as well as project-oriented curricula that bridge in-school and out-of-school experiences and that flow from students' personal interests (particularly important to middle school students).

(4) *Providing a consistent and coherent pattern of science education from kindergarten through college.* The articulation of the different levels of education with each other provides a chance for establishing the beginnings of a "consistent and coherent" vision of science education as a basic component of the K-12 school curriculum. The connection between high school and college-level courses is similarly important because of the "trickle-down" phenomenon and the expectations of "prerequisites" (real and imagined) at the high school level.

Each of the above task forces would have a mandate to generate a detailed framework for a new curriculum at the both high school and middle school levels. Each framework would reflect a different approach and philosophy (much as SCIS, SAPA, and ESS reflected different guiding conceptions of the elementary science curricula). These frameworks would not be curricula, but they would be detailed enough to serve as planning documents from which curricula could be developed. The formulation of detailed alternative visions of the curricula would be useful in guiding subsequent major NSF curricular projects, as well as being appropriate and useful to states and localities in their own development efforts.

These task forces could be thought of as nonpermanent centers: each task force would have a small staff, would meet frequently over a few years, and would hold public forums, as well as carry out coordinated studies related to the task force's focus. The task force mechanism is well suited to bringing together the interdisciplinary expertise needed to construct innovative and viable frameworks. In addition, NSF-sponsored task forces would be highly visible and could effectively orchestrate public discussion and debate among the wide range of constituencies involved in determining K-12 science curricula. In this way, these task forces could bring to national attention the need for, as well as the possibility of, radical curricular reform. The collective effect of such activities would be to forge a broad-based sense of purpose and appropriate response to the curricular needs at the high school and middle school levels. Task forces composed of individuals representing a wide range of expertise and interests would have the advantage of bringing a broad view of the nation's needs to the problem, which would certainly include but not be limited to the perspective of the disciplines.

This initiative would aim at producing the following kinds of outcomes within 5 years:

(1) New articulations of the goals and forms of the middle and high school curricula--the coherent and consistent patterns of science education that would provide all the nation's children with a sound background in the knowledge, skills, and attitudes of science.

(2) Several detailed visions of radically new alternative emphases and approaches to science education (e.g., curricula based around information technologies, an integration of conventional subject disciplines, informal experiences or science and technology issues in the community).

(3) Better understanding of the barriers to a curriculum that serves the broader pool of students, and some general principles for overcoming them.

(4) A focusing of national attention on the issue of science education for all and the generation of a national commitment to a sustained effort to address this issue.

It is important to understand that this initiative might well include support for projects related to various programs of the SEE Directorate. For example, research projects would be funded to support the curriculum goals. Similarly, national studies might be done to explore the status of curriculum and curriculum change throughout the nation. Programs in SEE's Division of Teacher Preparation and Enhancement could support conceptual work on the implications of a new curriculum focus for teachers, for teacher preparation, for inservice support of teachers, etc.

These task forces would require funding at an average level of $3 million to $4 million per year, or $15 million to $20 million over 5 years. These estimates assume that four different task forces are funded, with each task force consisting of 12 members (supported part-time) and five full-time staff members. Each task force would have resources for travel and meetings, as well as discretionary funds for supporting several associated studies and support projects. In addition, the Directorate would have up to $1 million per year to fund research and development projects compatible with the work of the task forces.

2b.2 Fund Field-Based Experimentation with Alternative Conceptions of Science Education

This initiative, intended to complement the more theoretical work of the preceding initiative, would offer support for projects that demonstrate the potential and feasibility of alternative conceptions of science curriculum at the middle and high school levels. Research-based products and practices would be tried out in school settings as part of whole new curricula, not simply new courses or modules. Large projects might be funded in areas similar to or the same as those discussed in the task forces. Examples might include:

- Technology-based curricula for schools or districts that teach science, mathematics, and perhaps other subjects in a way that derives from, and is centered on, the new technologies.

- Approaches that integrate the school curricula with frequent involvement in out-of-school activities. Such a curriculum would demonstrate ways to center science learning on individual and group work in the community, in informal institutions, and in student-initiated projects.

- Curricula that pursue science from a historical, ethical, and philosophical perspective. Including but not limited to science and society issues, such a curriculum could focus on science starting with contemporary problems and exploring them in light of historical precedents.

- Inquiry-based curricula that begin with the study of natural phenomena and are structured according to students' own interests. The emphasis of this conception would be on teaching the art of exploration, of following one's own questions.

To some degree, this initiative is a more focused extension of what is now going on in NSF's materials development program. However, in funding this initiative, NSF would emphasize (1) projects aimed at exploring new conceptions of science for a broader pool of learners, and (2) projects that explore and test the viability of large guiding conceptions for the curricula.

NSF could support projects such as these in a two-stage process: first through planning grants to many project teams to conduct an exploratory and planning process, and later through large grants to a smaller number of projects to pursue full-scale trials of the most promising curricular conceptions.

The idea behind these two-stage efforts is that ambitious alternatives to current goals and approaches to science education are difficult to realize. They need to be thought through more carefully than is possible in the typical proposal process; the interdisciplinary teams required for these projects need time (and incentives) to assemble. Somewhat in the mode of its current support for unsolicited grants, NSF could invite development teams and consortia to put forward new curricular conceptions and accompanying prototype materials that redefine, in effect, the curricular territory for the middle and high school levels. Since such projects will probably require large collaborative teams working over extended periods of time, it makes sense for NSF to fund the initiative in at least two stages, with the first stage exploring a range of ways to proceed.

If this initiative were fully funded, it would require \$40 million to \$50 million over 5 to 7 years. In the exploratory and planning phase, NSF could fund up to 50 projects for 2 years at an average of \$100,000 per year. This would provide 10 different prototypes for each of the major areas proposed for development. In the second phase, NSF would fund 30 large projects in three or four different areas at an average level of \$1,500,000 per project per year (for a 3-year period). In addition, \$600,000 to \$800,000 per year would be made available in each area to fund thorough evaluation and associated research efforts.

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Opportunity 3

TO MATCH SCIENCE AND MATHEMATICS EDUCATION TO THE DIFFERENT NEEDS IN A DIVERSE STUDENT POPULATION

If science and mathematics programs are to be made more effective for a broad range of students, more attention must be paid to subgroups in the K-12 student population that, in the past, have not reaped fully the benefits of science and mathematics education. In these fields, the needs of women and minorities require particular attention, as do the needs of the physically handicapped and the gifted.

Various factors make it both pressing and opportune for NSF to address this issue, among them: (1) demographic trends in the United States suggest that the nation must take steps soon to better use the talent of groups currently underrepresented in science, technology, and mathematics; (2) losses occur early in the educational process, so that early intervention is necessary; (3) Congress and the Foundation as a whole have determined that attention to human resources is a key issue for the NSF; and (4) efforts by the NSF have both a symbolic importance (coming from the premier federal science agency) and a national dimension that together cannot be duplicated by any other funding agent (Berryman, 1983; Bloch, 1987).

The Nature of the Problem and the Opportunity for NSF

Not all subgroups within the increasingly diverse student population present NSF with an equal challenge. The scale of the problem and the potential yield of solutions are demonstrably greatest in the case of women and underrepresented minorities. The needs of gifted students (many of whom fall into the previous two categories) are also important and are often overlooked in the schooling process, but as a result of 5 years of national attention to "excellence in education," school districts across the nation have strengthened programs for this category of student considerably. The physically handicapped also deserve attention and have specialized needs in science learning, especially in relation to opportunities for hands-on activity or laboratory experience, but they constitute only a small fraction of the total student pool. Women and underrepresented minorities, by contrast, constitute more than half of all students.

The problem can be described narrowly in terms of the flow of minority and female students through the "pipeline" leading to scientific and engineering careers or, more broadly, in terms of students' preparation for participation in a scientifically dominated economy and society. Either way, the situation is disturbing.

With regard to the scientific and engineering "pipeline," underrepresentation occurs at all points along the pipeline, but in different degrees for different underrepresented groups. Beginning at the "output" end, women and minorities (with the notable exception of Asian Americans) are greatly underrepresented in the scientific, technical, engineering, and mathematical professions themselves (Berryman, 1983; NSB, 1985). These subgroups are also underrepresented in the higher education portion of the "pipeline" leading to jobs in science, mathematics, and technology (National Research Council, 1986). Still earlier in the educational process, minorities, especially blacks and Hispanics, are underrepresented in high school science and mathematics courses, and they do relatively poorly on standardized tests in these subjects as early as the elementary grades (NCES, 1984). Although girls are now enrolling in high school mathematics and science courses at almost the same overall rate as boys (NCES, 1984), beginning at the high school level they receive lower average scores than boys on a wide variety of standardized tests in science and mathematics, including Advanced Placement examinations (College Board, 1986; Featherstone, 1986).

The degree of underrepresentation in technical careers for both women and minorities continues to be quite large. In 1983, whites and Asians earned baccalaureate degrees in natural science and engineering at a rate of about 50 degrees per 1,000 22-year-olds, whereas blacks, Hispanics, and Native Americans earned these degrees at a rate of about 16 per 1,000. Comparable figures for all males and all females are 61 per 1,000 and 26 per 1,000, respectively (Government-University-Industry Research Roundtable, 1986).

With regard to preparation for participation in society and the economy, there are obvious consequences of pipeline attrition and the profound disaffection with science that underrepresented groups experience. More than other groups within the student population, these groups are often functionally not equipped for many occupational roles (which presume some degree of scientific/mathematical literacy), to say nothing of their ability to cope with the life demands placed on them by a technologically oriented society.

Demographic trends make the situation increasingly acute. First, the size of the 18- to 19-year-old group will decline substantially in the next decade, while the proportion of minorities increases; as a result,

> Unless education in mathematics, engineering, and the sciences is made more attractive and effective for women and minorities, the quality and number of newly educated professionals in these fields is likely to fall below the nation's needs, with predictable harm to its economy and its security. (NSB Task Committee on Undergraduate Science and Engineering Education, 1986)

Equally important, women and minorities together account for a large majority of the student population. That proportion is growing steadily larger as the minority population of the United States swells, so that, by the year 2000, minorities will compose at least 25% of all 18- to 19-year-olds (Bureau of the Census, 1983).* They

* The Census Bureau figures reflect only racial minorities, whereas the estimate we use is increased by 5% to include ethnic minorities, principally Hispanics. Other estimates we have seen range as high as 40%.

will comprise a significantly larger proportion of the student population in many states and localities: for example, 12 states will have "minority-majority" student bodies by the year 2000 (Hodgkinson, 1985). Questions about the effectiveness of education in science, mathematics, and technology are likely to become more urgent if growing proportions of students do relatively poorly in science and mathematics, or avoid taking these subjects altogether.

NSF's role in assuring that the nation has an adequate supply of science and engineering professionals gives it a special stake in seeing that women and minorities receive a high-quality K-12 science and mathematics education. In addition, Congress, the NSB, and others have supported a broader mandate for NSF in K-12 science education: to upgrade the scientific literacy of all students. This perspective, too, leads to serious concern about science education for women, minorities, the physically handicapped, and other underrepresented groups. Assuming that NSF espouses the goal for K-12 science education set forth in the beginning of this volume (and in the *Summary Report*)--to produce a broad pool of interested and competent science learners through the age of 18--then the necessity of doing something about science education for currently underrepresented students is clear.

Predictable demographic shifts make it timely to change science and mathematics programs soon to meet better the needs of underrepresented groups; waiting would risk just the situation that the NSB Task Committee has warned against: the possibility that not enough professionals will be trained in science, technology, or mathematics. In addition, now is a better time to experiment with--and develop--effective strategies, before the scale and intensity of the problem increase, as current discussions of "at-risk youth" suggest it will (Hume, 1987).

Although historically NSF has not been centrally concerned with questions of underrepresented groups, the Foundation has a number of characteristics that make it well qualified to support work in this area. These include: long experience with curricular materials, including research and evaluation studies that focus on particular subgroups of students; an advisory committee for science education whose members could be helpful; a reputation for sponsoring high-quality projects; a history of operating small programs targeted at women and minorities, both in SEE and in the rest of the Foundation; and a currently declared Foundation-wide priority on making headway on this issue. For example, if NSF's pending budget request were to be approved, various directorates together would provide about $28 million in FY 1988 to increase the participation of underrepresented groups in science and science education (NSF, 1987). In addition, the Foundation's national perspective sets it apart from state and local agencies, and its place as the central "advocate" for science in the federal government lends special significance to its actions toward underrepresented groups.

The limitations on NSF's role need to be recognized. The Foundation (and, to an extent, its Education Directorate) reflect the makeup of the scientific community, which has relatively few female and minority members and consequently tends to be less sensitive to these groups. NSF is not well positioned to address the many forces unrelated to science or mathematics within the education system that inhibit women and minority participation in many fields of study. Furthermore, the Foundation has not been (nor should it be) a major standard bearer in the fight for social equality, as has, for example, the U.S. Department of Education. By virtue of these facts, NSF must look for aspects of the problem where its expertise and legitimate role can make a difference.

The nature of the opportunity for NSF depends, in part, on what else is being done in this field, and whether those activities are sufficient. The Foundation's energies and funds are best spent in areas that are not yet, or inadequately, addressed by others, and also in ways that reinforce other foundations' initiatives.

A number of private foundations are operating sizable programs in this area. For example, the Ford Foundation's Urban Mathematics Collaboratives project involves nine cities with large minority enrollments. The primary participants are teachers, but the aim is to improve teaching and student learning. Local industries and businesses are involved, providing a variety of learning experiences for the teachers that strengthen their understanding of the uses of mathematics in the "real world." The Ford Foundation (through a contract with the Education Development Center) provides each site with technical assistance; the University of Wisconsin is documenting and evaluating the effort. SEE could learn from the experiences of this project. The Carnegie Foundation also supports programs that are aimed at increasing the participation and achievement of women and minorities in science and mathematics, such as the Science Rich, Science Poor initiative, which links inner-city schools with universities and other institutions that can provide science resources for teachers and students. In other projects, Carnegie is concerned with ways to get higher proportions of minorities into teaching, including in science and mathematics fields.

Many other programs include efforts to increase the participation and achievement of women and/or minorities. Examples include the Junior Engineering Technical Society, the Young Astronaut Program, and the University Partnerships program of the University of California. The American Association for the Advancement of Science maintains an Office of Opportunities in Science, which has, among other things, extensively researched intervention programs undertaken to improve the quality of mathematics, science, and technology education for underrepresented groups (Malcom, 1986).

Nonetheless, with a few exceptions (such as University Partnerships; EQUALS, based at the Lawrence Hall of Science; and member programs of the National Association of Precollege Directors, such as MESA), most of the programs in this field do not reach large numbers of students or teachers. Many school districts remain without programs, and many students and teachers are unaware of any program.

Depending on the type of approach that is chosen, NSF will be able to serve larger or smaller numbers of students. Broadcasts of television programs such as "3-2-1 Contact!" reach millions of students daily, and curricular materials may also reach large numbers. For "pipeline" purposes, however, or to develop model programs, NSF might be content with much smaller numbers of participants. In the past, for example, some of the summer programs for students funded by SEE's Student Science

Training program were able to serve only a relatively small number of "students with demonstrated high potential but limited educational opportunities."

In light of the importance of increasing the representation of women, minorities, and the physically handicapped in the science learner pool, and given the large variety of mechanisms NSF might use to address the problems, this seems a promising opportunity for SEE to pursue.

Even with a more substantial effort by NSF and others, change in this area, although not glacial (witness the increase in the fraction of women in medical schools), is likely to be slow. Many factors and social forces are involved in determining a person's interests and capabilities, including home attitudes, school climate, teacher quality, informal or out-of-school experiences with science and mathematics, and availability of student financial aid. Only some of these can be influenced by NSF, even indirectly. For example, one observer writes:

> The most significant problem [in science education] for Black and middle school students is access to quality education in science...[most] are educated in resource poor schools of the inner cities or rural communities. (Malcom, 1986)

The magnitude of the problem underscores the importance of finding intervention points that take best advantage of NSF's limited resources and capacity to influence the situation.

NSF (SEE) Programs and Policies in Relation to This Opportunity

Before SEE's disestablishment in the early 1980s, there were a number of NSF programs focusing particularly on science and mathematics education for groups with special needs. These were: Women in Science (1974-76, 1979-81); Minorities, Women, and the Handicapped (1977-78); Resource Centers for Science and Engineering (for minorities, 1978-81); Physically Handicapped in Science (1979-80); Research Apprenticeships for Minority High School Students (1980-82); and the Student Science Training program, for talented high school students (1959-81). A number of these programs were considered effective, according to scientists and science educators we interviewed (including Student Science Training, the oldest program in the Directorate except for graduate fellowships), but none were reinstated when SEE was reestablished in 1983. Also, in earlier years there was a special NSF advisory group called the Advisory Committee for Minority Programs in Science Education. That committee no longer exists, although there is one operating across all directorates called the Committee on Equal Opportunities in Science and Technology.

NSF's past experience with programs and initiatives targeted at women and minorities seems to have been mixed. Examination of the literature, as well as interviews, indicate that a number of improvements could be made to programs in this area. These include good documentation of program operation and results, better evaluation of projects and the program itself, and better dissemination of positive results. There are a number of studies that would be useful in establishing better programs aimed especially at women or minorities (see, for example, Aronson, 1976; Malcom, 1986).

By contrast with the 1970s, when NSF addressed the needs of underrepresented groups by creating programs targeted to this purpose, SEE's current approach to this area is defined primarily by a directorate-wide policy covering all proposals:

> Projects involving members of [underrepresented groups, such as women, minorities, and the physically handicapped] as principal investigators or staff, or as the target audience are especially invited.... (Preamble to all SEE program announcements, 1987 version)

This policy has been in effect since the reinstatement of the Directorate in 1983; to date, the results of the policy have not been encouraging, especially with regard to the attention paid by SEE or prospective grantees to minority groups, either as target audiences or as principal investigators.

In FY 1984 through FY 1986, SEE supported a small number of projects aimed especially at women and/or minorities. Most of these have been supported by the Science and Mathematics Education Networks (SMEN) program, the Instructional Materials Development (IMD) program, and the Informal Science Education (ISE) program. For example, SMEN made a grant to the National Action Council for Minorities in Engineering (NACME) to improve minority youths' understanding and awareness of mathematics and science education. Another SMEN grant went to the University of California at Berkeley for "Family Math and Science," a program in which minority students and their families are a special target. The Southeastern Consortium for Minorities in Engineering (SECME) received a grant from SMEN to disseminate a successful program that interests minority high school students in engineering careers and prepares them for such careers. A scattering of projects funded under other programs also address this area:

- A grant from IMD to Oklahoma State University was for "increasing the participation of Native American students in higher mathematics." Purdue University received an IMD grant for a project focusing on science education for rural girls. Gallaudet College received a grant for improving education of the hearing impaired in the life sciences.

- ISE's awards for children's educational television programs, including "3-2-1 Contact!," "Square One TV," and "The Voyage of the Mimi," have all been based on solicitations that stressed the inclusion of female and minority characters. Millions of students are reached by these series.

- Most recently, a FY 1987 award was made to the Education Development Center for a project to improve urban elementary science. Mathematics and language skills will be reinforced, and the accomplishments of minority scientists will be emphasized.

A review of this kind of investment with regard to minority participation in science education suggests the limited effect it has had or is likely to have:

> 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,...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. (Aronson, 1987)

A strategy that relies primarily on initiatives from applicants, without any special solicitations or programs, is unlikely to lead to many proposals focusing on the needs of underrepresented groups (as recent SEE history indicates). NSF would like to change this situation, and has proposed in its FY 1988 budget request to Congress two targeted programs. At the higher education level, NSF would establish resource centers at institutions with significant minority enrollment to increase the participation of minorities in science and engineering careers. The NSF budget summary also identifies as a priority increasing the participation of women and disabled persons in NSF activities generally; however, the means for doing so are not clear in the document. A second proposed targeted program, if approved, would provide enrichment activities for "Junior Scholars"--talented high school students--to stimulate interest in science and engineering careers. It is uncertain whether this program will include special summer programs for high-ability students with limited educational opportunities, as did the Student Science Training program.

Because NSF's (SEE's) evolving strategy remains somewhat unclear and is untested, it is difficult to say how it will operate over time. However, given at most a small number of targeted programs, applications to nontargeted programs may focus on underrepresented groups. Much will depend on the way SEE implements and reinforces its current policy position, through review procedures, outreach to potential grantees, building awareness among SEE staff, etc. For example, it is important that people knowledgeable about the particular field that is the focus of a proposal (such as working with Mexican-American students or training inner-city teachers) be used whenever possible to review such proposals. In turn, selecting appropriate reviewers requires some depth of knowledge and sensitivity on the part of staff regarding the target population as well as the subject matter.

SEE's current or future strategies for dealing with underrepresented groups runs up against deep-seated perceptions within the science education community that will require concerted effort to overcome. Consider the following observations about the way minority principal investigators perceive SEE (Aronson, 1987).

- Minority project directors tend not to view NSF (SEE) as a ready source of funding.

- Because of heavy teaching loads and a reluctance to devote time and energy to an effort that is seen as having a low probability of success, minority researchers often do not write proposals even when they have good, workable ideas.

- Minority proposers have a frustration with SEE's apparent inability to consider proposals with an understanding of the context in which they are written.

- Many minority practitioners feel that SEE has not internalized the need to work with minorities and therefore deals superficially with minority issues.

No policy by itself will do much to counter these perceptions. NSF (SEE) will need to match its words with actions.

Under the current Directorate-wide strategy, SEE has funded some excellent projects. However, it is not clear that "model" programs (which is what many are called) are being rapidly disseminated. Nor is it clear that a large number of creative new proposals will be attracted. With this strategy and level of funding, NSF cannot expect rapid progress in increasing participation by women and minorities.

Promising Initiatives

If the FY 1988 budget proposal is approved by Congress, SEE will somewhat expand its science education activities focusing on underrepresented groups. However, from the point of view of the number of regions (resource centers serve a limited area) or individuals who would be served by SEE grants, public and private resources will be able to respond to only a fraction of the needs that exist. Additional funding alternatives in this area (beyond those in the FY 1988 budget) deserve consideration.

As is the case for all children and youth, there is a choice here for NSF regarding the breadth of its focus: should the Foundation invest in those women and minorities most obviously destined for careers in mathematics, science, and technology, or in efforts to broaden the pool of science learners from minority and female backgrounds? For example, a focus on women and minorities (or other underrepresented groups, such as the physically handicapped) within the proposed Junior Scholars program for talented secondary school students would primarily serve narrowly defined "pipeline" needs. On the other hand, an effort to reconsider curriculum for the student mainstream would serve the broader goal of increasing the science learner pool.

NSF also has choices to make about the age and educational levels at which to concentrate its efforts for maximum effect in this opportunity area. Early intervention is quite important for women and minorities. Many decide in elementary or middle grades that "math and science are not for me" (e.g., Malcom, 1986). For minorities, lower average standardized test scores are evident beginning in elementary school. A number of the most successful programs for recruiting minority youth into scientific or engineering fields begin at the elementary grades. Ideally, different programs or initiatives will be matched to different educational levels.

3.1 Mount a Targeted Experiential Program for Secondary Students from Underrepresented Groups

NSF has proposed in its FY 1988 budget that SEE begin operating an enrichment program for secondary school students, the Junior Scholars program. Although not an explicit part of current plans for this program, one component might focus on women and minorities, educationally disadvantaged youth, or other subpopulations that are underrepresented in science, mathematics, and technical fields.

Some of those interviewed for this study felt that NSF-supported enrichment programs for secondary students have been notably successful--for example, awards to NACME and SECME, and those projects within the Student Science Training program that served disadvantaged and handicapped students. There is evidence from these and other programs for underrepresented secondary students (such as Talent Search, Macy Foundation-supported high school programs, etc.) that they can be highly successful. As one example, a SEE Program Officer noted that from one series of Student Science Training projects for the physically handicapped, every one of the 19 students who were able to be mainstreamed has gone into science.

Given the previous popularity of these programs, the fact that there are many models that seem to work, and that SEE expects to aim the Junior Scholars program at secondary students, it seems natural that a portion of the new program would be devoted especially to talented, educationally disadvantaged students. For NSF, there are very few disadvantages to operating such a subprogram, except that only a small fraction of the eligible population could be served and that a targeted subprogram would reduce the resources available for the remainder. However, given the small number of minority scientists, mathematicians, and engineers, even a slight gain at the end of the pipeline would be useful and could be considered a very good investment of resources.

Budgeted at $3.7 million for FY 1988, the proposed Junior Scholars program is designed to serve 1,500 academically talented students through summer and academic-year enrichment programs. Earmarking $1 million to $1.5 million of this amount for projects especially designed for underrepresented groups would seem an appropriate starting investment by supporting at least 400 to 600 students per year from these groups (in addition to women or minorities who might participate in nontargeted projects).

3.2 Fund Research Focused on Underrepresented Groups in Science Education

Educators and scientists have only a limited understanding of why some groups are underrepresented in science and mathematics. Even such important factors as level of parents' education operate differently with different groups (Berryman, 1983). We do know something about the characteristics of effective programs for this segment of the population (Malcom, 1986), but it is not clear why some programs designed for these groups work well, while others do not. Nor are these groups' "learning styles" or culturally based preconceptions about science and scientific phenomena well understood. It seems likely that particular topics, media, technologies, or methods are more effective than others for a particular group. Under this initiative, research would be supported to answer such questions.

An intensive research initiative focused on how women and minorities best learn science and mathematics would lay the groundwork for more progress in this area. Without a knowledge of "what works," the field is limited to "common sense," intuition, and guesswork. Current efforts (under the leadership of the National Association of Precollege Directors) to identify examples of successful K-12 science/ mathematics programs for minorities and to discover common elements among these successful programs indicate a need for better knowledge.

There are various means by which SEE might support changes or additions to science and mathematics programs to make them more effective for women and minorities. One interesting research question that arises is whether curriculum materials or instructional practices that are especially successful with these subgroups are equally successful with the remainder of the population. It seems that they can be, in the same way that a television program such as "3-2-1 Contact!" was especially designed to appeal to girls and minorities, but attracts a large and more general audience. Similarly, studies of a popular NSF-funded elementary science program from the 1960s, SCIS (Science Curriculum Improvement Study, which was a comprehensive "hands-on" K-6 curriculum designed for all children), show that it was especially successful for minority, disadvantaged children (Bredderman, 1982; Wellman, 1981). The advantages in using such "targeted" materials or practices would be twofold: (1) women and minorities would receive a better education in science and mathematics, and (2) more effective science and mathematics education for underrepresented groups might help everyone learn better.

Support for research is potentially a highly leveraged use of funds (assuming the initiative supports good research that becomes well known), potentially affecting development of tens of millions of dollars worth of materials and hundreds of millions in services. In addition, support for research of the highest quality is NSF's greatest strength, suggesting that initiatives emphasizing research deserve special consideration. There is already a significant base of research, some of which has been cited. To choose one other example, a special issue of the National Council of Teachers of Mathematics' *Journal for Research in Mathematics Education* was devoted to minorities and mathematics in 1984 (Kilpatrick et al., 1984).

On the other hand, the talent necessary for such a specialized research program to succeed may not be marshalled easily. Further, research may not easily reveal keys to success; for example, successful programs may depend so greatly on local factors that few common elements will be found.

If NSF were to implement this initiative, a targeted competition could be administered. To support 6 to 12 studies per year at $800,000 to $1.2 million (in all) would require a 5-year total of $4 million to $6 million. The resources required are modest. However, on the scale of the current program for Research on Teaching and Learning, they are sizable (one-third of its annual budget). It would probably be necessary to increase the budget of the research program while this initiative was under way, either by increasing SEE's overall budget or by using monies previously allocated to another program.

3.3 Develop Curriculum Materials and Instructional Methods for Selected Groups

We know that some approaches, such as the enrichment programs discussed above, increase the rate of participation in science courses among women and minorities. Perhaps such approaches and/or materials can be used as part of standard elementary and secondary courses. Under this initiative, SEE would support the search for such methods and materials. To a limited extent, this support is already taking place as part of the Instructional Materials Development program (for example, the program made a 1987 grant to develop an urban elementary science program). However, through a targeted solicitation or other means, work in this area could be increased and more rapid progress could be made.

Ideally, the materials and approaches in question would increase participation and achievement for everyone, but more for women and minorities (so as to reduce the gap). This outcome is not impossible, as the studies of SCIS (cited above) showed. Evidence from other investigations (e.g., the AAAS' exemplary programs study) suggests that "what is good for underrepresented groups in science education is good for all" (Malcom, 1986).

Conversely, improving secondary mathematics and science courses for the average student may be particularly helpful to underrepresented groups. For example, there is widespread agreement that mathematics courses need more applications and concrete approaches, and that science courses are typically too densely packed with new vocabulary. Making improvements in these areas would be likely to help those who had been having the greatest difficulties most.

SEE might solicit applications for projects focusing on curricula for urban schools, for vocational programs, or for other instructional settings in which the student population has a high need for improvement in science and mathematics and a disproportionate number of women and/or minorities. For example, minorities are overrepresented among the non-college-bound and in inner-city schools, where their exposure to science is less. Or, to take another example, in 1982, fewer than 10% of graduating students in high school vocational programs (with large numbers of minority students) took 3 or more years of science, compared with 54% of those secondary school students enrolled in academic programs (NCES, 1984). Materials developed for groups such as those in inner-city schools or vocational programs should be especially sensitive to the needs of women and minorities. This strategy avoids any appearance of serving students based on race or sex, yet targets groups with high needs.

One possible variation on the theme of this initiative would be to request applications for projects that would develop supplementary materials of special relevance to women and minorities. These might include films, readings, or laboratory activities. The use of computers and other information technologies in mathematics and science may be especially effective for minority groups. Supporting development of such materials would be far less expensive than developing whole courses. However, the dissemination of such materials is often difficult, and their impact is likely to be less than that of a full course. (SEE, of course, has supported some projects like this in the past.)

Advantages of an initiative focusing on materials include the fact that the need for better materials used in typical schools is a serious one, and that many others besides women and minorities would be likely beneficiaries. Disadvantages include the fact that, aside from supplementary materials, publishers and other distributors of school materials do not think in terms of supplying products or services to partic ular subgroups of the school population. However, they do think in terms of marketing to urban schools, vocational schools, etc.

A focused effort to develop materials and approaches for women and minorities might require $15 million to $20 million over a 5-year period, assuming 8 to 10 projects of approximately $500,000 each per year. At a given time, the effort would need to concentrate on one level of education, be it elementary, middle, or high school.

3.4 Promote Exemplary Models for Serving Students from Underrepresented Groups

The National Science Board Commission on Precollege Education in Mathematics, Science and Technology commissioned a report from the Office of Opportunities in Science of the AAAS, to assess programs that help increase access and achievement of females and minorities in K-12 mathematics and science education. An important conclusion of the report is that:

> More support is needed for dissemination of information about successful programs or replication of effective models. (Malcom, 1983)

The goal of this proposed initiative would be for NSF to play a major role in promoting exemplary programs for underrepresented groups by disseminating information about them, funding a limited number of replications of such models each year, and, in general, taking a more active role in publicizing the successes that demonstrate what is possible, as well as the need to implement more such programs.

Many of the successful programs for minorities, women, and other underrepresented groups start outside the school system (since often the school system is not providing appropriate instruction and support). But, according to the AAAS report, the same programs usually end up inside the schools because of the important role of the teacher (who typically sees a given student four or five times per week) in motivating students as well as in instructing them. It would be appropriate to include in this initiative examples of both in-school and out-of-school programs for students underrepresented in science and mathematics.

A considerable benefit could be achieved simply by focusing more attention on the problems and on examples of successful programs. Associating NSF's name and prestige to such an effort could be quite helpful. In one sense, NSF does this each time it publishes a targeted solicitation, which, in effect, says, "NSF has determined that this problem is very important and has allocated public funds for solving it, or at least for moving closer to solutions." In this case, additional publicity beyond that given to a typical solicitation might be appropriate, such as production of a brochure describing the nature of the problem, giving examples of successful programs, and highlighting the involvement of various sectors of society: government at all levels, business and industry, private foundations, etc. Endorsement by respected figures--from astronauts and practicing scientists to the Director of the NSF--might increase the public's interest.

Dissemination of information about successful programs for underrepresented students would help to generate interest and support for new programs. In addition, NSF could take advantage of existing dissemination mechanisms, such as the Department of Education's National Diffusion Network (NDN), by assisting successful programs, where necessary, to document their operation and their effectiveness. (Without such documentation, NDN will not include a new program in its network.) The cost of providing assistance with documentation would be very low, especially compared with developing a new model program.

Finally, NSF (SEE) itself has a role to play in replicating successful programs for currently underrepresented groups. To a small extent, this is being done already, through such grants as the one to SECME for disseminating a proven program aimed at minority high school students. From the point of view of having a national impact, the main problem with the current grants aimed at programs for underrepresented groups is simply that there are too few of them.

There are a great many school districts, youth groups, and other organizations that could effectively use funds for starting up proven programs in science and mathematics education aimed at underrepresented groups. Given a large number of applicants to choose from, SEE might concentrate on cities with high concentrations of minority students, applicants who are able to match NSF funds with other monies, or other projects in which there would be substantial leveraging of NSF funds.

The cost of adding 6 to 9 additional $300,000 grants aimed at replicating effective programs in this area, plus providing some technical assistance to help existing programs enter the NDN, would be about $2 million to $3 million annually, or $10 million to $15 million over a 5-year period.

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PART TWO: OPPORTUNITIES RELATED TO THE COMMUNITY OF PROFESSIONALS CONCERNED WITH EDUCATION IN THE SCIENCES

One side effect of the efforts to address the issues of content and approach that were described in the preceding part will be to generate intellectual vigor within the science education community. There are also other opportunities to address directly the types and qualities of the people within this community, with the long-range goal of making the community more cohesive and intellectually alive, while attracting a more diverse array of members (e.g., informal science educators, currently uninvolved members of the scientific community).*

NSF has the chance to bring about widespread effects on the science education community in the short term. The immediacy and urgency of national needs--for example, the need for support to teachers in the upper grades--also makes activities focused on this goal especially appropriate, although NSF's investments are likely to have longer-range and more indirect effects as well, e.g., through investments in the informal science education community.

The Professional Community

In one sense, there is no single community of professionals concerned with education in the sciences. Rather, as noted in the introduction to this volume, there is a collection of groups that are sometimes loosely related to one another, but more often isolated from one another. Thus, when we refer to the professional community, we mean the *potential* community of individuals who are involved with K-12 education in the sciences and engaged in significant dialogue about it.

Aside from government or private funding agencies, the following groups play an essential role in that dialogue:

- *Research scientists, mathematicians, and engineers*, particularly those in industry or university disciplinary departments who take an interest in precollege educational issues and involve themselves in educational activities.

- *Teachers* of mathematics and science at the elementary and secondary levels; teaching faculty at higher levels.

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* See *Volume 2 - Groundwork for Strategic Investment* for a discussion of other, ongoing investments NSF could make to strengthen the professional community as part of its "core function" of promoting professional interchange.

- *Educational policymakers and support personnel*, such as school district curriculum specialists or administrators, inservice training directors, and others who devote a significant amount of their time and attention to science education matters.

- *Teacher educators*, often bearing the label "science educator" or "mathematics educator" and typically located in colleges of education or university education departments.

- *Informal science educators* who work within educational institutions outside of school (museums, recreational associations) or within print and media broadcast organizations (radio, television, newspapers).

- *Developers*, typically located in private publishing firms, universities, informal education institutions, or educational technology firms, who are concerned with the development of materials or technology for use in science education.

- *Educational or social science researchers* based in universities or research firms.

- *Professional societies and associations* representing the groups described above.

Although these groups are relevant to both mathematics and the sciences, the configurations differ somewhat. For mathematics, there is greater cohesion across groups and more consensus on fundamental needs and strategies than is true for the natural sciences, where disciplinary groups are more separate from one another.

Despite their shared interest in science education, there are deep cleavages between these groups. Schoolteachers are profoundly separated from scientific practitioners; members of the mathematics community seldom speak to the disciplinary scientific groups, who themselves are often out of communication with one another. Researchers in some scientific disciplines tend to take a dim view of educational or social science research, which rests on different paradigms and assumptions. Developers and school people are often out of touch with one another. These cleavages exist for deep social reasons, rooted in status distinctions and institutional differences. Efforts to overcome these differences confront massive barriers, among them an incentive structure within the sciences that does not reward involvement in education; institutional boundaries between formal schooling and informal education; and the separation of informal science education media from one another.

Nonetheless, there are grounds for optimism about the professional community and for believing that NSF has a central role in promoting it. Some of these grounds reside in NSF's history; the "golden age" of NSF's involvement in science education in the 1960s and early 1970s witnessed a great deal of dialogue among the groups, especially between educators and a small number of practicing scientists who collaborated on development teams or who participated in summer institutes for teachers. These institutes transmitted a clear signal that science and mathematics teachers were important, as were their links to the subject disciplines.

The following signs of a readiness for greater interaction and collaboration among groups concerned about education in the sciences underscore the potential for NSF to play an influential role:

- Many commission reports and analyses have raised consciousness among scientists, educators, private-sector representatives, professional groups, and individuals in government about the importance of collaborative involvement in improving science education.

- Concerned members of the scientific community want to believe that there is something they can do, but they are not sure what.

- The thrust of many current state reforms and the national movement to upgrade teaching emphasizes "professionalization" of teaching, implying (for the highest levels of the profession, at least) graduate-level training and closer ties to the subject disciplines.

The Opportunities at a Glance

Two of the most attractive opportunities for NSF relate to teachers: (1) the ongoing support of teachers now in the classroom or newly entering, and (2) the examination of strategies for attracting and increasing the quality of new entrants to the profession with emphasis on revamping teacher education programs.

- *Opportunity 4: To bolster the support cadre serving mathematics and science teachers*. The large proportion of underqualified science and mathematics teachers presents a critical challenge to NSF (and others) that must be met if the pool of science learners is to be significantly broadened. At the middle and high school levels, the opportunity for the Foundation lies in developing a nationwide "support cadre" consisting of "lead" teachers, local curriculum specialists, and others, who, in turn, act as a resource to middle and high school teachers on an ongoing basis. At the elementary level, NSF is in a position to stimulate the development of change advocates and leaders at the district and state levels. NSF's (SEE's) investments of the last few years in training "leadership teachers" provide some models for how this can be done, but the current scale and direction of NSF's inservice teacher support (which emphasizes innovative model development and workshops for the full range of teachers) are unlikely to contribute significantly to the larger goal. The Foundation should consider multiyear training for support cadre members through summer institutes and follow-up, expanded recognition programs, and supportive alliances between universities and school districts.

- *Opportunity 5: To help attract and prepare the next generation of well-qualified teachers.* To cope with the demands of teaching science and mathematics to a broadened pool of learners, the next generation of science and mathematics teachers must be imbued with a new sense of purpose, intellectual frameworks that are appropriate to the task, and the professional skills to accomplish the task once in the classroom. Substantial retirements over the next decade and a vigorous nationwide push toward teacher education reform make it opportune for NSF to invest in this area. Although many of the forces affecting the supply and preparation of science and mathematics teachers are beyond NSF's control, the Foundation has a significant contribution to make to the "professionalization" of science and mathematics teaching, the quality of teacher education experiences (in particular, the scientific content of disciplinary courses and subject-specific pedagogy), and the systematic documentation of current experiments with teacher education and recruitment approaches. SEE's current investments in this area focus on creating model programs for middle school teachers. Further investments on a broader range of targets--including increased support for teacher educators, efforts to increase understanding of teachers' pedagogical knowledge in science and mathematics, and experimentation with retraining approaches--would lead to more powerful impacts on the preparation of teachers.

A third opportunity relates to leadership development and the interaction of groups within the internal science education community:

- *Opportunity 6: To strengthen the informal science education community.* Over the last decade, educators outside of schools have assumed an increasing presence in K-12 science education--in particular through television, but also through institutions such as museums and science centers. These ways of conveying science education have an apparent capacity to motivate a wide range of learners and potential (although poorly understood) effects on the acquisition of knowledge, skills, and attitudes. This type of education is more likely to help broaden the pool of interested science learners given the right professional leadership, understanding of scientific and educational issues, and efforts to examine the potentials and limitations of informal media or approaches. In part a by-product of NSF (SEE) investment, a critical mass of well-qualified, thoughtful science educators has begun to assemble over the last decade within the different media (e.g., television, radio) and institutions (e.g., museums, science centers). NSF has a long-term opportunity to expand the science education capabilities of these institutions and media by investing in further professional development, by supporting networks and collaboration (both within and across media), and by supporting research and evaluation efforts that can inform further efforts.

Opportunity 4

TO BOLSTER THE "SUPPORT CADRE" SERVING SCIENCE AND MATHEMATICS TEACHERS

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NSF's (SEE's) investments of the last few years in training "leadership teachers" provide some models for how this can be done, but the current scale and direction of NSF's inservice teacher support (which emphasizes innovative model development and workshops for the full range of teachers) is unlikely to contribute significantly to the larger goal. The Foundation should consider multiyear training for support cadre members through summer institutes and follow-up, expanded recognition programs, and supportive alliances between universities and school districts.

Defining the Opportunity for NSF

As in the 1960s, when NSF invested heavily in summer institutes, science and mathematics teachers need a great deal of support to carry out their jobs effectively, advice about appropriate materials, help with teaching problems, content knowledge, etc. Today's middle- and secondary-level science teachers often lack strong science and mathematics backgrounds and are not well prepared for the variety of courses they are assigned. At the elementary level, even fewer teachers have educational backgrounds or special training that enables them to provide high-quality science experiences for their students.

The current difficulties and deficiencies have multiple and deep-seated causes:

- For the last 15 years, few new science teachers have entered the profession. Between 1971 and 1980 there was a 64% decline in the number of undergraduates entering science teaching (Shymansky and Aldridge, 1982). The work force has aged, and its knowledge of science has become obsolete (Pelavin et al., 1984).

- Few new teachers who enter the profession have strong backgrounds in science and mathematics. Not many with undergraduate degrees in science and math choose teaching (Ford Foundation, 1985). By one estimate, nearly one-third of secondary-level science teachers are severely underqualified to teach science (Aldridge, 1986).

- The teachers who fill positions vacated by those leaving are often reassigned from teaching other disciplines. The number of teachers who have provisional or temporary certification appears to be very high and growing (NSTA, 1982; Williams, 1983).
- Some evidence suggests that there is an exodus of the most qualified teachers from science teaching to other careers that are more profitable and that provide more professional working conditions (Shlechty and Vance, 1981).
- Even at the secondary level, few science teachers teach only one discipline. Many teachers must teach biology and physics and mathematics, for example (NSTA, 1986).
- There appear to be few alternatives to NSF workshops for teachers to gain the knowledge and skills that will help them directly in their classes (Exploratorium, 1986).

The range of conditions outlined above illustrates that current difficulties arise not simply because teachers do not have a chance to "update" their understanding of the ever-changing knowledge base of the sciences they teach. Rather, the growing teacher shortages and the rising rate of underqualified teachers both reflect a deeper and more fundamental malaise within the teaching profession.

What Science and Mathematics Teachers Need

It is evident that knowledge of science and mathematics content is necessary but not sufficient to produce good science teaching. Research studies do not confirm a strong relationship between how much science or mathematics a teacher knows and how much the student learns:

> The relationship between teachers' scores on a test of subje matter knowledge and their effectiveness is not necessarily simple or straightforward. While it seems plausible that effective teaching requires a threshold level of knowledge, particularly in mathematics and science, the relationship between the scores that are above the threshold and teaching effectiveness may not be linear. Moreover, it is plausible that there is a negative relationship between subject matter knowledge and other attributes, such as interpersonal and pedagogical skills, that contribute to effective teaching. (Juster et al., 1987)

Conversely, there is little evidence that focusing on pedagogy and general teaching methods has much impact on learners: innovative teaching approaches alone do not seem to produce a significant improvement in student outcomes (Welch, 1985).

priate content and pedagogy. Many teacher educators argue that what is needed is a pedagogy specific to each discipline and a subject matter understanding in the discipline that is relevant to the way it is to be taught (e.g., Shulman, 1986). At the same time, teachers need to have an experience that motivates them and interests them both in the science they are learning and in the challenge of conveying it to their students. One mathematician interviewed for this study, who for years conducted teacher support programs, described what he had learned about the key characteristics of inservice programs:

> "In all of science education one topic is ignored (although the summer institutes came closest)--and this is the topic of educating teachers in the subject matter *in their own class context*. Summer institutes could not help teachers once they were back in the class.... Of course, while they are in the workshops we need to generate a situation in which teachers have a high morale and an esprit de corps. Central to this is the idea of treating teachers as professionals and letting them learn for themselves. But this is not enough. Learning for oneself has got to reduce to practice for one's kids."
>
> "Teachers, especially secondary teachers, do not have a playful spirit. They want to take notes, not try out things for themselves. This is how they learned science. This is the main reason that teacher training fails to create more hands-on learning in classes--the te. .chers do not really know firsthand (or even like doing) what they are trying to get the kids to do...."

These kinds of needs are not met in one-time workshops. They are not met by having teachers attend college science courses or even listen to famous scientists lecture. Indeed, the results of the summer institutes and other NSF-sponsored workshops strongly suggest that one-dimensional solutions will not enable teachers to change their classroom behaviors or practices in a meaningful way (Miles, 1983; Green, 1981). The following institutional factors play a role in determining the extent to which classroom changes actually occur (Miles, 1983):

- The supportiveness of the school administration.
- The match between the science program and the existing classroom structure.
- The degree of practical changes required.
- The in-classroom follow-up assistance that is available to support the changes made.

The powerful influence of these factors implies that support for the continuing education of teachers should be more than funding workshops for teachers. A more substantial, intensive and long-term effort is needed--one that conducts workshops in a broader, more inclusive context of helping teachers to learn new ideas and approaches *and* to apply them in their classrooms. To have a significant long-term impact on the teaching profession, all of the factors listed above must be purposefully engineered into NSF's teacher support programs.

However, if the Foundation undertakes longer, more inclusive, more complex approaches to supporting teachers, it faces a serious dilemma. There are many aspects of the teacher problem that make it almost intractable from NSF's point of view:

- *The scale of the problem is huge.* There are, for example, approximately 1.2 million elementary school teachers and 200,000 high school science and mathematics teachers.

- *The costs of meaningful intervention are very high.* Typical NSF workshop costs are on the order of $25 to $40 per hour per teacher. Moreover, a threshold of something like 100 hours of instruction (a 2-week summer workshop and follow-up) is needed to make any kind of significant impact, making minimal costs per teacher to be $2,000 to $3,000 per year.

- *The needs are deep and ongoing.* "Refresher courses" or "teacher enrichment" are largely euphemisms. The truth is that a majority of teachers need basic help in understanding the qualitative essences of the disciplines they are trying to teach, as well as detailed help with curriculum ideas and materials.

- *Ultimately, it is not a federal agency's role to train teachers.* Control and responsibility for the professional training and support of teachers increasingly are recognized as belonging to the states and localities (Clark and Astuto, 1986).

Although the scale of the need is much larger than NSF's resources are likely to be, and although the constraints on the Foundation's role are severe, it cannot afford to neglect the problem if it is serious about strengthening science and mathematics education in the nation. The quality of what is learned depends heavily on the quality of teaching; teachers have great autonomy in their classrooms, and their abilities and interests strongly influence the quantity and quality of what students learn. They not only can determine what students will study, but they also set the tone and expectations for that study. Teachers do indeed appear to be the key; there are no solutions to improving science and mathematics education in the schools that do not centrally involve them (Gilmar, 1985). Curricular revisions or technological innovations will have negligible effects in the absence of teachers who are confident, skilled, and interested in using them.

NSF has considerable expertise to draw on in addressing the "teacher problem." Successful teacher support at the secondary level requires the collaboration of scientists, science educators, and expert teachers. Through its history of curriculum development and teacher training programs, NSF has developed connections with these constituencies as well as amassed a wealth of successful experience in blending content and pedagogy.

Three Scenarios for NSF's Response to Teachers' Needs

In light of the importance of the teacher's role, the unique strengths that NSF brings to the problem, and the constraints that limit NSF's chances of influencing the situation, we can briefly examine the feasibility of three alternative scenarios of how NSF might intervene.

(1) *Return to the summer institutes*--Perhaps most remembered in the history of NSF's support for precollege science education are the "alphabet curricula" projects and the summer institutes for teachers. Throughout our interviews with a wide range of people involved with science education, we heard numerous pleas to reinstate the summer institutes; professional teacher groups also have advocated a similar course of action (NSTA, 1986). There is little doubt that the summer institutes of the earlier era were very popular with the teachers they served--not only did they help them with the specifics of teaching their disciplines, but they also brought energy, prestige, and professional collegiality into science teaching:

> "The institutes were very successful and were the only mechanism that brought sustaining life to teachers. Many teachers feel that the institutes were the height of their career.... Teachers need a continuing supply of fresh energy, because without this energy there are forces--territoriality, increasing age, and professional ambition--all of which will lead to isolation and stagnation...." (former Institute Director)

> That the institutes have been seen to have a good impact seemed clear. Among many federal programs of support for curriculum and teaching, the institutes were mentioned to us most often and in a positive vein.... (Stake and Easley, 1978)

NSF's commitment to education at the time of the summer institutes comprised a much greater percentage of the total budget of the Foundation than it does today (more than 40% in the early 1960s, compared with about 6% today). From 1954 through 1974, NSF spent more than $500 million on teacher institutes of one form or another, with $378 million focused on summer and academic-year institutes for secondary science and mathematics teachers. In this time period, approximately half of the nation's secondary teachers were "reached" by these institutes (GAO, 1984). (By comparison, from 1984 to 1986, NSF spent approximately $20 million on secondary-level training efforts, reaching a maximum of 2% to 3% of the nation's secondary teachers.)

The summer institutes, along with the new curricula, were central in the nation's effort to address what were seen as serious problems in the nation's education in the sciences. In 1959, the scientific disciplines were changing rapidly, with education badly lagging and failing to reflect the modern nature of the new physics, biology, and chemistry. The purpose of the summer institutes was more specifically to:

> ...improve the competence of the participating teachers by providing courses that are specifically aimed at overcoming deficiencies in their knowledge of the subject matter of science and mathematics. Most of the participants 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. (NSF, 1959)

Other goals included renewing teacher interest in science itself and bringing teachers to see their task as sharing this enthusiasm for science with their students. Finally, the institutes sought to improve "communications, sympathy and understanding between groups" such as scientists and teachers (NSF, 1975).

Similarities between now and the 1960s suggest that a rebirth of the summer institutes might be timely. Today's international economic crisis is creating a sense of national urgency about the state of science education similar to that created by the launching of Sputnik. Today's teachers need assistance as much as, or more than, teachers of that era. This is a popular option--with Congress and with the teachers themselves.

The minimal level of resources required to make a significant impact on secondary teachers alone can be estimated at $500 million over 5 years, with NSF providing $250 million of it. In addition to monetary resources, the initiative would require 200 different institutions (mostly universities and science centers), each of which provide the workshops and follow-up support to 200 teachers per year.

The prospects for serving elementary school teachers in the same direct fashion are much more gloomy. Several factors greatly reduce the impact of NSF's investment in direct support of teacher training at this level: there are 5 times as many teachers; each teacher works with only 30 students; only a fraction of their time is spent on science (more on math); the backgrounds of these teachers are typically very weak in the disciplines; and the kinds of support and training they need are more difficult for university-based scientists to provide.

The resurgence of summer institutes would no doubt provide an infusion of energy into the secondary-level teacher ranks, and would, in the short term, send a strong message of support to the nation's teachers. There are, however, some significant dangers. First, NSF will not have the resources (both monetary and institutional) under any believable funding scenario to work with enough teachers at a level that is deep enough to significantly help them in their teaching or to address the deeper malaise of the profession. All of the above discussion, as well as extensive analysis (Carnegie Forum, 1986; GAO, 1984), suggests that upgrading teacher quality is a difficult long-term undertaking requiring deep reforms. Summer institutes as previously conducted are unlikely to accomplish these ends. Second, although they are a distinct improvement over the typical 1- or 2-day inservice workshop supported by state or local funds, summer institutes are generally designed as one-time-only experiences. Currently, NSF supports institutes that have some follow-up associated with them, but even that is not typically carried out over a long period. Third, unlike the earlier period of extensive summer institute funding, there are many sources of support for teacher institutes or training experiences of various kinds (the U.S. Department of Education, state education agencies, private foundations and firms, etc.). This fact leads to confusion over NSF's role: in what way is its contribution unique, or is it "just another funding source?"

(2) *Development of new inservice models*--Another, and less direct, course that NSF might pursue is the funding of experimental efforts aimed at creating and evaluating innovative approaches to teacher enhancement. Experiments similar in spirit to the Ford Foundation's Urban Mathematics Collaboratives could help foster new approaches to inservice teacher support (Ford Foundation, 1985). Following this approach, NSF would assume the role of leader and catalyst; such an approach would cost NSF much less cost than trying to *do* inservice training for the nation at large. A serious effort at developing alternatives over 5 years could cost approximately $25 million.

The questions with this option lie not with the resources that are required but with the efficacy and potency of this approach. Although states and localities are increasing their own inservice efforts, there remain real questions as to the "market demand" for inservice models. In short, there are serious questions as to who will actually use the knowledge that NSF generates and as to the extent to which new models or knowledge will affect the amount or quality of inservice support for the nation's mathematics and science teachers. There are already proven ways of helping teachers (as the summer institutes illustrate). Perhaps the barrier lies not in the lack of knowledge of how to proceed but more in generating the national will to do what is inevitably an expensive job.

(3) *Development of local and regional resource staff*--A third scenario lies midway between the first two. In this case, NSF would not attempt to serve all of the teachers (or even 50% of high school and middle school teachers), nor would it restrict itself to testing model approaches that have little direct impact. Rather, NSF would focus on providing in-depth training for a group of professionals--a "support cadre"--who can serve as resources to all secondary and middle school teachers. Such professionals would include "mentor" or "lead" teachers as well as local supervisors and specialists.

The cost to NSF for a 5-year training program for 5% of the secondary school science and mathematics teachers (along with supervisors and specialists) can be estimated at $120 million, or $24 million per year. Similarly, the cost of training a national pool of resource staff corresponding to one elementary specialist for every two districts would be approximately $100 million over 5 years.

We argue that the best opportunity for NSF lies in the third scenario. Funding programs that train teachers directly, as the Foundation did in the past, neither takes best advantage of NSF's strengths, nor is it an efficient use of NSF's limited resources. (This is especially true at the elementary level.) The numbers of teachers alone preclude critical-mass effects. A more promising prospect, we would argue, exists in leveraging support through a newly created layer of middle and high school resource staff and through elementary "leaders" or "change agents." Through these channels, NSF can still take on the ambitious goal of significantly improving the quality and quantity of teacher inservice support available to the nation's science and math teachers. In aiming its efforts at the creation of a nationwide pool or cadre of resource staff, NSF would attack problems that are accessible to its intervention, use mechanisms that draw on its unique strengths, and integrate its efforts with other significant efforts in the field. The resource staff mechanism allows NSF to use more focused and more sophisticated ways to make its teacher education investments have long-term, wide impact than it can through attempting to train a large number of teachers directly or through an even more removed model program approach.

One educator we interviewed, who had years of experience in providing support for elementary- and secondary-level science teachers, supported the logic of working with the best teachers:

> "In summary, my general principles of improving science education are: (1) the teachers are the key to improving science education; (2) teachers need to have lots of experience in doing what they want their kids to do; (3) thus, they need to learn the subject matter in the way they will teach it; (4) they need local in-classroom support from their own well-trained colleagues (the British have a system of "advisors" that visit classes for extended periods); and (5) we need to work with the best teachers--those who ask for help. Get them going and others may come to them for help and inspiration...."

Part of the rationale for this approach to the opportunity lies in the potential for aligning NSF's efforts with the larger teacher reform movement that is under way in this country. The Carnegie Forum on Education and the Economy (1986) and Holmes Group (1986) reports provide a focus for this reform, as well as prescribing general directions for change in the teaching profession. We would argue that NSF should tailor its approach to supporting teachers in a way that is harmonious with--indeed, on the leading edge of--these movements. Thus, rather than simply fund enhancement workshops for teachers, NSF can design its teacher-oriented initiatives to support the larger goal of upgrading the profession of science teaching. To coordinate its programs with existing reform movements will require skillful leadership on the part of NSF (SEE), as well as the ability to coordinate with professional societies and state and local agencies, and considerably greater resources than NSF (SEE) is presently investing.

A Focus on the Profession of Science Teaching

To know exactly how to proceed along these lines, it is important to understand the malaise of the profession as it now exists. The Ford Foundation has identified the following three fundamental problems in the science and mathematics teaching profession (Ford Foundation, 1985):

- Salary levels that are not competitive with other occupations requiring comparable professional training.

- Lack of opportunities for professional growth: poor preservice training, lack of continuing education, absence of career opportunities in teaching.

- Unprofessional working conditions: lack of autonomy, isolation, and the absence of collegial opportunities for professional growth.

To the extent that it can, NSF must address these problems if the benefits of teacher training are not to be washed out by the poor conditions of the profession overall. NSF can help to influence professional working conditions, to create new career opportunities, and to provide a rationale and mechanism for higher salaries. (The initial preparation of teachers is discussed in Opportunity 5.)

Let us consider what many believe is the heart of the matter: low salaries. Salary levels are very fundamental in determining who is drawn to teaching and who stays in teaching (Levin, 1985). Of the teachers who leave teaching, 60% report salary as the main reason, compared with lack of administrative support (17%), lack of student discipline (15%), and no chance for advancement (15%). Both the low salary levels and the flat professional structure greatly affect the teaching profession, as is well described in the Carnegie Forum report:

> Teacher salaries are extraordinarily compressed when compared to other occupations demanding a college degree. They start low and remain low.... Most teachers approach the top of their scale within 10-12 years after entering the work force.... It is small wonder then that half of all teachers leave the work force within seven years.... The salary structure impels able teachers, those most likely to raise the level of performance of the schools, to leave the profession just as they acquire the experience to assume effective leadership. (Carnegie Forum, 1986)

NSF has little direct power over salaries for teachers. The Foundation, however, can help outline a role for resource agents that provides a structure and rationale for higher salaries. For example, by establishing a full-year salary for resource agents and science/mathematics specialists and showing how districts might use such resource agents on a full-year basis (for curriculum development, teacher training, etc.), NSF might begin to create a niche for such professionals to be rewarded for their ability to contribute to the improvement of their own districts.

The discouragement of today's science and mathematics teachers comes as much from unprofessional conditions as from lack of salary (Chubb and Moe, 1986). It runs from the most experienced to the most junior:

> There are many reasons why science education is falling short of its potential. Large classes, heavy teaching schedules, lack of training, isolation from other science teachers, and little support for innovation are all factors that drive science teachers to text and test oriented teaching. Experienced and highly

dedicated teachers, under the load of teaching many large courses, "burn out" and feel little of the excitement and interest that brought them to teaching in the first place. New science teachers, on the other hand, often have little background in science and are being asked to teach their students scientific facts and concepts about phenomena which they themselves have never seen. (Exploratorium, 1986)

Many of these people tend to "burn out" because of the extra demands on their time and the lack of rewards. One skilled teacher on sabbatical told us:

"Next year I will be expected to teach 35 out of 39 periods. One or two periods I will be expected to do lunch duty or parking lot duty. Then, of course, in my 'spare' time I am asked to lead a curriculum development committee and run a few workshops for teachers over the year as well...."

Opportunities for professional growth and for professional collegiality are an ongoing need central to the health of the professional community of science or mathematics teachers (as in any profession). Because secondary teachers in general have less background in the sciences than they used to, they identify less with particular scientific disciplines. They tend not to think of themselves as physicists or mathematicians. Professional scientific societies seem to provide teachers with a source of identity less than they did in the past.

NSF clearly has a role to play in improving the health of the professional community. In planning its original summer institutes, NSF was keenly aware that the institutes had the potential for rewarding the participants with a sense of intellectual inspiration, professional identity, and pride:

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.... (NSF, 1959)

Ironically, some efforts today to improve science education, particularly at the state level, are ignoring the need that teachers have for professional status and responsibilities. Legislated reforms instead are driving teachers even more to a text and test orientation. The teacher's professional sense of identity and autonomous role should be central in the design of reform activities:

A troublesome feature of the current reform movement is that it could exacerbate these problems. In the effort to achieve minimum educational standards and teacher accountability, many reforms, such as mandated instruction programs and the use of tests as the single measure of performance, tend to further mechanize and routinize an already fragile profession. As a by-product, the profession is likely to become even less attractive to the most able candidates. (Ford Foundation, 1985)

In summary, then, NSF has an opportunity to address fundamental sources of the teacher malaise in their programs that support science and math teachers at all levels. NSF can argue for, and demonstrate the feasibility of, a national pool or "support cadre" of science resource staff (consisting of lead teachers, science supervisors, and curriculum specialists) who, in turn, can work with all of the nation's science teachers. The concept of a group of people, highly trained and motivated in the teaching of their own disciplines, serving as an ongoing inservice resource could be a powerful idea that affects the profession and practice of science teaching at both national and local levels. It is also an idea that is consistent with deeper reforms now emerging in the teaching profession.

Current NSF (SEE) Efforts to Improve the Capabilities of Science and Mathematics Teachers

Within SEE's Teacher Preparation and Enhancement Division, four programs support various approaches to the professional development of teachers; three of them contribute centrally to the continuing education and support of teachers already in the schools (Teacher Enhancement, Presidential Awards, and Science and Mathematics Networks).* In addition, some projects within the Materials Development, Applications of Advanced Technologies, and Informal Science Education programs support aspects of teacher development.

These programs and their predecessors currently embody four distinct and recognizable strategies for improving the development of teachers: (1) direct teacher education (both pre- and inservice), (2) communication of information among teachers (and others), (3) recognition and "empowerment" of teachers (e.g., through awards programs and leadership training), and (4) the study of teachers and teaching. Current efforts strongly emphasize funding the first of these strategies: direct teacher education, primarily inservice, with more funds going toward science than mathematics. For example, nearly three-quarters of all teacher-related projects in fiscal years 1984–1986 were for inservice education; two-thirds were in science rather than mathematics. Although SEE has tried to encourage projects aimed at the middle school and elementary levels, it still funds more projects at the high school level (perhaps because, over the years, it has built a constituency of high school workshop leaders).

The picture painted above is, in fact, not static. The Foundation's current strategies for improving the initial or continuing education of science and mathematics teachers are in flux, reflecting an evolution in SEE's overall approaches. The funding strategy has gone from the funding of workshops and institutes (similar in approach to the old summer institutes and initiated largely by university science faculty) toward more school-centered and collaborative efforts, as a SEE program officer we interviewed described to us:

* A fourth program, Teacher Preparation, emphasizes grants to projects concentrating on preservice teacher education.

"I think it is important that we shift to programs that originate from and focus on the school dis' 'cts...because ultimately universities cannot solve the problem for dist cts. The universities don't live there--why should they end up with the residual knowledge that comes from implementing the project...? For example, the Teacher Enhancement Program is exploring a grant with a very large school system, where the district will initiate and coordinate the programs. Of course, all the collaborative elements will be there, but the emphasis will be on the district.... There are, however, consequences of this school-centered approach: programs are more likely to become embedded in the school district.... It probably means funding fewer larger and longer-term projects, and it also means that it will probably be even more difficult to involve scientists...but ultimately NSF cannot fund programs and techniques that districts themselves are not willing to pay for...."

In addition, there is a heavy emphasis on funding projects that can serve as models and exemplars to others (as outlined in the second scenario):

> The Foundation has a dual strategy. In the first place it seeks to support well-designed projects that will benefit the participants by making them more competent in their subject matter, more comfortable in its presentation, and more committed to their profession and their pupils.... Such outcomes are necessary...but not sufficient. The Foundation also expects that such projects should add to the base of knowledge about how teachers can most effectively be prepared.... (NSF, 1987)

A program officer described the new emphasis and its implications in this way:

> "I am convinced that the Teacher Enhancement Program is moving more and more toward generating models and knowledge. For example, we will insist much more heavily on adequate documentation and evaluation. We will not fund duplicate projects. We will not fund a third year for a project that has been successful two years if there is nothing further to be learned...."

Since its reinstatement in 1983, SEE has worked hard to find feasible and productive ways to approach the very massive and intractable teacher problem, given limited resources. It has increasingly recognized that it should not and cannot directly support the development of the nation's science and mathematics teachers. Consequently, it has sought less direct ways to gain increased leverage and influence over the process of teacher development. Its efforts to date appear to have met with mixed success, and its policies for the future also appear mixed in potential:

- In the most recent program announcement, SEE has eliminated (as a separate emphasis) funding aimed at "Local and Regional Teacher Development"--an effort that could neither train significant numbers of teachers nor yield other kinds of long-term benefits (e.g., teacher leaders, models, knowledge of the process). However, it still calls for projects that help "less well-prepared teachers" with the hope that such projects will draw in leadership teachers or ultimately be institutionalized. This kind of direct training has little potential for payoff.

- The heavy emphasis on "model development" also appears to have difficulties. The idea is to learn about new, more powerful ways of supporting teachers. However, by its own admission, SEE is not attracting many proposals that offer real alternative or innovative approaches. As one SEE program officer commented:

> "I hate to use the word--but we really are in a kind of 'rut' when it comes to teacher training. There is now a 'traditional' way to do teacher training. We get many many proposals for 2-week summer workshops. We aren't getting many really innovative ideas...."

In addition to needing more innovative ideas, there are real difficulties in evaluating teacher training projects and engineering the use of the knowledge that is gained through such evaluations. There are additional questions about the exact size and nature of the "market" for the ideas that are learned about the teacher development process.

These difficulties suggest that SEE should not attempt to make every teacher training project a "model" project or a major research project. Rather, should NSF choose to emphasize experimentation and the development of innovative approaches, it needs to use a more targeted and deliberate approach. Such experiments should be few, large, and funded with enough evaluation and support funds so that they ultimately produce the kinds of knowledge about teacher development that can have a real impact on the field.

SEE has also attempted to gain leverage over the teacher development process through leadership training programs. Its current efforts typically fund longer workshops for better teachers. These workshops are typically conducted by a team of scientists and educators. On the basis of reports from the principal investigators, such workshops appear to be successful at upgrading the skills of the teachers who participate, but the next step toward empowering these teachers to affect their colleagues in their own districts has, with a few exceptions, not been taken. For example, in a recent meeting of SEE-supported principal investigators of projects aimed at developing leadership teachers, the following consensus evolved about the process of developing lead teachers:

- Excellent teachers do not automatically make good lead teachers. The ability to work with one's peers is different from the ability to teach students well.

- The process is time consuming--an ongoing 3-year program is probably the minimum required to give teachers confidence in their own abilities and the skill necessary to work with their peers.

- The leadership skills (e.g., doing workshops, team teaching, classroom support, networking) must be taught directly.

- Mechanisms and resources for allowing lead teachers to work with other teachers must be built in from the beginning. Local district commitment for the lead teacher function must exist, and perhaps "neutral arenas" (such as science museums or universities) are needed for resource teachers to gain credibility in working with their fellow teachers.

- The "spirit" of the program must be right. Teachers have a strong egalitarian ethic--resource teachers must work on a professional and collegial basis with their colleagues. Those who become lead teachers must in fact rise to these positions naturally, and possess both intellectual prowess and personal presence.

NSF has begun to develop some of these aspects in its leadership projects; other aspects need further encouragement. The NSF-supported Physics Teacher Resource Agents program (PTRA), run by the American Association of Physics Teachers (AAPT) appears to embody many of the above principles and to be a good example of how leade ship programs can evolve from being merely advanced "summer institutes" to being service-oriented professional development programs (Van Hise, 1985). These programs will need long-term support and stability to build a presence that can have a growing and cumulative impact on the whole secondary science teaching field.

The history of the PTRA project reveals both strengths and weaknesses in NSF's current approaches. Inconsistent documentation of the project limits the project's potential as a model. The project has had five different program officers over its 3-year history. Each change in program officer has brought new demands for different kinds of evaluation information. A request by AAPT for SEE to continue funding the PTRA was denied, partly on the basis that NSF was interested only in "models" and that the PTRA model had been proven. But testing the model, by itself, may not be an especially sensible goal, if there are few other funding sources likely to support PTRA-like projects once the model has been developed. However, NSF is providing 1-year funding that will allow PTRA to establish a network among those leaders already trained, which may help to sustain some of the project's long-term influence, after NSF funding ceases.

The PTRA example points out the need for a clearly articulated long-term policy of supporting the profession, or NSF again will risk being charged with "hit and run" funding efforts that cause considerable dislocation and discontinuity in the efforts of the field to build its strengths.

SEE's Division of Teacher Preparation and Enhancement is also making efforts to build the teaching profession through its Science and Mathematics Education Networks and Presidential Awards programs. The Networks program is proving to be a very flexible tool for engineering interactions among different groups of professionals (e.g., the American Federation of Teachers and the community of mathematics educatic researchers) and for facilitating the flow of information about ways to improve practices. The Presidential Awards program appears to be successful in providing recognition to very good teachers and in keeping science education in the public eye.

These programs are limited, however, by a lack of coordination with one another. SEE's modus operandi is the autonomous program officer, and the lack of a larger integrating strategy at the division (or Directorate) level, as well as the lack of mechanisms for cross-program coordination, keeps each of these programs limited in scope and mission. There are informal attempts to link presidential awardees to teacher workshops, but more powerful use could be made of these individuals (to its credit, SEE has surveyed its awardees to assess their potential for wider contributions to the professional community). Similarly, other kinds of coordination could yield other bridges (the Networks program is beginning to initiate some of these types of crossovers). Because the program (not the division) is, for practical purposes, the unit of operation, the coordination between programs becomes an extra effort rather than the result of normal division teamwork in pursuit of a larger strategy. Some examples of coordinated actions are illustrated in the following suggestions for initiatives.

Promising Initiatives

The arguments above suggest that NSF has an opportunity to support the nation's science teachers in a new mode--through the development of a pool of well-trained professionals who can work in their own districts as resources to their own science and mathematics programs. The first initiative described below focuses on the secondary and middle school levels; the second initiative addresses the elementary level.

4.1 Develop a Pool of Teacher Resource Fellows at the Secondary and Middle School Levels

This initiative is designed to address the opportunity described above by establishing a nationwide pool of "Teacher Resource Fellows," who will be available to provide continuing teacher education and support. This pool would be composed of individuals who are the functional equivalent of a "lead teacher," as described in recent proposals for reform of the teaching profession.

> In most professional organizations those who are most experienced and highly skilled play the lead role in guiding the activity of others. We propose that districts create positions for a group of such people, designated "lead teachers...." Lead teachers would gain their authority primarily from the respect of their professional colleagues.... Some lead teachers will take overall responsibility for the work of groups of professional teachers, while others serve as consultants or experts on the particular areas of the curriculum.... What is central is that by vesting responsibility for instruction in lead teachers, schools will capitalize on the knowledge and skills of their most capable staff and create a career path worth pursuing. (Carnegie Forum, 1986)

Not only can "lead teachers" play an important role with their colleagues, but they can also have a very important leadership role in changing the priorities and curricula of science education so that it is well suited for all students:

> The [NSF-supported studies of the status of science education] clearly show that most important curriculum decisions are made by teachers. These include the determination of course offering, selection of textbooks, and development of classroom activities. Thus, if teachers are convinced that the actual thrust of the science curricula is not consistent with the needs of most students, it is possible to change that situation.... Teachers probably have more ability to cause such changes to happen than any other group of people, and it is important to realize that teachers are the most important authors of educational policy. (Harms and Yager, 1981)

The PTRA, described above, and Woodrow Wilson Fellows projects supported by NS are concrete examples of a first step toward exploring the potential of resource staff at the high school level. Using these programs as a beginning model, NSF could work in conjunction with professional associations, with industry, and with other funders to create a widespread system for designating and training "NSF Teacher Resource Fellows." These Fellows could serve as a network of inservice resource staff--who could support their colleagues in mathematics and science in a wide variety of ways. NSF Teacher Resource Fellows could be identified through state and district channels, through professional associations, or through existing award programs (such as SEE's Presidential Awards for Excellence program).

There already is an informal pool of resource staff in place. A small proportion, perhaps a fifth, of current high school and middle school science and mathematics teachers have exceptionally strong teaching backgrounds in science and mathematics (some from experience in NSF-supported summer institutes), whereas nearly half of the teachers are newer and far less experienced. This initiative would seek to take advantage of this distribution in experience by making more extensive use of teachers with stronger backgrounds.

The pool of resource staff includes not only talented teachers but also science specialists, science supervisors, or others in the position of supporting and training other teachers. The idea is to find people in the position (or potentially in the position) of serving as a trainer or resource agent for other teachers.

The role of science supervisors is critical to this effort, not only because of their central position in school districts, but also because they afford a point of leverage for upgrading the overall profession:

> Good supervisors, like good teachers, are hard to find.... The supervisor's role is pivotal.... A good supervisor is often the catalyst that makes a poor science program into an adequate one, or an adequate program into an excellent one.... It may be argued that efforts should be made to reach all classroom teachers directly...as the NSF programs did so successfully in the 1960's. But the Exeter II conferees, some of whom took part in that effort, were mindful

> of the greater cost effectiveness of supporting and upgrading the supervisors first.... It was felt that the benefits for school science programs would be greater than those obtainable by any other comparable use of funds.... (Brinkerhoff and Yager, 1986)

In addition, supervisors (unlike lead teachers) have the advantage of an already established niche in the school district administrative structure.

Existing professional networks could be used to support the NSF Teacher Resource Fellows, to let them exchange ideas and thereby continue to develop their expertise as master teachers, and to empower their ability to influence their own school systems. Ultimately, designation as a Teacher Resource Fellow by NSF could in itself become recognized as a major milestone in the career of a teacher or supervisor.

To initiate the development of this support pool, NSF could fund a range of programs and/or training centers around the country that intensively developed the skills of NSF Teacher Resource Fellows over a period of several years. Over 5 years, 20 such centers, each working with 100 teachers a year, could support a number of resource staff equal to 5% of the nation's secondary-level science teachers. The focus would be on both improving the Fellows' own teaching skills and, equally importantly, training them to work with others. Simultaneous to developing these teachers' skills, NSF would need to engineer substantial state and local district commitments for support that would allow the Fellows to devote significant time to working with other teachers.

One scenario would be to subsidize the Fellows over the summer and assure them a full-time salary for 4 out of 5 years. Two of these years the summers would be spent in intensive training; the other two would be spent working within their own districts. During the year the Fellows would be given support, as well as some release time for training and their own leadership activities. Ultimately, the states and localities would be responsible for seeing that the majority of their teachers, aided by these resource agents in a wide variety of ways, receive substantial ongoing inservice support.

Reform of this nature is not just a pipe dream. Some states are already initiating programs that conform to the general scenario outlined in this initiative. Connecticut is experimenting with a "buddy system" that pairs experienced "mentor" teachers with first-year "rookies." Tennessee this year will spend nearly $100 million implementing a three-tier career ladder for its teachers. Those teachers on the second- and third-level tiers qualify for summer work in their districts, which further increases their salaries. In recent years, at least 10 other states have launched similar career ladder programs that offer additional pay for additional time and responsibilities. Increasingly serious attention is also being given to the establishment of teacher certification standards--an effort that will necessarily dovetail with the career ladder reform.

One mechanism available for upgrading teachers to the level of resource staff is through the development of regional science consortia. Under this initiative, NSF would supply catalytic support for the creation of partnerships between universities, informal science institutions, industry, and willing school districts in a particular area with the dual aim of developing resource staff and simultaneously providing support for local science teachers. The goal of developing a regional resource staff and the "adopt-a-district" approach provides universities and informal science institutions with a well-specified scenario for interacting with, and helping, surrounding schools.

Such regional consortia, with clear aims and long-term support, are much more likely to result in institutionalized and ongoing programs than are isolated teacher workshops. The staff of universities who historically have carried out NSF's teacher workshops are particularly well suited to working with more advanced teachers, supervisors, and specialists. In addition, the facilities of a university or science museum provide a good arena for the resource teachers to learn to work with their peers.

In the short term, a pool of NSF Teacher Resource Fellows could contribute significantly to upgrading the knowledge and confidence of those science teachers now working in the system and those teachers entering it from other disciplines. In terms of the numbers, a network of resource agents could be developed in the next 5 to 10 years, which in turn could significantly affect a majority of the nation's secondary and middle school teachers of science and mathematics.

The development of a comprehensive support cadre for high school and middle school science and mathematics teachers is a massive and expensive undertaking (although far less expensive than attempting to provide adequate support for all teachers directly). We estimate that this initiative will require that NSF invest a total of $20 million to $30 million per year, or $100 million to $150 million over 5 years. (The actual cost is twice this figure, and we assume that states, local districts, and private sources will match NSF's investment.) The program for each of the 8,000 to 12,000 resource staff to be supported includes the following support:

- Two 4- to 6-week summer institutes at $4,000 per summer.

- Four years of support during the academic year at $1,000 per year.

- Three years of support for local school activities (workshops, curriculum development, material or lab development, special projects) at $2,000 per year.

- Two summers of full-time support for local district or regional support activities for work with other teachers (workshops, curriculum development, etc.) at $3,000 per summer.

4.2 Develop Science/Mathematics District Leadership at the Elementary Level

The problems of science instruction at the elementary level are different in nature from those at the secondary level. (For a more complete description of science education issues at the elementary level, see Opportunity 2a.) At the secondary level the professional problems involve a teacher corps that needs training, rejuvenation, and professionalization. At the elementary level the problems are much more deeply rooted in the culture and traditions of the school system. Because the number of teachers is tenfold that of the secondary level, and because the curriculum content needs of these teachers are difficult both to define and to meet, the appropriate role for NSF is much less clear at the elementary level.

That is not to say that the need is not great; nor is it meant to imply that NSF considers the secondary level more important. On the contrary, in terms of the ultimate goal of broadening the pool of interested and competent young science learners, there is a strong argument that the elementary level should have higher priority. Need and importance, however, are not sufficient to justify heavy NSF investment. An entry point, a point of leverage, is also needed.

Exemplary elementary science programs afford one point of entry. In studies of elementary school districts that have instituted "exemplary" science programs, the only common factor appears to be the presence of a leader. That is, in each district there is one individual who is (1) familiar with and committed to a vision of high-quality elementary science education, (2) skilled in institutional politics, and (3) willing to stick to the task without moving on to another job. This finding is reinforced by a decade of research on the adoption of innovations, which emphasizes the crucial role of the "innovation champion" (Tornatzky et al., 1983). NSF could perhaps best facilitate the development of elementary science programs throughout the country by helping to train such committed leaders. Perhaps more important than a new curriculum or approach is the need for trained and committed leaders to instigate and sustain changes.

There is indirect evidence that NSF can, in fact, create such leaders. Many of the leaders in today's elementary science education were heavily involved with the early NSF elementary science curricula projects (ESS, SCIS, SAPA). In fact, it now appears that the legacy of these projects may be as much the long-term development of the professionals who worked in them as the actual curriculum materials developed. The generation of educators who "grew up with ESS" still represents the strongest force for improving elementary science, although after 20 years there are few of these individuals left in the profession. Perhaps the time is right for NSF to experiment with ways to find, train, and support new leaders to implement grass-roots [illegible] in their districts.

The role and functions of elementary-level leaders would be multiple. They could carry out curriculum design and development, conduct teacher workshops, and serve as advocates for elementary science in their districts. Perhaps most important, they could help to shift the tone and flavor of science education at the elementary level from science as a "noun"--facts to be remembered--to science as a "verb"--

a process of finding things out. These leaders could work with teachers and administrators in their districts to change their perceptions of the nature and role of elementary science instruction. Many studies have pointed out that the priorities and expectations of both teachers and administrators in the area of elementary science play a key part in any effort to increase the amount and quality of science teaching at the elementary level:

> For science education of any sort to prosper at the *elementary* level, teachers must value science outcomes and consider them worth pursuing.... An important attribute for teachers at the elementary level is the perception that the study of science is much more than an exercise in reading comprehension. Rather, it is a vehicle for learning about the natural world. Teachers who view science in this way will naturally use a variety of techniques including direct observation, experimentation, individual and group projects, questioning and reading. They will do this not only to help students learn about the natural world, but also to develop those processes of inquiry they can continue to use to gather and process information.... For [teachers'] confidence to exist in the absence of a broad command of scientific knowledge, it is necessary for elementary teachers to see science as a way of investigating simple and common phenomena, especially those in the immediate environment. Conversely, it is important that elementary teaches not feel it is their responsibility to convey a large body of facts, theories, or "scientific" terms to their students. (Harms and Yager, 1981)

This initiative suggests, then, that NSF should deliberately set out to train such leaders at the elementary level. Such leaders could be found among the 1,000 or so existing science coordinators or among talented teachers who aspire to that job. All of the arguments made in the description of the previous initiative about the importance of science supervisors apply equally strongly at this level, although different individuals may be involved (in smaller districts, the same individual may act as science supervisor for the elementary and secondary levels; in larger districts, different individuals typically have these assignments). Such potential leaders could be provided with extensive experience in elementary science, in new approaches to elementary science (e.g., use of technology, integration with other subjects), and in the political skills needed to establish viable programs at the district level.

One condition for accepting such leaders into training would be the substantial commitment of the districts to benefit. The greater the commitment of the districts to pursue some sort of exemplary program, the more NSF might be able to support the leaders in training and in implementing new programs.

There is evidence that at least some local districts might be open to such an approach. Across the country, following state reforms, many districts are supporting committees of teachers developing curricula to meet state goals and frameworks. Although some districts will address their needs in science education by simply adopting a text series, a good proportion will develop their own curricula, either to serve as the main curriculum or to supplement it. The expertise of these local curriculum developers is limited, and their results are uneven at best. There is much reinventing of the wheel. Leadership training could include preparation for local curriculum development roles, closely coupled with local reform efforts; this might be an attractive and viable program for many districts.

The training of each leader would extend for 3 to 5 years and take place in the context of bringing about change in the leader's own district. Thus, at the conclusion of the program, not only would the leader be established, but 5 years of effort would already have been invested in the upgrading of the district's science and math programs.

The elementary leaders program, like the high school and middle school resource staff program, is a large and expensive undertaking. We estimate that over 5 years about 6,000 specialists, about one for every two to three school districts,* could be trained for an NSF investment of approximately $20 million per year, or $100 million over 5 years. Again state, local, and private sources would have to match these funds. These leaders could then be given the following kind of support:

- Two 4- to 6-week summer workshops at $4000 per summer.
- Two summers of full-time support for work with their districts at $3,000 per summer.
- Five years of academic-year support and networking at $1,000 per year.

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* Not all school districts are large enough to support such an individual in a specialized role. For example, districts with enrollments of less than 2,500--21% of the 15,500 school districts in the United States--are more likely to be served by specialists located in a county office or regional consortium, if they are served at all.

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Opportunity 5

TO HELP ATTRACT AND PREPARE THE NEXT GENERATION OF WELL-QUALIFIED SCIENCE AND MATHEMATICS TEACHERS

Attracting and preparing the next generation of well-qualified science and mathematics teachers is as pressing a problem as that of providing support to the present science and mathematics teaching force. The current national movement for the reform of teacher education and the teaching profession, spearheaded by the Holmes Group (1986) and the Carnegie Forum on Education and the Economy (1986), argues persuasively that to accomplish the goals of a better qualified and prepared teaching force, both teacher education and the teaching profession need to be fundamentally restructured in ways that will attract academically qualified persons into teaching and will offer a course of study to successfully prepare future teachers.

These reform movements have identified several elements of the proposed restructuring (e.g., differential staffing in the schools, lengthening the course of study for teacher preparation programs, and greater emphasis on the teacher's knowledge of subject matter). However, the reformers have yet to examine in detail the meaning of this restructuring for particular subject disciplines like mathematics and science. Nor have the reformers fully explored the consequences of these reforms for teaching practices in today's schools.

NSF has long been concerned with teachers' (1) understanding of subject matter in science and mathematics and (2) ability to facilitate this understanding for their students. The emphasis of the reform movements on greater mastery of content and associated pedagogy converges with NSF's long-standing concern and paves the way for NSF initiatives.

This opportunity assumes a need for fundamental restructuring within the science and mathematics teaching profession without assuming that current reform prescriptions are necessarily the direction to pursue. NSF might address two separate but related targets of intervention implied by this opportunity: (1) the mechanisms for attracting to the teaching profession--and retaining--college graduates with adequate academic backgrounds in science and mathematics, and (2) restructuring teacher education programs so that they prepare future science and mathematics teachers more effectively than at present.

Problems of Teacher Supply and Preparation

These targets imply two sets of problems that must be resolved. Attempts to attract and retain mathematics and science college graduates into teaching are influenced, in large part, by the status and reward structure of the teaching profession, the conditions of the workplace, and the competitiveness of teacher salaries.

Attempts to design effective teacher education programs are influenced, in large part, by understanding of how best to prepare beginning teachers or facilitate their continued professional development and by the conditions (faculty qualifications, course content, etc.) within the institutions that prepare teachers. Because the factors related to these two targets are somewhat different, we treat them separately in the discussion that follows.

The Problem of Attracting and Retaining Qualified College Graduates in Teaching

The present shortage of qualified science and mathematics teachers is documented in several national reports (e.g., Darling-Hammond, 1984; Plisko, 1983; Aldridge, 1986); and, over the next few years, the shortage is expected to increase. Even though there is debate about the exact size of the shortage, most agree that it will be substantial. Several factors will contribute to an increased need for secondary school science and mathematics teachers: (1) increased student enrollments, (2) possible reductions in the average class size, (3) the retirement (and attrition) rate of the present teaching force, and (4) new state graduation requirements for additional science and mathematics courses (Whalen, 1983). Through 1990, openings for science and mathematics teachers are predicted to be 16,000 per year (Rumberger, 1984).

Clearly, there is a need to attract qualified persons into science and mathematics teaching. However, an increase in the number of qualified persons enrolled in teacher preparation programs will not guarantee that this need for teachers will be met; a large percentage of teacher graduates are not teaching 1 year after graduation. Among all new science and mathematics teaching graduates in 1979-80, only 61% were teaching the following year (Rumberger, 1984).

Several interrelated reasons for teachers' leaving the profession are discussed in the literature: (1) the low salaries offered teachers; (2) poor working conditions; (3) the low status of the teaching profession; and (4) the lack of personal, professional, or financial incentives offered teachers. It is difficult for NSF to address directly the most powerful of these forces--low salary and poor working conditions. Similarly, NSF's influence on the status of the science teaching profession is limited by the overall dynamics of the professional labor market. But the nature of professional rewards and the health of the professional community as a whole provide NSF with a set of conditions it can influence, if not change substantially.

Any consideration of these issues must be grounded in the hard economic facts of the teaching profession. One of the major factors contributing to the shortage of science and mathematics teachers is the greater salaries that science and mathematics graduates can command in industry or the government. In 1982, a new graduate with a bachelor's degree in computer science could expect more than an $8,500 advantage ($10,000 in physical or earth science) in choosing a position in business or industry instead of teaching (Levin, 1985). These advantages become more significant when compared with salary advantages in other fields: a new graduate with a bachelor's degree in humanities could expect only a $1,000 advantage. There are various reasons for this salary disparity:

- Fewer persons major in science and mathematics because the course of study for these majors is considered demanding. Thus, the small supply increases the salaries these majors can command in industry, business, and government (Levin, 1985).

- In their search for technical and scientific talent, the defense industries have bid up the salaries of these majors. Between 15% and 20% of all scientific and technical personnel are employed, either directly or indirectly, by the Department of Defense (DeGrasse, 1983; NSF, 1984).

- In geographic regions with the greatest concentration of the electronics industry, the percentage of unqualified science and mathematics teachers is higher than in other regions of the nation. In 1982, 84% of science and mathematics teachers in the Pacific states were unqualified (i.e., teaching a subje[illegible]hich they were not certified), and 63% of the science and mathematic[illegible]chers in the West South Central states were unqualified. The national average of unqualified science and mathematics teachers is 56% (Plisko, 1983).

But it is a mistake to see the problem of attracting and retaining teachers as solely a matter of dollars and cents. Observers rightfully point to--and promote--the intrinsic factors that motivate teachers to join the profession:

> For all its disadvantages, teaching still is an intimate, significant involvement with individuals. Many professional jobs no longer are. Most of us remember one, two or, at most, three teachers who fundamentally shaped our lives. The opportunity for that kind of significance in the lives of others is denied to most people in their vocations; it is not denied to teachers, and that is a very important, though economically illusive, benefit of teaching. Fortunately some able adults, who have been successful in less intense human environments, still aspire to repay their debt by becoming one of those rare teachers who indeed profoundly and memorably assists a young person to become an informed, productive, enlightened, and concerned adult. (Graham and Fultz, 1986)

These kinds of considerations have, in the past, motivated many individuals to enter teaching temporarily or as a permanent career. A subtle climate of public and professional opinion can reinforce or inhibit these factors in the occupational decisions of would-be science and mathematics teachers.

Problems in Teacher Education

Current analyses of teacher education and reform proposals have helped to raise a series of issues about teacher education with profound implications for programs that prepare science and mathematics teachers.

The separation between preservice and inservice teacher education--Reform proposals call for a rethinking of both the traditional separation between inservice and preservice education and the standard curriculum of most programs that prepare mathematics and science teachers. For example, the reports of the Carnegie Forum on Education and the Economy (1986) and the Holmes Group (1986) recommend developing a series of steps for the teaching profession, from apprentice teacher to master teacher. Teachers would progress through a program of study that would begin before they are certified and continue for several years after. Whether or not one accepts these specific recommendations, they make clear the importance of developing a more fulfilling professional reward structure.

Pedagogical content knowledge--Forward-looking science and mathematics educators are also attempting to identify ways in which the traditional separation between content and pedagogical knowledge can be eliminated and emphasis can be placed on the "pedagogical content knowledge" needed by teachers. This has been described as going:

> ...beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching...[which includes] the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations--in a word, the ways of representing and formulating the subject that make it comprehensible to others. (Shulman, 1986)

This concept of pedagogical content knowledge has tremendous appeal to the educational community because it focuses on cognitive dimensions of teaching not previously given adequate attention in teacher education.

The concept of pedagogical content knowledge has implications for science and mathematics teachers and, subsequently, for teacher education. The way in which teachers view the structure of their discipline influences the way in which important concepts are presented to students. For example, how can the statistics teacher best teach the concept of standard deviation, or the physics teacher teach the concept of conservation of momentum? How does the presentation of these concepts fit into the structure of the discipline? How should teacher education programs help teacher candidates structure their discipline so that they can present important concepts to their students effectively? Several prominent teacher educators recently put the matter this way:

> How many elementary teachers, for example, teach arithmetic with complete familiarity with the number facts of addition, subtraction, multiplication, and division but with no comparable understanding of the organizing principles of number theory? Probably a good many do, and probably a good many children thus learn accurately how to add,

> subtract, multiply, and divide. What does not happen, however, and what is crucially important, is that for those children who do not easily master the number facts, the teacher has few, if any, intellectual resources to explain to the children WHY the numbers work together in the way that they do, thus eliminating a pedagogically effective way of helping them overcome their difficulty in learning the number facts themselves. (Graham and Fultz, 1986)

No systematic body of knowledge regarding how students learn concepts crucial to a science or mathematics discipline has been developed. However, NSF could contribute to the development of such a body of knowledge by establishing and funding a research program aimed at understanding the pedagogical knowledge needed by science and mathematics teachers. Such understanding could, in turn, be incorporated into teacher education programs.

An adequate grounding in scientific disciplines--Related to the issue of pedagogical content knowledge is conceptual knowledge. That is, to be capable of teaching the scientific concepts related to the student's daily life, teachers themselves must have a deep understanding of these concepts and multiple ways to teach them. For example, a student may ask his or her teacher, "When a glass of water stands out overnight, what are the bubbles on the side of the glass?" To answer this kind of question (or to help students answer it for themselves), the teacher needs some knowledge of thermodynamics. Thus, the education provided teacher candidates must contain the conceptual knowledge needed for teachers to develop their pedagogical content knowledge.

Multidisciplinary preparation--What--and how many--scientific disciplines should prospective teachers master? On the basis of recent survey data (Aldridge, 1986), it appears that out-of-field assignment of science teachers is prevalent. For example, only 35% of all courses taught by physics teachers are physics courses; therefore, these physics teachers are teaching other courses than those in their field of academic training. This finding implies, among other things, that breadth rather than depth is important in science teacher preparation--for example, prospective teachers' gaining mastery of two or more subject areas such as chemistry and physics, biology and mathematics, earth sciences and chemistry. Proposals to structure "5th year" teacher preparation courses emphasizing a bachelor's degree in a single scientific discipline may therefore be misguided.

Preparation for the use and role of technology in science education--Technology in education raises issues in the content of teacher education that are as profound as pedagogical or conceptual content. Only when teachers are willing to integrate educational technology into their teaching, establishing it as a crucial factor in the learning environment, will the potential of technology be realized fully. Although many states are requiring teacher candidates to complete a course in computers, these courses are usually at the computer literacy level or are an introduction to available educational software. Teacher education could offer teacher candidates an opportunity for more in-depth understanding of how computers might be used to help students' conceptual understanding of the discipline and ultimately change the existing learning environment. NSF could be in the forefront of preparing a new cadre of teachers willing to use, and capable of using, available educational technology to its fullest potential in science and mathematics teaching.

The structure of teacher education programs--The structure of teacher education has also properly received much attention. As mentioned above, the Holmes Group and the Carnegie Forum have issued reports recommending a restructuring of teacher education. Following these recommendations, teacher candidates would enter teacher education programs with a strong understanding of their discipline. The teacher education program would be a progression from apprentice teacher to master teacher, each step requiring certain levels of expertise in the teaching of the discipline. To date, possible alternative structures for science and mathematics teacher education have not been developed, although more modest restructuring of programs in the direction called for by reform proposals has been done:

> There is a growing trend to offer within the preservice period, or right after that period, a contract which allows the novice teacher to obtain full responsibility for a particular class, often with full pay, yet with close supervision of a tutor, accompanied by weekly seminars which deal with the freshly emerging classroom problems. (Tamir, 1983)

The need to connect teacher education more effectively with what teachers will need in their professional work is well recognized.

Science and mathematics teacher educators--There is a serious need for qualified science and mathematics educators, persons recent in their fields and capable of advancing an understanding of how best to educate science and mathematics teachers. These individuals occupy a critical but difficult position in the preparation process and are consequently in need of support. A leading science educator observes:

> There are some indications that many teacher educators enjoy mixed, if not poor, reputations among those with whom they interact in the course of their work (Nelli, 1981). Teacher educators are often criticized for virtually opposite qualities: Students and school teachers fault them as excessively theoretical (Buchanan, 1982), impractical (Lortie, 1975) and high minded, while their colleagues on campus fault them for being atheoretical and non-empirical (Katz et al., 1982). (Tamir, 1983)

Vigorous and visionary leadership in the community of mathematics and science teacher educators is necessary if they are to transcend the constraints with which they currently work and effect a significant transformation in the teacher preparation process. A degree of urgency accompanies this concern; many leading science educators will soon retire or have already done so, and the number of persons qualified to replace these leaders is small (the situation is not so critical among mathematics educators, but still deserves attention).

The Opportunity for NSF

In addition to the forward momentum toward reform, the opportunity for NSF is precipitated by several facts: the prospects for massive turnover among science and mathematics teachers over the next 10 years due to increased attrition and the retirement of an aging teacher force (Darling-Hammond, 1984); the gap between the production of new teachers from conventional programs and the likely need; and the inappropriateness of many conventional science/mathematics teacher preparation programs for the needs of new teachers in the schools (DeRose et al., 1979; Graham and Fultz, 1986).

Science educators are well aware of the deficiencies of current teacher preparation programs, as expressed in a recent discussion of middle school teacher preparation:

> We science educators teach one or two methods courses to prospective teachers (2.5-5% of their college coursework), hover helplessly around those who teach science and education courses to our students, and then accept the responsibility for graduating teachers who feel ill-prepared to meet the demands of classroom teaching. Constraints of enrollment and the realities of academic life add further frustration. The relatively few prospective middle school teachers, limited faculty time, courses tailored to the needs of the more numerous "others," and packed, stable programs work against marked increases in new and special courses for prospective middle school science teachers. We are left, therefore, with developing and *infusing* the relevant and necessary elements into existing science and education courses. We are also left with the formidable *professional* task of improving our methods teaching. (Schafer, 1986)

Recognition of these deficiencies and constraints sets the stage for ambitious efforts to develop better forms of teacher preparation.

Although many of the forces affecting the supply and preparation of science and mathematics teachers are beyond NSF's control (Levin, 1985; Harvey, 1986), the Foundation has a significant contribution to make to the "professionalization" of science and mathematics teaching, the quality of teacher education experiences (in particular, the scientific content of disciplinary courses and subject-specific pedagogy), and the systematic documentation of current experiments with teacher education and recruitment approaches.

NSF's most powerful impact on these matters is likely to be on subject-defined teachers (high school, middle school, and elementary specialists); consequently, these should be the primary focus of attention. The elementary generalist teacher, who is responsible for teaching science along with many other subjects, is another matter. The prospects for NSF having a major influence on the preparation of these teachers for science education are not particularly bright. The curriculum for elementary school teaching is far too broad; elementary school teachers are by definition generalists and cannot be expected to be specialists in all subjects. As the elementary school curriculum increasingly addresses competing interests (e.g., drug abuse, mainstreaming, educational technology, child abuse), the possibility of increasing the number of science courses required of teacher candidates also decreases. Nonetheless, although NSF cannot expect a significant expansion of the science or science education courses required of elementary school teacher candidates, well-planned courses aimed at increasing elementary school teachers' interest in science and understanding of the scientific process might be feasible. The discussions that follow pertain, for the most part, to secondary school teachers unless identified otherwise.

In contrast to Opportunity 4, NSF's role in Opportunity 5 emphasizes demonstration, program and leadership development, and research aimed at influencing the standards of practice among teacher education programs, including alternative preparation and retraining programs aimed at "nontraditional" teacher candidates. These programs are likely to serve the majority of newly entering science and mathematics teachers (Pelavin et al., 1984) and have been the focus of interesting experiments recently (Adelman, 1986). In the midst of the rebuilding process that is under way in teacher education institutions and in teacher preparation and recruitment activities across the nation, NSF's special contribution is to keep programs focused on the subject-specific dimensions of teacher preparation and on the requirements for effective professional work.

Now is the time to invest resources in this area before the influx of new teachers begins in earnest. The Foundation's efforts can be complementary to, and supportive of, the momentum in the reform of teacher education and the teaching profession, and can capitalize on the attention that these initiatives have received in the last 4 years.

NSF (SEE) Programs in Relation to This Opportunity

NSF's (SEE's) current investments approach this area of opportunity most directly in the development of model teacher preparation programs. More indirectly, SEE funding for recognition activities (awards for excellent teachers; to some extent, the training offered "leadership" teachers) contributes to attracting and retaining qualified teachers by augmenting the existing array of professional rewards. We discuss the two areas separately.

SEE's Contribution to the Professional Reward Structure

At present, SEE's major effort to attract (and retain) qualified college graduates to science and mathematics teaching has been indirect; by bolstering the professional rewards for good teaching in two ways. First, the Presidential Awards for Excellence in Science and Mathematics Teaching program has been designed to give national recognition to outstanding middle and secondary school teachers in public or private schools from each state in the country. The award recipients, selected through a two-stage review process, receive a grant of $5,000, as well as a trip to the White House for an awards ceremony.

Second, many projects within the Teacher Enhancement program (formerly funded as "Honors Workshops" or, subsequently, as "leadership development" projects) also contain an element of recognition for outstanding teaching. These activities support the identification and inservice education of outstanding science and mathematics teachers. After the inservice activity, these teachers are expected to provide inservice education to other teachers within their own or other school districts. This form of recognition is more dilute than the Presidential Awards, however; a more extensive leadership training process would probably be required, along the lines discussed under Opportunity 4, for this activity to influence general perceptions of professional rewards.

To date, SEE's activities related to attracting (or retaining) qualified science and mathematics teachers have focused on increasing the status of the profession by giving recognition to outstanding teachers. The appropriateness of such an activity for NSF is unquestioned. The Presidential Awards program is a relatively low-cost program with high visibility, but it is difficult to assess the degree to which this program is instrumental in attracting qualified science and mathematics teachers to teaching; in all probability, the effect on potential teaching candidates (if any) is slight. The impact of these investments on the retention of existing teachers is probably greater. The leadership projects did not have the visibility of the Presidential Awards, and recognition is more at the local than at the national level. It is also questionable whether these projects have had an impact on attracting qualified persons to science and mathematics teaching. However, the benefit to the leadership teachers or Presidential Awardees themselves is considerable. Many of these teachers serve as mentor teachers and/or pursue graduate degrees.

NSF (SEE) does not sponsor any other activities aimed at directly attracting qualified persons to science and mathematics teaching. However, the Studies and Analyses program is funding projects investigating the characteristics and availability of science and mathematics teachers. For example, one project is investigating the factors influencing science and mathematics teachers' decisions to stay in teaching. The results of this project (and others that might receive support) may increase our understanding of how best to attract and retain qualified science and mathematics teachers.

SEE's Investments in Improved Preservice Teacher Education

NSF's long history of involvement in science and mathematics teacher education concentrates primarily on inservice education, as reviewed under Opportunity 4. Although NSF operated a Preservice Teacher Education program from 1969 to 1977, it was funded at an extremely low level: a little more than $11 million over the 9-year period--approximately 2% of the funds that went to inservice teacher education in the first two decades of NSF's involvement in K-12 science education--were spent on preservice programs, primarily for the development of a small number of model programs. Since the reinstatement of SEE in 1983, the Directorate has shown more interest in this area of investment, although investments in preservice and inservice teacher education are small in absolute terms: approximately $20 million--between a fifth and a quarter of SEE's funding for "teacher preparation and enhancement" over the last 4 years--has gone to the improvement of preservice teacher education activities.

The current Teacher Preparation program is set up to fund teacher preparation projects for elementary, middle, and secondary schools. SEE's most significant investments in teacher preparation so far have been aimed at developing comprehensive preparation programs for teachers to be certified at the middle school level. For example, most of the projects funded under the Teacher Preparation program during FY 1986 were for middle-school teacher preparation. Later in FY 1987 and FY 1988, all grade levels of teacher preparation are likely to be funded.

These investments support a variety of comprehensive teacher preparation programs that seek to develop improved alternatives for the whole teacher preparation process, from initial recruitment through follow-up during early teaching assignments. The projects are likely to produce high-quality programs in the individual institutions that receive the funds. The more important question has to do with the wider impact of these models. A recent review of NSF's investments in middle school science education put it this way:

> The recent solicitation for model teacher preparation programs is a reasonable first step toward improving preservice preparation for middle school science teachers. However, this initiative by itself is unlikely to have the desired impact nationally. While projects are expected to include a method for providing information on the models once they are developed, without some aggressive dissemination plan there is the danger that adoption of each "model" will be limited to the individual institution for which it was developed. In addition, because NSF is interested in having the projects implemented quickly, each is to be designed to meet current certification standards. Since certification standards vary so widely among states, a model developed for one state may be unacceptable in many others. (Weiss, 1986)

The middle school initiative has limited generalizability because many states do not recognize middle school certification. This fact, however, does not mean the programs have no value for states that prepare teachers for this level or that might consider it.

Wider impact of demonstrations such as these presumes careful documentation, examination, and some form of dissemination. The current (1987) program announcement lists the following goals for the Teacher Preparation program: "(a) Stimulate a reexamination of the teacher preparation process; (b) catalyze the generation of models for preservice preparation; and (c) broaden the knowledge base about the preparation of effective science and mathematics teachers." These goals are worthwhile and important to the field; however, the achievement of these goals requires that each project be carefully assessed and be designed to maximize the goals for reexamination, model building, and knowledge generation. It does not appear that the projects awarded so far have all been designed with these goals fully in mind. Without good assessment of individual projects and synthesis of knowledge across projects, these projects will not "broaden the knowledge base." To its credit, SEE has recognized the need for cross-project study and has begun to experiment informally with ways to make this happen.

Promising Initiatives

To help attract and prepare the next generation of well-qualified science and mathematics teachers, NSF (SEE) is most likely to make a significant contribution in the following areas: (1) experimentation with incentives to attract and retain qualified science and mathematics teachers and teaching candidates; (2) funding for research that builds understanding of teachers' pedagogical content knowledge; (3) support for the development of alternative teacher education programs that will attract qualified candidates from a nontraditional pool; (4) demonstration program development in particular "trouble spots" along the teacher education pipeline (e.g., improved undergraduate science courses for "preprofessional" students, including teachers); and (5) support for upgrading the community of science and mathematics teacher educators.

5.1 Experiment with Incentives to Attract Qualified Individuals Into Science and Mathematics Teaching

The relatively low salaries offered to teachers and the nonprofessional atmosphere of the workplace are two frequently mentioned reasons why qualified persons are not attracted to the teaching profession. NSF cannot directly change these conditions (e.g., by providing funds to increase teachers' salaries or directly changing the professional climate of secondary schools); however, NSF has the opportunity to support experiments aimed at changing these conditions.

Job enhancement programs, in which science and mathematics teachers complement their teaching with other substantively related work (e.g., in the summer) and simultaneously augment their salary, are one interesting possibility that deserves further exploration. For example, NSF could develop collaborative efforts with industry and other government agencies that would provide teachers with part-time employment (either in the summer or during the school year) in the teachers' disciplines. By being actively involved in their discipline, teachers would gain a sense of professionalism often lacking in secondary school teaching.

Recent survey data (Aldridge, 1986) suggest that the greatest need for science and mathematics teachers is in geographic regions with the highest concentration of high-technology industry. These regions would also offer the greatest opportunity for summer employment, creating a reasonable match between need and availability.

NSF might consider a program whereby highly qualified teachers would be chosen competitively through a process managed by appropriate third parties (such as professional societies or their regional affiliates). The program would match teachers with summer job situations related to their expertise. The selected teachers would have the choice to work during the summer and increase their annual income. This additional employment would need to be attractive and have the potential of increasing the teacher's salary by $5,000 to $8,000 per year. We base these figures on the Levin (1985) analysis discussed above.

Such experiments need to be carefully managed and evaluated. Significant pitfalls need to be avoided, such as placing teachers in "make-work" positions that are not professionally challenging, or--the opposite problem--setting up situations that lure teachers away from their classroom roles into attractive jobs within the corporate sector. By encouraging projects that incorporated appropriate research components, NSF could help the science education community learn a great deal about the potential for these approaches.

Other forms of incentive deserve experimentation too. For example, NSF (SEE) could support fellowships for undergraduate science and engineering students to gain teaching experience in elementary and secondary schools. This initiative would provide an alternative for undergraduates majoring in science, mathematics, or engineering who have an educational inclination to learn about the teaching and learning of their science. Even a small number of students entering education from science and engineering fields could provide a cadre of well-trained, discipline-based secondary school teachers. By carrying out the program in different kinds of sites, carefully evaluating it, and making it highly visible, NSF could establish the undergraduate fellowship as a viable mechanism for addressing the teacher shortage problem and for bringing short-term assistance to local schools.

Assuming that projects were set up so that NSF funded both the majority of project start-up costs and an initial summer stipend for participating teachers (with phased-in contributions from the private sector), a wide- ranging set of experiments could be supported for $20 million to $30 million over a 5-year period (assuming a total of 2,000 to 3,000 teachers--400 to 600 per year--receiving a summer stipend of $7,500 and $5 million to $7 million as seed money for the start-up costs of 8 to 10 projects in different regions of the country).

5.2 Fund Research to Increase Understanding of Teachers' Pedagogical Content Knowledge in Science and Mathematics

NSF has a tremendous opportunity to increase understanding of teachers' pedagogical knowledge and to facilitate the translation of that understanding into teacher preparation programs. Because such an understanding is still in its earl; stages of development, NSF should approach this initiative as a carefully planned p gram of investigation, stipulating the focus for investigation over a specified period of time. For example, the program might approach the issue from an intradisciplinary point of view, funding projects related to pedagogical knowledge in one scientific discipline, followed by projects related to other disciplines. Or the program might take an interdisciplinary approach, attempting to understand similarities across the different disciplines within the physical or biological sciences.

Much of the burden for the success of this initiative would be placed on SEE staff, who would be responsible for identifying the appropriate focus for investigation at each stage of the program. A great deal of time and effort would be required to analyze proposals and to work with the principal investigators in developing an appropriate method for answering the questions of interest. Thus, the program officer's role would change from grantsmaker to intellectual manager of a research program. NSF might consider funding outside experts to work with the program officer, to help synthesize the results of completed projects and identify the next focus of investigation.

An investment of $10 million to $15 million over a 5-year period would be sufficient to carry out this initiative, assuming 20 to 35 research projects (averaging a total of $400,000 per project extending across 2 or 3 years) plus an amount for synthesis and dissemination among teacher educators and teacher preparation institutions.

5.3 Support Alternative Teacher Education Programs To Attract and Certify Qualified Teacher Candidates from a Nontraditional Pool

The current pool of recent college graduates is not providing the number of teacher candidates needed for science and mathematics; and, among present candidates, women and minorities are greatly underrepresented. Some educators believe that we must turn to other sources of candidates to meet this pressing need. Currently, several alternative teacher education programs have been designated specifically to attract and prepare college-educated but uncertified persons for the teaching profession from nontraditional routes (Adelman, 1986). These programs enroll persons with at least a bachelor's degree--typically, in mid-career--and offer course schedules to expedite the candidate's eligibility for certification. These candidates may or may not be employed teachers (working under an emergency credential) while enrolled in the program. Most programs offer special assistance or supervision for their employed candidates. Candidates enrolled in these programs come from a diversity of backgrounds; for example, retired military personnel, reentry women, or persons wishing to make a mid-life career change. Few of the existing programs have been designed specifically or solely for science and mathematics, but with NSF support, such programs could be tailored more specifically for science and mathematics teaching.

Such programs would be especially helpful for inner-city schools, which have difficulty competing with more affluent districts for high-quality teachers within all disciplines, but especially in science and mathematics. For inner-city schools, these programs could place emphasis on recruiting and educating much-needed minority teachers. Alternative teacher education programs designed collaboratively with inner-city schools and universities could help attract more qualified science and mathematics teachers to the inner city. Teacher candidates could be offered part-time teaching positions by the school district, extensive supervision, an accelerated teacher education program, and tuition scholarships and/or stipends. To increase the probability that these teacher candidates would continue to teach in the inner city, NSF could continue support to teachers during their first 1 or 2 years of teaching in the form of assistance from outstanding teachers within the district or university faculty.

Given the demographics of the labor market (with a very large cohort at mid-career over the next decade), NSF support for such programs has a high probability of increasing the number of qualified science and mathematics teachers and possibly increasing the number of qualified science and mathematics teachers willing to teach in the inner-city schools.

NSF support for this initiative could take one of three forms: (1) seed money to pilot test or expand the science and math components of a few promising models, (2) funds for comparative evaluation and documentation of successful program models, and (3) tuition stipend support for individuals to take advantage of these programs. Because there are relatively few existing models that are designed specifically for science and mathematics teachers, SEE's funds might be better spent in the first two areas. Between $15 million and $20 million over a 5-year period would be sufficient to develop a variety of models (up to 20), in addition to documenting and evaluating their effectiveness. Once proven models exist, NSF might shift its approach to direct funding of incentives to attract more candidates to these projects.

5.4 Stimulate Innovative Development Aimed at "Trouble Spots" in the Teacher Preparation Process

Along with its investments in comprehensive teacher preparation programs (e.g., current investments in middle school teacher preparation or initiatives such as 5.3 above), SEE can productively target "trouble spots" in the current teacher preparation process and direct funds toward creating a variety of innovative solutions. NSF should tackle only those aspects of the teacher preparation process that are most susceptible to its influence. For example, the setting of state teacher certification standards, which constrains the flow of new entrants, is probably an inappropriate target, whereas the content of science and mathematics courses for prospective teachers clearly is more likely to be influenced by NSF-supported improvements. We illustrate this initiative with four potential targets for funding that appear promising.

Support the development of undergraduate degrees preparing science teachers--This initiative has implications for the preparation of both elementary and secondary school teachers. As discussed above, elementary school teachers are, by definition, generalists and cannot be expected to have a strong background in a particular scientific discipline. In turn, secondary school teachers, although usually educated in a specific scientific discipline, often teach science courses other than those for which they have academic preparation.

NSF could support the development of undergraduate programs that would adequately prepare secondary school science teachers to teach in more than one science subject. Part of the present shortage of science teachers could be decreased if such programs were available to science teacher candidates. For example, as mentioned above, because of the small number of physics courses offered in secondary schools, physics teachers generally are assigned to teach science subjects other than the subject in which they were trained. Undergraduate programs combining study in two disciplines--e.g., physics and chemistry, or earth science and biology--could prepare future teachers for these kinds of teaching assignments.

The appropriate combinations of undergraduate science subjects would need to be identified, and this effort would require collaboration among science departments on a university campus. Not only would the appropriate combinations need to be identified, but to maintain the integrity of each subject, the appropriate depth would need to be determined.

For elementary school teachers, NSF should support the development of a sequence of courses that would provide these teachers with an understanding of the scientific method and general knowledge of topics taught at the elementary school level. Critics of the teaching of elementary school science frequently state that teachers do not understand the scientific method; courses in the philosophy and history of science might well facilitate this understanding.

NSF might consider supporting the development of a course of study for elementary school science specialists--perhaps the most promising way to ensure that (some) elementary school teachers have a solid background in science. But, in some quarters, resistance to this idea remains strong. The current movement in many elementary schools is to decrease the number of specialists and place more responsibility on the classroom teacher. Critics of the specialist approach argue that elementary schools have become fragmented and lost the original intent of allowing young children to have *one* teacher for the entire school day.

Support the development of methods for integrating educational technology into teacher education programs--This initiative is riskier in that it calls for NSF to support radically new approaches to integrating educational technology into teacher education programs. The intent is to go far beyond the current computer courses in most teacher education programs and develop a cadre of teachers who are willing to view technology as an integral dimension of education capable of changing the present learning environment. This cadre of teachers would be willing to accept that the role of the teacher is most likely to change drastically.

The initiative advocates that teacher preparation programs have a strong cognitive-science component. For example, present foundation and methods courses might be deemphasized and greater emphasis placed on cognitive psychology, computer science, and software development. Teacher candidates completing these programs would be similar to the kind of teacher described in the report of the Holmes Group (1986). Emphasis in these teacher education programs would be on the learner and on creating a learning environment specific to the needs of each student.

Support the development of teacher education programs designed to begin during preservice and continue through the first years of teaching--The full implications of the recommendations of the Carnegie Forum on Education and the Economy (1986) and the Holmes Group (1986) for science and mathematics teacher education are not yet known. NSF has the opportunity to support projects attempting to implement those suggestions in a variety of ways. Some projects might propose to establish a program of preservice courses leading to certification and continue the program on to a master's degree. Some projects might propose to establish programs for first-year teachers, providing them support in the classroom and offering courses in the teachers' discipline. Some projects might propose working with state certification officials and establishing new certificates that are more in line with the recommendations of the reform movements. Teacher education programs would be developed for these new teacher certificates.

This initiative is politically feasible and would give NSF a great deal of visibility. The groundwork has already been done for this initiative, and the field is ready for such changes. NSF would help put in motion what has already been thought of. The costs of these projects would be about equal to the costs of the projects currently funded under the Teacher Preparation program.

NSF may not wish to pursue all these possibilities at the same time. We estimate the total cost of developing innovative approaches to particular aspects of the teacher education process over a 5-year period to be roughly $20 million to $25 million. This assumes that NSF supports the development of five to six model programs at $2 million each for two of the "trouble spots" described above, with an additional $1 million over the 5 years devoted to cross-project research and evaluation, to enhance the demonstration function of these investments.

5.5 Support and Upgrade the Community of Science and Mathematics Teacher Educators

The need for well-qualified science and mathematics teacher educators at the university level is as urgent as the need for precollege science and mathematics teachers. This need provides NSF with an important opening. A recent review of NSF's (SEE's) activities in relation to middle school science education came to a similar conclusion:

> While the need to upgrade teachers' skills is frequently noted, little attention has been given to the need for continuing education of the people responsible for providing teachers with preservice (and inservice) education. NSF/SEE can provide leadership in this regard by supporting the development of materials to keep science teacher educators up-to-date about relevant research findings and new instructional materials. An existing network, the Association for Education of Teachers in Science (AETS), would be appropriate for disseminating such materials. (Weiss, 1986)

This initiative would allow NSF to play a high-level, highly leveraged role in revitalizing the field of science and mathematics teacher education. A relatively small number of leaders--30 to 40 such persons--can make a tremendous impact on the field. One well-qualified science or mathematics teacher educator has an impact not only on his or her students but also on the students of those students. A single teacher educator is thus in a position to influence a significant cohort of teachers. The relatively small number of individuals in these positions nationwide gives NSF a manageable number to focus on and the possibility of substantial long-term leverage.

The relatively small size and organization of the teacher education field suggests that NSF (SEE) could productively address teacher educators' needs on two levels simultaneously through: (1) leadership development, and (2) continuing education and support activities aimed at all currently practicing teacher educators in science and mathematics.

NSF could provide scholarships and stipends for doctoral work, perhaps requiring a joint program of study between a science department and a school of education. Qualified persons would need to have a graduate degree in a scientific discipline in addition to doctoral-level work in education. Most likely this program should be established only at major research universities (e.g., along the lines of Stanford's former Mathematics Education program, which has graduated many of the leading scholars in mathematics teacher education today).

Along with the scholarships to attract talented people to prepare for science and mathematics teacher education positions, SEE might support an aggressive program of multiyear "national seminars" for science/mathematics teacher educators, perhaps resembling summer institutes for teachers in the past, only aimed at the professional needs of individuals in teacher education positions. These seminars are a natural "arena of collaboration" between educators and members of the scientific community, and could do much to invigorate the intellectual interchange among those who prepare the nation's science and mathematics teachers.

An investment of approximately $15 million to $20 million over a 5-year period would begin a process of support and upgrading that might need to continue over a decade. (Our estimate assumes $80,000 per doctoral scholarship; $250,000 per year for 15 to 20 seminar projects, each funded for 3 years and collectively serving most of the current science and mathematics teacher educators.)

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Opportunity 6

STRENGTHENING THE INFORMAL SCIENCE EDUCATION COMMUNITY

Over the last decade, educators outside of schools have assumed an increasing presence in K-12 science education--in particular through television, but also through institutions such as museums and science centers. These ways of conveying science education have an apparent capacity to motivate a wide range of learners and potential (although poorly understood) effects on the acquisition of knowledge, skills, and attitudes. This type of education is more likely to help broaden the pool of interested science learners given the right professional leadership, understanding of scientific and educational issues, and efforts to examine the potentials and limitations of informal media or approaches.

In part a by-product of NSF (SEE) investment, a critical mass of well-qualified, thoughtful science educators has begun to assemble over the last decade within the different media (television, radio, print media) and institutions (museums, science centers). NSF has a long-term opportunity to expand the science education capabilities of these institutions and media by investing in further professional development, by supporting networks and collaboration (both within and across media), and by supporting research and evaluation efforts that can inform further efforts.

NSF's investments aimed at strengthening the informal science education community will help to establish a more secure foundation for a second form of investment in this area--funding aimed at extending informal science learning resources that have a direct and widespread impact on the nation's population. We discuss these investment possibilities in Opportunity 10.

Informal Science Education as a Professional Field

Historically, informal science education has not grown as a unified professional field. Rather, informal science education practices have evolved separately in different media and institutions: efforts to communicate science in television, radio, museums, and clubs, for example, are undertaken by people who work primarily in those media and are so grounded in the media in which they operate that they often have not thought of themselves as "informal science educators." Professional societies, journals, and funders also tend to divide themselves by media or discipline, staying within the boundaries of their own domains of print, broadcasting, or public science institution. Rarely have science television producers been familiar with the work of science museums; zoo directors have not known about interactive science learning centers; and amateur science societies have known little about informal science curriculum materials.

A constant theme in interviews conducted for this study was the hybrid nature of the professional training required for work in the informal science field. In addition to expertise in scientific and educational domains, informal science education often requires specialized experience with the nature of the media or institutional channels through which the informal experiences occur, such as journalism, TV production, or museum exhibit design and management. Many informal science projects meet the needs for different types of expertise by employing a team of individuals with complementary backgrounds (science, media, children's learning). This approach has been taken by many broadcast media production groups and science museums.

These collaborations are strengthened when at least some project members (especially senior staff) have an understanding of, and appreciation for, the multiple domains of science content, educational research, and media techniques. Yet few opportunities exist for talented individuals to develop expertise in multiple domains, as the director of a training program for science broadcast specialists explained:

> "There is a terrible lack of good people in TV science. There are less than a dozen people capable of producing a good science show. I have had to do searches to find good people and I have had great trouble.... We designed this program because we came to the consensus that even a few very good people could make a big difference."

Today there are signs that a "field" of su professional informal science educators is beginning to develop. A decade in which informal science education efforts have grown rapidly has given birth to a subset of professionals who are typically trained in a scientific discipline, and have come to educate themselves in the art of communicating science in an informal setting. Although they work primarily in one medium, their perspective and interest is primarily educational, as opposed to those who are primarily media oriented. Thus, these professionals serve as content specialists in helping design children's science television; they oversee the design of exhibits in science museums; they produce short science radio "spots" for commercial radio; and they carry out research and evaluation on the effectiveness of such efforts.

Within different media there are also beginning to be training and support mechanisms for this small field of informal science education. For example, the Association of Science and Technology Centers (ASTC) now represents science museums and sup ports a wide range of professional activities; the Kellogg foundation and the Fund for the Improvement of Postsecondary Education (FIPSE) program have supported the pro fessional development of educators within science museums (Munley, 1986; Diamond and Duensing, 1986; Semper et al., 1982); the Council of Science Writers supports broadcast and print science journalists; the Macy fellowships support the professional training of selected science broadcast specialists each year.

There is also a growing tendency for multiple-media and cross-media efforts in informal science education. Such efforts are difficult, since the barriers between media are well established. The American Association for the Advancement of Science

(AAAS) is one of the few societies actively involved with different kinds of media (Rogers, 1981), and NSF is one of the few foundations concerned with cross-media support in the entire field of informal science education. Located at the center of, and well-connected with, the members of this diverse community, NSF is well positioned to support both within-media and cross-media efforts. Through NSF's efforts, a small group of informal science educators could coalesce into an influential professional community.

The Opportunity for NSF

Foundations like NSF have the ability to promote the capacity and influence of whole fields of endeavor. The Sloan Foundation has fostered the field of cognitive science; the Getty Foundation is having an important effect on the field of art education. In a similar way, NSF has the potential to foster and promote informal science education as a self-aware professional community. In England, an editorial in *Physics Education* concluded, "The two missing ingredients in British science popularization are coordination and funds. Neither the media, the universities, the teachers, nor the institutions know what is expected from them because there is no single coordinating body, and no effective funding body." (*Physics Education*, 1985). In the United States, NSF is ideally positioned to fulfill both of those roles.

Informal science education is not a new endeavor. However, the kinds of sophisticated educational efforts on the Public Broadcast System (television series for children in science and mathematics such as "3-2-1 Contact!" and "Square One TV") and in science museums ("The Quantum Atom," "Evolution Exhibits") are new. They require great interdisciplinary expertise; the creators of these efforts have little collective professional experience to draw on. Unlike the formal setting, there is almost no research or evaluation to guide current efforts; there are not even many professionals who have extensive personal histories of work in this area. Thus, the lack of an experience base--either intellectual or professional--is a key constraint limiting the number and quality of educational activities in the informal domain. It is also a constraint that NSF is well suited to address.

Attempting to build the capacity of this professional community would require a small but long-term commitment by NSF. There are several reasons why this investment is a reasonable risk for NSF.

First, the target group is small and large investments are not needed. When viewed alongside the massive formal public school system, the numbers of professionals devoted to informal science education is tiny. Nevertheless, because informal science education typically aims at a mass audience, the influence of a well-trained professional or a well-conducted study can be significant in affecting the quality of projects that reach millions of people. The leverage and feasibility of the idea of training informal science education professionals are demonstrated by the short history of the U.C. Berkeley SESAME program, where a half dozen graduate students assumed influential positions in leading informal science education institutions such as the Smithsonian, San Diego Museum of Natural History, New Mexico Natural History Museum, and New York Hall of Science.

Second, as discussed before, the timing is right. Informal science activities are continuing to grow in popularity (see Opportunity 10), and the professionals and institutions that support them (e.g., science museums, zoos, broadcast producers) are similarly growing. NSF investments in people and ideas are likely to reap increased benefits as the practices of informal science education grow not only in number but also in sophistication.

Third, for years NSF has served as the major supporter of informal science education across several media (especially television and science museums). There is a natural opportunity to extend and build on its earlier investments. Research and professional development funded by NSF can help complement its development efforts in the field. As it funds more and larger projects in this domain, NSF needs to capitalize on its investments. The Foundation's support for research and professional development can provide the community with a needed identity, stability, and sense of continuity.

NSF's (SEE's) Programs in Relation to This Opportunity

Professional development and research are two primary ways any professional field sustains and regenerates itself. In its present funding for informal science education, NSF is doing little to support these functions directly, except as a by-product of its other investments in this domain.

Current and Projected Investments in Professional Development

SEE has placed relatively little emphasis on funding projects that aim directly at professional development (such as graduate fellowships, internships, or professional conferences). Indirectly, SEE's support for large-scale development has had the effect of building some professional capacity within the field. For example, in funding projects at science museums, SEE has indirectly contributed to professional development by supporting:

- Institutions that create new genres of exhibits.
- Publications that disseminate new techniques and ideas to other institutions.
- Consortia and traveling-exhibit projects that foster cross-fertilization between institutions.
- Collaborative arrangements structured to allow smaller institutions to have access to knowledge, skills, and resources of larger, more sophisticated institutions.

- Professional associations (e.g., ASTC) that can serve as a nucleus for the sharing of ideas and as a spokesperson for shared interests.

Through such efforts, NSF has encouraged professionals to work together, to review each other's work, and to share ideas. In this way, SEE hopes ultimately to strengthen the internal professional capabilities of science museums to the point that the museum field can become more widely capable of generating high-quality exhibits. But this goal is still a long way off, as a SEE program officer describes:

> "The museum field is becoming mature, with staffs becoming more professional, although they are not like professional staffs of natural history museums--which have become rigid. Most science museums' staffs are a little like 'happy idiots' inventing things. The dream of a staff in every museum having a good knowledge of informal education has not yet been realized."

SEE staff acknowledge the need for better professional development, but note that the mechanisms for obtaining it are not yet clear:

> "Professional development is a crucial need of the science museum field, but it may be one that NSF cannot meet very well. It is hard to do 'preservice' because there aren't standard modes of entry into the field."

With regard to science broadcasts for children, SEE makes even less attempt to foster professional development directly. To be sure, NSF's major projects have helped to train professionals and advance the state of the art of science broadcasting. There are, however, constraints that limit the contribution of these investments to professional development. Because NSF's broadcast projects are typically large and expensive, there are few of them; only a small number of organizations have the technical resources to undertake such projects. Consequently, NSF's funding of broadcast series has helped to train a very few professionals who work in the few organizations that specialize in science broadcast productions. Moreover, there is a problem of discontinuity over time, especially for professionals working in producing science programming for children. A "3-2-1 Contact!" staff member describes the situation they faced:

> "After the first season the funding was discontinued, so the staff drifted away. When a year or two later the second season was funded, it meant that a whole new staff had to gear up and learn the game."

It is in science journalism that NSF has funded programs most directly aimed at professional development. Seminars for science writers and editors, in both the print and broadcast media, have been popular and have been perceived as very useful. Facilitating the communication between scientists and the public via journalism is a role that NSF is suited for and one that has considerable potential for contributing to NSF's educational goals (Carey, 1986; Friedman et al., 1986). The small experiments with professional development in science journalism bear close examination with an eye toward analogs in the museum and television domains.

However, the basic notion of funding professional development projects goes against the current priority of the Informal Science Education (ISE) program, which emphasizes projects that have immediate, widespread impact on the ultimate audience. From this perspective, professional development must never become an end in itself, as an SEE program officer explains:

> "NSF supports museums as a means to an end. That is, it supports programs in museums that produce worthwhile educational results. It does not support museums per se-- either to strengthen them or to keep them alive....
>
> "You might say we are interested in helping others move weights; we are really interested in getting the weight moved, and not in helping others to become weight lifters or develop strong bodies ... that is not our job...."

The wariness of supporting professional development implied by these comments is often, but not always, warranted. In the informal science domain, where a few individuals are capable of having a large impact on the field, the conditions may favor investing in long-term capacity building.

Investments in Research on Informal Science Education

SEE is funding a few projects to learn more about the characteristics of informal science learning, assess the state of the informal science education field, and study currently funded experimental projects. Projects of this sort in the Studies and Analyses, Research on Teaching and Learning, and Informal Science Education programs include a survey of science learning centers, an evaluation of major television investments, and a general assessment of the informal sources of people's learning about science. The research effort to date, however, is very small. Together, these projects comprise less than 2% of the total informal science education expenditures and only a small part of NSF's investment in science education research.

SEE's contribution to the collective base of professional knowledge in this field is surprisingly modest given the substantial levels of investment NSF has made in informal science education. In particular, NSF has done little to elucidate questions concerning the promise or nature of this mode of science learning. From our interviews and our review of the literature, informal science education appears to provide motivating science experiences to a diverse range of young people in ways that can complement and extend what takes place in schools (see Opportunity 10). Ratings show that large numbers of children watch children's science television (Chen, 1984), and observational studies indicate that science museums have the potential to involve whole families in the learning process (Diamond, 1980). However, very little is known about the kind of learning that takes place in informal settings or even to what extent informal experiences provoke further pursuit of scientific interests.

To date, SEE has apparently avoided more extensive investments in research and evaluation related to informal science education for several reasons:

- Informal learning experiences are extremely difficult to study.
- Extensive research and evaluation have seemed an unwarranted diversion of resources from the main task of supporting innovative development projects.
- Only in the last half dozen years have informal science learning resources become sufficiently widespread (and investments grown) to raise pressing questions about the nature of this kind of learning (and the value of these investments).

Furthermore, along with many informal science educators, SEE has been reticent (properly so) to apply traditional evaluation techniques to informal learning situations. Pretests and posttests do not apply well to the open-ended, multifaceted learning experience that takes place in informal settings (Hicks, 1986). An NSF report put it this way:

> Conventional evaluation techniques, designed for the structured goals ... and objectives of the classroom, are largely irrelevant and unsuitable.... Few evaluation procedures are able to define and detect the ... ephemeral and individual effects, and those offered are extremely costly. (NSF, 1981)

As a result, SEE relies on largely anecdotal evidence (it is strongly positive) in believing that its programs in the informal domain are successful. Given the level of investment in the domain, the lack of knowledge, and the potential return of such knowledge, an increased research and evaluation effort in this domain appears both needed and timely.

Promising Initiatives

The initiatives that best address this opportunity focus on building the base of experience and continuity of expertise within the professional community. The first initiative focuses on the professionals themselves; the second initiative aims at projects that enhance the knowledge base underlying the practice of informal science education.

6.1 Foster Professional Development

NSF can use two distinct approaches to upgrade the expertise of professionals working in informal science education. One approach is indirect--to embed opportunities for professional development in all of its development projects; the other approach is to support projects that train new professionals and that provide opportunities for present practitioners to increase their own knowledge and skills. NSF (SEE) is already doing the former and should continue, but it should complement this activity with explicitly designed activities aimed at direct professional development.

NSF, as pointed out earlier, has helped to develop the field to its present level of expertise. ISE and earlier Public Understanding of Science (PUOS) programs have supported scores of development projects in broadcast, museums, and other arenas of informal science learning. One of the important by-products of this work has been the development of the professional skills of those involved in the work. Providing opportunities for those already working full-time on informal science projects to extend their knowledge and skills in the context of learning "on the job" is a natural and effective approach for fostering professional development.

A program officer in a private foundation expressed the need to be concerned with professional development in this way:

> "I believe that one very important criterion in judging an initiative is the effect it will have on those who are engaged in it. I see every initiative as having an important training effect on those who carry it out.... This is a major outcome of every grant--not a side-effect. I plan each grant to generate a process that will be beneficial to those involved. In this way, I can pursue high-risk projects because even if they fail to achieve their stated goals, they will still be very beneficial."

There are many advantages to the indirect approach of providing these kinds of natural "inservice" opportunities for informal science educators. One is that these people are already employed and in a position to use their skills. Another is that working on "real" projects provides a more motivating and challenging context for developing skills. Finally, of course, NSF (SEE) gets both the development and the training impact of its dollars. NSF (SEE) can do more, however, to make sure that its development projects simultaneously provide valuable training, and that aspects of professional development are built into all of its projects. In designing its funding, NSF can emphasize the degree to which initiatives encourage opportunities and mechanisms for the people in the field to develop their own skills. Funding of projects that involve collaboration among the staffs of different institutions, for example, is one mechanism that NSF already is using to help share the expertise concentrated in large institutions. Providing large development projects (e.g., television productions, large exhibition development) with add-on funds explicitly designated for a broad range of professional development activities would be another.

If it is to have a lasting effect on the informal science education community (and ultimately the target audience), NSF (SEE) should consider other, more direct ways to enhance the skills and knowledge of the small group of professionals specializing in informal science education. Three options are particularly promising: informal science education centers (that combine graduate training with other activities related to the field), conferences, and projects that foster cross-media linkages.

Informal science education centers--There are no standard entry points to the profession of informal science educator. Some have come from the media side, perhaps more from the science side. Many science museum directors, TV science producers, or others with broad expertise have entered the field through personal contacts, happenstance, and persistence in the face of professional and financial incentives that favor scientific research, commercial television, or other activities unrelated to education (e.g., Wheeler, 1986). Neither university science departments nor schools of education provide appropriate training for people to work in informal science settings. The few notable exceptions include interdisciplinary programs in science and mathematics education at Berkeley or in media and education at Harvard, MIT, and Columbia Teachers College. Not surprisingly, many alumni of these programs are currently working on NSF-funded projects in informal science education.

NSF's support for two to four centers for professional development in informal science education (preferably consisting of a collaborative arrangement between a university and an informal education institution) could do much to attract better people to the field and to continue the growth of those already working in it, by providing a center for research as well as graduate-level training in informal science education. Programs at these centers could include multiyear fellowships beginning at the graduate level and extending into postgraduate study, shorter-term "sabbaticals" for practicing professionals to obtain further study or experience (as with the Kellogg Foundation Fellowships), or short internships that help prepare individuals and organizations for work in specific domains.

This initiative could be implemented through solicitations targeted to those organizations with the capacity to design and implement such training programs. Analogous to NSF's Graduate Fellowships for scientific research, these programs would help prepare young professionals with the skills and perspective needed in informal science education. This initiative could also seek matching funds from local educational, media, or private-sector institutions.

Conferences--In addition to supporting centers, fellowships, and internships, SEE may wish to fund conferences that bring together diverse groups within the informal science education community. There currently is no forum for such a meeting or sharing of ideas. SEE should, as a matter of course, convene periodic conferences of the principal investigators from all SEE projects related to informal science education.* A different and equally important kind of professional interchange could occur in "Gordon-style" conferences, where people from a wide range of professional activities related to informal science education could be brought together to educate each other from the perspectives of different media. Such gatherings allow those in the field to learn from each other, facilitate future collaboration, and help NSF design new initiatives.

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* This might happen as part of SEE's "core function" efforts to promote professional interchange, described in *Volume 2 - Groundwork for Strategic Investment*.

- *Projects fostering cross-media linkages*--Finally, NSF might support specific development projects that create linkages between media where the potential for synergy is high. Examples include projects that link television with science museums, or that foster the transfer of some of the expertise gained over the years in science museums to the staff of other informal institutions (such as zoos and aquaria). Linkages between the schools and informal institutions are discussed in more detail in Opportunity 10.

We estimate the resources needed to support professional development opportunities for those working in informal science to be $3 million per year, or $15 million over a 5-year period. This level of support could provide:

- Support for four "centers" of informal science education, each at $500,000 per year.
- Support for individual opportunities (fellowships, internships, sabbaticals) for 25 individuals at an average of $25,000 per year.
- Support for conferences, projects linking media, other avenues fostering intermedia collaboration at $500,000 per year.

6.2 Develop Profitable Lines of Research and Evaluation

There is considerable evidence that informal learning experiences are an important factor in establishing early scientific interests and abilities (see discussions in Opportunities 2a and 10). But there is much that is not understood about this kind of science learning. As informal science learning opportunities for children proliferate, so do the questions about the effects of these experiences. For example, how do informal experiences affect learning and motivation? How does informal science learning interact with the more formal (e.g., school-based) science learning? Research to answer these and other questions can productively be pursued by SEE in two related ways:

(1) SEE can provide support for detailed evaluation studies of its own informal science programs and projects.

(2) SEE can invest in efforts to understand the basic nature and impact of informal learning.

Evaluation--NSF is funding many of the major innovations in the informal science education field. In breaking this new ground, SEE has both an opportunity and a responsibility to document the successes and failures of its experiments. SEE needs both to learn from the projects it funds and to share what it learns with those in the field who can benefit from it. Without this feedback from the projects and without transfer and wide sharing of the knowledge, it becomes difficult to make incremental improvements in approaches, strategies, and projects with each new funding cycle.

Within the last decade, the field of educational evaluation has broadened its range of methodologies so that many kinds of questions can be asked and answered (Smith and St. John, 1985). In addition to market research techniques, which are currently being used to understand the nature and extent of the response to some of NSF's broadcast efforts, the following methods may be useful in helping SEE better understand its projects: natural histories or case studies, critiques, observational studies, and appropriately designed experiments (e.g., Diamond, 1980; Borun, 1977). Whereas no individual approach can tell the whole story, a collage of different views, even if they are incomplete, can help generate more complete documentation and an increased understanding of the projects that NSF funds in this domain.

Both formative and summative evaluations should be a major part of NSF's efforts. For the larger projects, both can be built into the project's basic rationale.

- Formative research can range from relatively informal approaches, such as that incorporated within the San Francisco Exploratorium's exhibit development process, to more elaborate design research protocols, such as that advocated by the British Museum of Natural History (Griggs, 1981; Griggs and Manning, 1983). "3-2-1 Contact!" offers an interesting and perhaps generalizable approach in its tripartite staffing model that integrates research into the mainstream of the planning and production process (Chen, 1983, 1984).

- Summative evaluations should be carried out at both the project and the program levels. Carried out by third parties, they should focus at a minimum on compiling a thorough documentation of the project and on answering basic qualitative questions about the nature of the project and its impacts.

Such efforts will contribute to the knowledge base useful to those working in informal science education.

Basic research about learning in informal settings--Given the potential impact of the informal setting on people's attitudes and knowledge about science and technology, SEE should consider supporting research into the general nature and status of informal science learning. Such research might examine the following kinds of questions that bear on the ultimate goal of broadening the science learner pool:

- The impact of informal settings, including the home, on the development of attitudes toward science.

- The relative role of informal experiences in the development of science careers (e.g., through longitudinal studies of scientists and science education professionals).

- Cognitive aspects of learning in informal settings.

- Prevalent public preconceptions and misconceptions about science and scientists and how these interact with experiences in informal institutions.

- The relationship between formal and informal learning, the relative impacts of each, and the ways that they interact with one another throughout people's lifetimes.

- The influences of sex, age, and socioeconomic status and social factors on the impact of informal institutions on science learning and attitudes.

- Descriptions of the state of the informal science education field generated through national surveys.

The cost for a research agenda focused on informal science education would be relatively small, requiring approximately $2 million to $3 million per year. This level of expenditure would fund:

- One large status study at $500,000 per year.

- Five to eight basic research projects at $250,000 per year.

- One to two cross-project evaluation studies at $250,000 per year.

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PART THREE: OPPORTUNITIES RELATED TO THE INFRASTRUCTURE FOR EDUCATION IN THE SCIENCES

NSF has important opportunities to help direct the thinking and activities of institutions, industries, and agencies that form the "infrastructure" for formal and informal science education. These opportunities emphasize NSF as a provider of substantive or technical guidance to the individuals who design, supply, or set policy for curriculum and instruction in the schools or who design and support informal learning experiences outside of schools.

This category of opportunities invites a mixture of initiatives ranging from those aiming at short-term impacts (e.g., dialogue with, and assistance to, people involved in state science education policy) to longer-range, more developmental goals (e.g., support for alternative test development).

The Infrastructure for K-12 Education in the Sciences

Many institutions, industries, and agencies can be included within the infrastructure for science education. Four of these deal directly with the content of the curriculum and instruction that takes place within K-12 science and mathematics programs:

- *Publishers and associated development groups* (including software developers). The industry that prepares commercial textbooks and other materials, including software for computers and children's tradebooks in science, comprises a variety of enterprises, but is dominated by a dozen or so large commercial firms.

- *Scientific supply houses and technical equipment manufacturers*. A small number of firms supply schools with scientific equipment of various kinds, alongside the large and growing electronic technologies manufacturers (particularly in the computer field, but also in video and communications technology).

- *The testing establishment*. Several large private firms and an array of other groups, ranging from professional associations to state or local education agencies, produce, distribute, or conduct testing programs that are widely used and often mandated in school science and mathematics programs at various levels. (Note that some publishers also develop tests as part of their textbook series.)

- *State agencies and regional educational groups*. This category includes various state-level groups that have been active in reforming public school science education in recent years (in particular, state education agencies, legislatures, reform commissions, textbook adoption bodies, and state certification boards), and a parallel set of groups at the regional level (often technical assistance centers, regional offices of the state education agency, multidistrict consortia, etc.).

Other groups that provide information, advice, or resources to school-based science educators may also be considered part of the infrastructure. Private foundations are a source of funds for small-scale additions to the school science program, typically on a seed-funding basis analogous to NSF's. Professional associations and affiliated groups form the professional network for teachers and others. Teacher education institutions and general postsecondary institutions produce newly trained professionals and guide much of the theoretical work within the field, in addition to being the location of a large portion of the nation's scientific research.

The institutions that design and conduct informal science education programs (discussed previously in Opportunity 6)--science museums and zoos, radio and television broadcast studios, newspapers and magazines, recreational associations--also form a significant part of the infrastructure for science learning in two senses. First, they are a potential resource to the school science and mathematics programs (and, to a limited extent, are currently used this way). Second, they are a resource for individuals' self-directed science learning.

Collectively, these institutions and agencies are exceedingly diverse and conduct their affairs according to imperatives that may or may not be in the interest of good science education. Publishers must show a profit; hardware manufacturers want to sell machines; test makers want to create instruments that are easy to administer and score on a mass basis; print and broadcast media seek to maximize their share of the reading or viewing audience.

By the choice of projects it encourages and funds, NSF's primary role with these groups and institutions is to help them incorporate exciting and intellectually sound science and mathematics into their activities. With the exception of informal science education institutions in the past decade and commercial publishers during the 1960s and early 1970s, NSF has not played this role. To the extent that NSF works with these institutions, it does so against substantial barriers. For example, as a federal government agency, NSF must tread lightly in the private sector, lest it be accused of tampering with the marketplace or favoring some interests over others. The Foundation's potential efforts to affect state education policies and practices are similarly circumscribed, because of the prerogatives for determining educational curriculum that are constitutionally reserved to lower levels of government.

NSF must also recognize that, with some exceptions, most of the institutions within the infrastructure represent unfamiliar ground to the Foundation's science education staff, most of whom come from university settings. Although SEE has recognized this problem and taken steps accordingly, its current expertise for dealing with these areas is thin. Current SEE staff include one individual formerly located in a state educational agency, several with private-sector experience (one in a large commercial publishing house), and no one with extensive expertise in testing or test development. If SEE staff had greater working knowledge of the way these institutions work and more professional connections within them, the Directorate would be able to operate more effectively in the science education infrastructure. This deficiency can be dealt with by bringing on rotating staff with special knowledge.

The Opportunities at a Glance

As the introduction to this volume has argued, many of these elements of the infrastructure have a great deal to do with the current state of education and present timely targets for efforts to improve the situation. Textbooks and testing in science and mathematics, for example, are widely regarded as driving forces behind curriculum and instruction in schools--forces that, in effect, define the curriculum, regardless of school district guidelines. But not all that needs to be done to improve the science education situation is susceptible to NSF influence. In light of the barriers to its working effectively in these areas, the most compelling opportunities for the Foundation lie with content-related improvements, the development of innovative techniques, and raising public consciousness about the issues that must be addressed by others.

Although NSF is not a part of the educational establishment, it can be particularly influential with institutions that, collectively, exert great influence over curriculum and instruction in science classrooms. Three opportunities arise in this regard:

- *Opportunity 7: To improve and expand mathematics and science education publishing capabilities.* The quality and diversity of published science and mathematics materials are a major determinant of what is taught in science and mathematics classrooms. Although currently available materials are not particularly appropriate to the goal of broadening the science learner pool, the increase in the student population and the interest in expanded science offerings signal a possible turnaround in the market for school and tradebook publications in science and mathematics aimed at school-age people. This situation presents NSF with a significant opportunity for near-term influence on the incentives and capacities of the publishing industry and the market to which it responds. Although the predominant mode of materials development over the last few years has been to leave questions of publication up to the grantees, SEE has started to support collaborative ventures with publishers in elementary science, which represents a potentially more effective way of engaging publishers in improving what they offer. NSF can also contribute to an expansion of the nation's science and mathematics education publishing capability over the long term by promoting alternative publishing routes for innovative materials that are unlikely to be supported by the established publishing houses.

- *Opportunity 8: To improve science and mathematics testing and assessment.* Testing influences curriculum and instruction in equally powerful ways; there is a growing belief (and some evidence) that current tests greatly constrain what teachers are willing to teach. The recent increase in school science and mathematics testing lends urgency to efforts to develop tests that capture the full range of skills, concepts, and attitudes that good science and mathematics teaching and restructured curricula convey (e.g., higher-order thinking skills, science laboratory skills). To date, SEE has done little to support work in this area, other than its contributions to national assessments. NSF's capacity for supporting cutting-edge R&D makes it an appropriate leader in the effort to create sophisticated and sensitive testing and assessment tools, as well as to understand the effects of current testing policies and instruments. NSF can also increase the attention and work devoted to this issue, building on other efforts (e.g., the Mathematical Sciences Education Board) to examine these matters.

- *Opportunity 9: To provide content-related professional leadership in state science and mathematics education reform.* Although their direct influence on local practices varies, states are increasingly active in education reform, especially in science and mathematics. Reform policies such as increased graduation requirements have particular bearing on efforts to broaden the pool of science learners. The momentum of state-initiated reforms in science education and the relatively short window for sustaining a reform thrust (perhaps 5 years), combined with a vacuum in professional leadership in many states, provide NSF with important and immediate chances to help direct and translate reform energies into educational change. Since the National Science Board issued its report *Educating Americans for the 21st Century*, NSF (SEE) has done little to assist state-level groups with the practical task of carrying forward specific reforms; a few grants have been made to aid network development among state science education specialists and to help track progress of science education reforms. NSF has various options before it to take advantage of this opportunity, including promoting national dialogue on state science education reform policy, supporting technical assistance to state-level policymakers and science education planners, and funding more extensive cross-state research on the implementation and effects of reform.

The infrastructure of informal science education institutions presents an additional opportunity:

- *Opportunity 10: To expand informal science learning resources and enhance their contribution to school programs.* Although what is learned in informal science education is not well understood, its capacity to reach and motivate diverse, mass audiences is well established. Print and broadcast media, informal educational institutions, and educational associations thus appear to have a role to play in any broad-based attempt to broaden the pool of science learners, either as a complement to school programs or as an alternative route for individuals to pursue science interests. Various factors make informal science education a ripe area for further NSF investment: the growing public interest in this kind of learning opportunity, the increasing recognition that informal science settings can do things the schools can't do, the potential for engaging the home environment, and the cost-effectiveness of investments in this area. The Foundation can continue and extend the initiatives it has already undertaken, with special emphasis on supporting innovations, broadening the impacts of current successful programs, and cultivating new arenas (e.g., youth groups and recreational associations). It also has a substantial opportunity to explore more actively ways for informal science education to support school-based programs.

Opportunity 7

TO ENGAGE AND EXPAND SCIENCE AND MATHEMATICS EDUCATION PUBLISHING CAPABILITIES

The quality and diversity of published science and mathematics materials are a major determinant of what is taught in science and mathematics classrooms. Although currently available materials are not particularly appropriate to the goal of broadening the pool of science learners, the increase in the student population and the interest in expanded science offerings signal a possible turnaround in the market for school and tradebook publications in science and mathematics aimed at school-age people.

This situation presents NSF with a significant opportunity for near-term influence on the incentives and capacities of the publishing industry and the market to which it responds. Although the predominant model of materials development over the last few years has been to leave questions of publication up to the grantees, SEE has started to support collaborative ventures with publishers in elementary science, which represents a potentially more effective way of engaging publishers in improving what they offer. NSF can also contribute to an expansion of the nation's science and mathematics education publishing capability over the long term by promoting alternative publishing routes for innovative materials that are unlikely to be supported by the established publishing houses.

Limitations of Existing Publishing Capabilities

Published materials used in precollege science and mathematics education (e.g., textbooks, laboratory manuals, supplementary materials) emerge from an industry dominated by approximately a dozen major commercial firms. The industry also includes a large number of smaller profit and nonprofit organizations, which supply a wide range of instructional materials (generally not textbooks), but the "reach" of this segment of the industry is relatively small.

The products of the major publishing houses have long been a source of complaint by the science and mathematics education communities. For example, although there are significant exceptions to the rule, observers fault the currently most popular middle and high school science textbooks for the following weaknesses: (1) they are too similar to one another, offering the teacher little real choice (Black, 1986); (2) they are overloaded with factual information and underemphasize the underlying guiding principles; (3) they are dense, heavily laden with vocabulary, and generally unappealing to students (Yager, 1983); (4) they do not reflect recent advances in scientific thinking or the emerging structure of the disciplines, except by accretion (e.g., additional subsections or chapters on recent hot topics). (For a discussion of curricular change in science textbooks see Quick, 1977.)

In mathematics, another problem is that students do not read mathematics texts, and therefore are not well prepared to study mathematics independently. The School Mathematics Project of the University of Chicago (UCSMP) intends to change the character of the textbooks it produces so that reading is part of each lesson; homework assignments (in grades 7 through 12) include questions on the reading, as well as problem sets (University of Chicago, 1985). Recent research has also shown that in grades 4 through 8, well under 50% of the pages in the major mathematics textbooks have any content that is new to the student, with the startling low of 30% being reached in grade 8 (Flanders, in press). (See Opportunities 1 and 2 for further discussion of needs in science and mathematics curricula.)

This textbook situation results from characteristics of the industry, from characteristics of the textbook adoption process, and, perhaps, from a lack of research attention to the characteristics of good science and mathematics textbooks. The industry suffers from a high degree of cautiousness, traceable in part to state-wide textbook adoptions (Capper, 1986) and conservative adoption policies in many districts, financial disincentives for innovation, and a long-term decline in the size of the textbook market. While total enrollments declined by about 10% in a decade, the expenditures for textbooks fell at a much faster rate, declining by 50% in the period 1965-82 (National Commission for Excellence in Education, 1983). Left to the industry's own devices, market pressures tend to reduce the degree of innovation and drive down overall quality.

This cautiousness colors publishers' willingness to accept innovative elements in a newly developed text or program. One biology educator we interviewed was told by a publisher for whom he was writing a textbook in the mid-1970s that he could not caption pictures or illustrations with a question (meant to stimulate the students' thinking); it was editorial policy in this firm to use simple declarative sentences or phrases as picture captions. A physicist working on an NSF-supported physical science program for the middle school in the mid-1970s commented:

> "I spent a lot of time on [that program] only to see the way the publisher transformed the 7th grade draft. The whole mode of presentation became more formalistic than the original. They made a workbook with fill-in-the-blanks. They lost the flavor of the project. The publisher thought the way we had it was much too loose. I wanted a more informal, less regimented approach.... The sample materials we developed for doing experiments...became fancier and more expensive and highly specialized so you could only get them from one source.... It all became too artificial--it gave the appearance of very special applications so the kids really learned that science wasn't something you could do in the real world."

Publishers face a conservative and difficult market. For example, it takes years and costs more than $10 million to produce a K-6 mathematics series, which includes more than 100 separate items, not counting Spanish language versions. One editor of elementary mathematics texts, who has received many letters from teachers, observed:

> From my very own experience with the letters we get, most letters say, 'On page 57, exercise 37 has the wrong answer.' I've never yet gotten a letter on the philosophy of a mathematics program from the teachers. (Makhmaltchi, 1984)

Another expressed the view that "in many ways it's a dumb market."

Problems are not restricted to science and mathematics (Bernstein, 1985). In many fields flaws have been identified in textbooks, including bad writing and skimpy coverage of important topics. (For example, several comprehensive textbook reviews have pointed out that the role of religion in American history is slighted in history textbooks [Davis and Ponder, 1986]). In science and mathematics textbooks, one reason for skimpy coverage is the requirements in many states and school districts that certain topics be "covered" (different topics in different places), which lead publishers to try to include as many of those topics as possible, a practice known as "mentioning" (Bernstein, 1985).

Publishers have responded to some of these criticisms by making changes in texts, but in science and mathematics, problems are still evident. Considering that research (including NSF-funded studies) shows that the textbook is the most important determinant of the curriculum, the adequacy of textbooks is a matter of deep concern (NSF, 1978).

Studies of the textbook adoption process do not diminish that concern. For example, one study found that the average individual reviewing a textbook for district adoption is faced with a rating sheet that includes more than 70 criteria, each of which is supposed to be numerically scored. This excess apparently precludes thoughtful reviews; instead, it seems to lead reviewers to "flip through" textbooks. In response, publishers produce attractive books that can pass "the flip test" (Farr and Tulley, 1985).

School publishers can afford to be more innovative with some of the ancillary materials they publish. One state mathematics supervisor, speaking of "the most exciting things published in math this year," listed two sets of nontext mathematics materials, one published by a major textbook publisher and the other by a smaller publisher specializing in ancillary materials. Development of both sets of materials had been supported by SEE grants.

The school curriculum, however, is dominated by the textbook. The adoption process for texts is supposed to focus on substantive matters. For example, the state of California last year rejected all elementary mathematics textbooks submitted for adoption, because of insufficient attention to problem-solving and other skills identified in the state's framework for school mathematics (California State Department of Education, 1985). About a year earlier, California had rejected all of the junior high school biology textbooks, insisting that publishers make revisions if they wanted their textbooks to be considered for adoption. As the state with the largest public school enrollment, California can have considerable impact on a publisher's sales.

As one would expect of a conservative industry in an old business, the textbook publishers do not tend to invest much in research and development, apart from market research and the normal development costs for new publications. For example, the publishers entered the computer software business only after many other companies had developed a large variety of products for educational use. In the K-12 market, computer software is not yet very profitable for any of the large publishers.

The Opportunity for NSF

Fueled by widespread public interest in reforming education (and science and mathematics education more specifically) and by the anticipated growth in the number of K-12 students (which translates into growing market demand), the industry may be in a position to make major improvements given the right stimuli, support, and incentives. There may also be ways to broaden and diversify the industry through advanced R&D or the creation of alternative publishing routes for good, creative materials that lack sufficient appeal to the current commercial providers, or by stimulating production of interesting science and mathematics tradebooks for children. NSF is equipped to play a significant part in these developments, given its recognized role as an arbiter of scientific quality and its proven record of supporting successful experimentation with instructional materials.

NSF is not the only actor positioned to influence the publishing industry, but few command NSF's discretionary resources, position of national prestige, and links to the scientific community. Other than established publishers and development houses, current and potential key players and their roles include the following:

- *State textbook review and adoption groups.* In a few key states, such as California, these groups have the power to shift incentives for publishers radically.

- *Private-sector foundations and other funding sources.* They are supporting some development of printed materials (e.g., the SOHIO Foundation), and could contribute to efforts aimed at improvement of the industry.

- *Scientific and science education societies.* Professional societies operate modest publishing and review activities (e.g., journals, yearbooks); engage in some development of school materials (e.g., the American Chemical Society, which has developed a year-long course for secondary school students), but face tough competitive pressures themselves (e.g., the demise of *Science 86* magazine and the continuing difficulties of *Discover*).

- *Local textbook review and adoption groups* (in private schools and in states without state adoption policies). These groups can be effective advocates for change; their collective preferences and what they are willing to pay for materials has potential influence over publishing decisions.

- *Independent reviewers.* The Educational Products Information Exchange (EPIE) provides textbook reviews to states and districts willing to pay for the service. Also, in 1985 the American Association for the Advancement of Science's reviews of *Science Books and Films* began for the first time to review science textbooks, beginning with biology texts. (The Center for the Study of Reading, partly supported by the Department of Education, has reviewed reading books, and is apparently held in high regard by publishers.)

- *Educational software producers.* The market for educational software is heavily influenced by a variety of smaller firms, such as Sunburst and The Learning Company. However, the large school publishers are increasingly involved with both stand-alone software packages and integrated textbook/software combinations.

Although the importance of published materials alone should not be overestimated (other factors like teachers and tests are equally important), they do represent a "de facto" curriculum in many of the nation's classrooms; and they are far from satisfactory. The Foundation's historical record establishes a strong precedent for supporting improvements in printed materials, as well as a base of experience for judging more and less successful approaches. A number of the curriculum improvement projects of the 1960s had a rapid and significant influence on other, commercially published textbooks (Quick, 1977). NSF's curriculum development investments of this period even had impacts on the industry as a whole, as suggested by a mid-1970s retrospective review:

> Federally-funded curriculum projects (along with a number of association-funded and foundation-funded efforts) have been one of the particularly significant change agents in elementary-secondary publishing since the late 1950's.... Many publishers expressed concern, when the federally-funded projects were first announced, about the role of the federal government in subsidizing the development of instructional materials....
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> When the editors, as part of their jobs became acquainted with the curriculum projects as they were being developed, and when some of their authors (and potential authors) became deeply involved in many of [these projects], the publishers began to realize the impact the programs would have on education. As they became better acquainted with the programs, it was clear that they would have to pay attention to them, and, despite some continuing misgivings and reservations, they did....
>
> Perhaps the larger contribution these programs have made to the improvement of education, is their impact on the development of instructional materials by commercial publishers. (BCMA Associates, 1975)

To be sure, the changes in publishing practice stimulated by this earlier wave of NSF funding were not all permanent, but a few NSF-supported curricula are still in commercial distribution after 20 years, such as the Science Curriculum Improvement Study distributed by Delta Education. The pitfalls in working with publishers to improve the content and approach of school materials are now better understood (and will be discussed in more detail below).

As a centrally positioned, impartial bystander (with no commercial interest at stake), NSF can play a facilitative role in the world of materials supply. The timing seems propitious. A long-term increase in the student population is just reaching the elementary level; by 1990, the number of students in middle school will increase (NCES, 1985). In the wake of statewide reform activities, a great deal of attention has been focused on excellence in curricular materials, as in other areas of education. An effort to promote higher-quality materials is well timed in the current climate of concern for excellence.

Nonetheless, venturing into the publishers' world takes NSF one step closer to two potential accusations: that it is tampering with the commercial marketplace and that it is seeking to mandate curricula or curricular content. Promoting diversity in available materials and working with as many interested and qualified publishers as possible seem to be among the more important means by which NSF can deflect or rebut such charges. Another potential problem is the substantial risk that, although a few small publishers, stimulated by NSF support, might produce new and widely distributed materials (as was true with The Learning Company in educational software), the major publishers of instructional materials for schools might decline any direct involvement with NSF.

NSF must articulate carefully its position in relation to the industry. It should be a force for quality in science and mathematics education materials, and not a national censor or a determinant of local decisions. Finally, NSF must recognize that improvements in materials for the classroom will be realized in instruction only to the extent that teachers are comfortable with and capable of using these materials.

NSF (SEE) Programs in Relation to This Opportunity

SEE is currently addressing this opportunity both actively and passively. The 1986 publication of an elementary science materials development solicitation was the first in a series of proactive efforts to engage publishers in large-scale collaborative ventures to develop "model programs in elementary science for the average American school." The elementary science solicitation has gone through one round of awards, and a second round is planned for the current fiscal year. A senior executive with lengthy experience in commercial science textbook publishing has been engaged to help the venture succeed, especially with the major publishing houses that were reluctant to become involved in the first round.

The Directorate also supports a variety of other materials development projects, some of which are aimed explicitly at attracting publishers. However, in general, most grants for development of materials are made with little expectation of commercial publication.

Developers receiving SEE support are typically left to negotiate their own publishing arrangements. Of the current crop of Instructional Materials Development program projects (other than those funded under the elementary science solicitation), only a few are likely to be picked up for mass distribution by commercial houses. The development of curriculum "modules" (discussed under Opportunities 1 and 2) accounts for most of SEE's materials development awards in the last 3 years, but their distribution is for the most part considered financially unattractive to the publishing industry. (There are, however, a number of important exceptions. For example, a series of software products in mathematics was enthusiastically picked up by a large school publisher, based in large part on the track record of the grantee and an assurance that the grantee would work closely with the publisher to make the products "marketable." In another case, a very large series of print modules on applied mathematics, which have been supported by SEE, are distributed by the sponsoring organization, COMAP, and some believe they have had a significant impact on publishers and on mathematics education more broadly.)

The few whole courses that are under development may or may not find a favorable reception; in one case, a recently completed alternative chemistry course for the general high school student is being published jointly by a professional association (the American Chemical Society, which coordinated the development of the course) and a private publishing firm. Another project, aimed at producing an alternative life science course for the middle school level, is likely to be considered by several publishing houses.

In its new solicitations aimed at publisher partnerships, SEE considers the early involvement of publishers very important in increasing the likelihood that they will have a stake, financial and otherwise, in marketing the product, which in turn increases the likelihood that the materials will be widely distributed and used. Publishers are also given greater responsibility for teacher education, which helps to break the link between SEE-sponsored materials development and SEE-sponsored teacher training--a link that caused intense congressional concern in the 1970s, during the MACOS ("Man: A Course of Study") affair (U.S. Library of Congress, 1976).

The targeted solicitations for elementary science represent a departure from NSF's historical approach to publishing. For example, in the past NSF provided support for the development of high-quality course materials that were later bid on by publishers when nearing completion. In other cases, course materials were published in trial versions only, with permission given for anyone to use the materials in commercial or noncommercial editions (Wooton, 1965). (There were also variations on these themes.) The problems encountered in these earlier development ventures form the basis for NSF's current direction; in particular, current policies are designed to avoid problems such as:

- Lack of initial understanding by publishers of what all the ground rules are (e.g., in terms of royalties).

- Lack of long-term commitment by publishers to the materials (e.g., a failure to market them aggressively).

- Substantial reinterpretation by publishers of a course or its component materials to make it "more marketable."

- Unmet needs for teacher training in the use of the new materials.

Continuing the currently active initiative in elementary science (and perhaps adding elementary mathematics to it, by linking that solicitation more closely to publishers) has much to recommend it. It has attracted a good deal of attention and creativity among proposers; publishers' early commitments have meant an approximate doubling of the funds available for development; the products that result are likely to be widely disseminated; a portion of the profits will be used for teacher training; and the publishers' initial investment gives them a continuing financial incentive in marketing the product.

But there are also some significant questions about this strategy. A scientist we interviewed, who had been involved in curriculum development for years, captured the feelings of many others we talked to. When the recent elementary science competition was announced, he wrote or called more than 70 publishers about collaborating. Some would have nothing to do with the NSF venture; regarding one large publisher's response, he said:

> "They would do the choosing [among possible programs to collaborate on]. So in effect it is the publishers which are the screeners. [This publisher] had received several programs, and frankly said they chose to go with the one closest to their existing program."

Our analysis suggests that the following are the biggest unanswered questions with regard to the elementary science solicitation strategy:

- The largest publishers are, so far, reluctant to participate.

- If they do respond, the incentives for maintaining quality in the face of conservative perceptions of the market (and conservative behavior by the market itself) may still "water down" the product; truly innovative materials are unlikely to be published and distributed widely.

- Overall, the strategy maximizes widespread distribution at the possible expense of addressing deeper concerns about content and approach. Products deriving from the efforts to reconceptualize science content or significantly reorganize and improve instruction in mathematics (such as those that are the aim of initiatives under Opportunities 1 and 2) are unlikely to survive in this kind of arrangement.

Within SEE, other kinds of current investment address aspects of this opportunity, but more obliquely. In particular, SEE's Applications of Advanced Technology program (AAT) has recently been putting emphasis on intelligent tutors and authoring systems, both of which bear a potential relationship to the way textbooks (and other instructional aids) are conceived, structured, or deployed in the future. For example, SEE now supports work on intelligent computer-based tutors for high school and elementary mathematics as well as various applications of interactive videodisc technology. These technologies are not now in widespread use in K-12 education. However, it once seemed farfetched to imagine computer software as an integral part of textbooks or courses; that is no longer the case, and science and mathematics are among the subjects that benefit most from the use of such software. It may be that the use of computer-based tutors (e.g., for "bottlenecks" in the curriculum), videodiscs, and other "futuristic" technological tools will also be common one day. Nothing we know precludes the possibility that school publishers may market such materials to schools and school-age children. It is only a matter of time before "smart" interactive technologies will be affordable on a mass scale and flexible enough to suit a wide range of science learning needs.

But there are risks for SEE. The time line for the results of these efforts is long and the outcomes uncertain. At current funding levels ($5.2 million in FY 1987 for all of AAT's projects), progress may not be rapid, since new technologies tend to be very expensive to develop, especially at the prototype stage. Nonetheless, the long-term prospects for at least some return (to the field) on these kinds of investments are good, although it is not clear how quickly these developments will make their way into the publishing world. This approach will be most attractive to those who believe that, over the long term, very substantial changes in method and approach are needed in the current K-12 educational system.

NSF's current investments in this area, although modest, are likely to nudge the inevitable development process in the direction of applications that will serve science and mathematics learning needs better.

Promising Initiatives

NSF has a variety of attractive options for investing funds in pursuit of this opportunity, some aimed at shorter-term incremental change, others at developing a better publishing capability in the longer term. The distinguishing feature among these options is the degree to which NSF wishes to depart from established publishing practices and arrangements.

Three of these initiatives are based on the premise that textbooks are an essential determinant of the curriculum in science and mathematics, and yet some catalyst is needed to make significant change in texts and the curriculum they embody. The remaining initiative is based on the hypothesis that children's science and mathematics tradebooks are one of the major avenues for out-of-school learning in these fields, and that there is a market for them that is ready for an infusion of new talent.

7.1 Repeat and Extend Solicitations for Publisher Partnerships (e.g., to Middle School)

The analysis presented above suggests that a continuation of the current initiative involving publishers makes a good deal of sense, both to determine its viability and in anticipation of a modest addition to the current commercial array of instructional materials. The middle school level is the next logical focus, given the predictable expansion in this market, the importance of the middle school years in forming attitudes toward science and mathematics, and other factors (NSF, 1978). Many of the key advantages and disadvantages have been summarized above.

The initiative would feature separate solicitations for middle school science and mathematics development projects that emphasized collaborative arrangements with publishers in a manner analogous to the current elementary science solicitation. (The fact that NSF was committing further development funds to this kind of project would be added incentive for reluctant publishers to participate.)

In addition to launching projects aimed at the middle school, SEE should also consider repeating its elementary mathematics development solicitation, with greater emphasis on collaborative arrangements with publishers.

SEE's elementary mathematics solicitation of 1986 differed in several ways from the science solicitation. The development of prototypes (rather than finished products) was emphasized; the involvement of publishers was not encouraged in the same way as with elementary science; and not as much NSF money (and less publisher money) was allocated to the competition. SEE may believe that available materials for elementary mathematics are better than those in science. However, our analysis suggests that the needs in elementary mathematics are substantial, that the available materials are not outstanding, and that NSF is presented with an excellent opportunity to address those needs. Serious consideration should be given to supporting elementary mathematics development in a parallel fashion to the elementary science solicitations, including a comparable level of effort and the involvement of publishers from an early stage.

Supporting this initiative, which aims at developing materials immediately marketable by publishers and usable by teachers and students, would not be the same as supporting the initiatives under Opportunities 1 and 2. Those involve substantial rethinking of the content, approach, or organization of science and mathematics. As such, they are inherently more long-term and would show the way for deeper changes in current approaches than could be expected from projects under this initiative.

The resource requirements can be estimated at between \$40 million and \$50 million over a 5-year period, depending on the extent of NSF's investment for both science and mathematics development. We base these estimates on the following: (1) \$16 million to \$20 million over 5 years for middle school science (assuming 4 to 5 projects at approximately \$1 million each per year for a 4-year funding period); (2) \$12 million to \$15 million over 5 years for an elementary mathematics solicitation (assuming 3 to 4 projects at \$750,000 each per year for 5 years); and (3) \$12 million to $15 million over 5 years for a middle school mathematics development thrust (assuming 3 to 4 projects at $750,000 each per year for 5 years). These estimates are roughly comparable to the current and projected investment levels for the elementary science solicitations, allowing for differences in subject area and level. (The current elementary science materials solicitation, for example, will total approximately $25 million over a 5-year period.)

7.2 Form a Consortium to Explore and Support Alternative Publishing Capabilities

NSF could stimulate the formation of a consortium of groups, including scientific and science education societies, private-sector foundations, and others (such as the National Geographic Society, which already has a significant publishing capability) to explore and support alternative ways to bring high-quality educational materials to large audiences at reasonable cost. One likely outcome of such a venture would be a nonprofit publishing capability jointly maintained by the consortium members (consortium participation might be motivated by such incentives as reduced rates for consortium members) and supported in large measure by revenues from the sale of publications. The overriding characteristic of consortium deliberations and operations would be an emphasis on high scientific and educational standards, the encouragement of diversity in approaches, and the insistence on innovation.

Specific activities for NSF might include:

- Conducting background research (market considerations, existing publishing capacity, costs, etc.).
- Supporting efforts to form a publishing consortium and maintain ongoing dialogue among its members.
- Providing seed support for the development of an alternative publishing capability; equivalent or substantial matching from a number of other partners could be a requirement.
- Monitoring grants with the expectation of self-sufficiency within, say, 5 years.

An example from an earlier period is illustrative of certain features of this initiative, although the medium was not primarily print. In 1971, SEE began supporting a nonprofit organization that would package and distribute high-quality computer-based instructional materials to colleges, universities, and secondary schools. At that time, no organization existed to distribute instructional programs (since there was no established commercial market). CONDUIT was intended to provide an organizational link that would search for materials, test and revise them, handle distribution, and provide author incentives. At least 1 million students benefited from using materials distributed by CONDUIT, and the organization also helped develop the marketplace for commercial organizations (Office of Technology Assessment, 1982). The biggest difference between CONDUIT and this proposed initiative may be that computer software was a new medium at the time. However, the important similarity is that previously "unmarketable" materials are the target.

Unlike Initiative 7.1, this option seeks to expand the national science and mathematics education publishing capability by adding a hitherto missing ingredient, which fills a market niche of sorts unlikely to be catered to by existing publishers. The option aims at long-term effects on the supply of high-quality materials; one would not expect to see significant output from an alternative capability any earlier than 3 years after start-up, although the shorter-term effects involve significant infrastructure building. In addition, the most important advantages of the option include:

- The ability to bypass many of the constraints inherent in much of commercial publishing.
- A possible long-term influence on commercial publishing practices and standards.
- Increased interaction among national-level groups interested in improving printed materials.

These advantages are tempered by some significant drawbacks:

- In the short term, the volume of materials that could be produced and distributed would be small and would never rival the volume that major publishing houses can produce.
- NSF must avoid competing directly with the private sector (operationally, this arrangement might only consider materials that major publishing houses had refused).
- Producing and marketing high-quality, innovative materials often makes great demands on publishers, and a new venture would need to be prepared for this. For example, school publishers may have hundreds of salespeople and dozens of technical consultants available; new ventures would find it extremely difficult to match such resources.

Across a 5-year period, an investment of between \$18 million and \$25 million (NSF's share) would be needed to support these kinds of activities. The bulk of the resources--perhaps \$14 million to \$20 million--would be necessary to establish and set in motion whatever alternative capability the consortium would seek to establish. The remainder would be required for background research, the establishment of the consortium, and its ongoing operational costs over an initial 5-year period.

7.3 Support R&D on the Science or Mathematics "Textbook of the Future"

Rather than concentrating on incremental improvements in current publishing capabilities, this alternative undertakes research and development on the "textbook of the future," especially drawing on existing and emerging electronic technologies (e.g., microcomputer, compact disc read-only memory or CD-ROM, videodisc, thin-screen displays, authoring systems, artificial intelligence), which offer bold new conceptions of the format for curricular "text" materials. The challenge will be to capitalize on what these technologies offer and to demonstrate the feasibility of alternative models for conveying scientific or mathematical knowledge, skills, etc. The possibilities for incorporating interactive capabilities, simulations, moving pictures, intelligent tutors, etc., are especially promising for instruction in science and mathematics. Such capabilities have been the dream of some computer visionaries for many years. A decade ago, in *Scientific American*, one could read that the lap-top computer would allow children "to have an active learning tool that gives them ready access to large stores of knowledge in ways that are not possible with mediums such as books" (Kay, 1977).

The Applications of Advanced Technology program currently supports research and development using many of these technologies (as indicated above). This initiative would build on some of what has been supported.

Although there are alternative distribution routes, we visualize most of this activity being done as "public domain" knowledge, with the results periodically made available to all interested commercial entities (as was done by the School Mathematics Study Group in the 1960s). This applies particularly to methods and standards, which should be widely available so that a marketplace can grow without excessive fragmentation. There is also room for grants and contracts leading more directly to product development (as with some past and present NSF-supported computer software).

The central advantage of this option is that it seeks to extend and apply the state of the art at a time when a variety of electronic technologies are growing cheaper and more sophisticated. The rapid proliferation of the microcomputer as a basic tool in schools proceeds apace, but technologies used less extensively in schools have much to offer. There are other reasons why it makes sense for NSF to undertake this initiative:

- This option draws on an area of NSF's proven strength--exploratory development of new technologies by a segment of the educational field that is ready to engage in these efforts. SEE supported development of BASIC and LOGO and demonstration of "intelligent videodiscs" for education, and has been at the forefront of education research with a variety of other technologies.

- The public domain provision ensures wide access to technical results, and reduces the likelihood of proprietary restrictions on use.

- Because few other institutions are likely to put in the "risk money," this effort is unlikely to happen without NSF support.

But there are other considerations that urge caution:

- The results of this option are unlikely to make their way intact into widespread use, although the most marketable aspects of the development efforts will do so.

- Technological developments such as these are probably far ahead of schools' or families' capacity to use them.

- Technological work can be very expensive, and not all prototypes will ultimately prove useful.

This kind of research and development is not inexpensive, given the current state of the art. We estimate between $15 million and $20 million over 5 years as threshold amounts to be assured of significant progress in a few technological areas.

7.4 Stimulate a New Generation of Science Tradebooks

This initiative represents another avenue to improving the science education publishing industry besides the textbook market. Science tradebooks (general-interest books on scientific, mathematical, or technological topics written for a young audience) are a significant source of scientific information to young people out of school and, to some extent, in school. Tradebooks are also, on the whole, a profitable undertaking for publishers. NSF could stimulate production of an outstanding new generation of these books in anticipation of the growing market at the elementary and middle school levels, both among schools (e.g., library purchases) and parents. NSF could accomplish this by competitive mini-grants to science writers, scientists, science educators, and others, who would produce an array of manuscripts across the spectrum of scientific topics. These would then be available to commercial publishers. (Discussions between SEE and the publishers should begin at an early stage in this process).

This option has perhaps stronger appeal to publishers, since it would not require much change in the way they do business but would expand the number of available high-quality tradebook manuscripts. Tradebooks are also inherently less risky for publishers than textbooks.

Tradebooks include a variety of hands-on guides, how-to activity books, punch-out construction books, and many other formats. Subject matter can range not only over any of the sciences, but over mathematics, technology, or interdisciplinary topics, as well. In short, the possibilities are endless.

The quality of currently available tradebooks varies greatly, but a number of people we interviewed felt that the overall level of quality was not as high as it ought to be, or as it once was. Although tradebook publishing has little direct influence over the production of texts or course materials, the possibility of stimulating higher-quality tradebooks allows NSF to contribute to an incremental improvement in the current array of educational resources.

However, the proportion of children (or their families) who purchase science tradebooks each year may not be large. Thus, with the exception of school districts making extensive use of children's science tradebooks (e.g., Fairfax County, Virginia) and families making larger-than-average purchases of such tradebooks, the impact of the initiative may not be great, at least in the short run. Over time, use through libraries could be substantial.

The level of funding needed to elicit worthy manuscripts is relatively low: we estimate that a $10,000 grant per writer would be sufficient incentive to attract good writers and lead to attractive manuscripts. Assuming 200 manuscripts annually as the target (not all of which would later find a publisher), we can estimate a need for $10 million over a 5-year period to influence a broad range of books in all areas.

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Opportunity 8

TO IMPROVE SCIENCE AND MATHEMATICS TESTING AND ASSESSMENT

The large increase in school science and mathematics testing (due mainly to growing demands for accountability, and for higher standards) lends urgency to efforts to develop tests that feasibly capture a much fuller range of knowledge, skills, concepts, and attitudes that good science and mathematics teaching and restructured curricula convey (e.g., higher-order thinking skills). NSF's capacity for supporting cutting-edge R&D, for drawing attention to critical issues, and for encouraging collaboration among diverse groups makes it an appropriate leader in the effort to establish a more sophisticated and sensitive set of testing and assessment tools.

The Opportunity in Context

There is some overlap between what is meant by "tests" and "assessments." However, in general, the purpose of tests is to focus on individuals: their knowledge, competencies, skills or other characteristics. Some tests are used for diagnostic purposes. Most tests are administered to measure achievement or competency (against some criterion). When such tests are given to large groups (e.g., all students in a district) they may be used to compare populations, although this is not usually the primary purpose. In contrast, assessment instruments and programs, while administered to individuals--very often a carefully drawn statistical sample--are used only to focus on groups. Groups might be students of a certain age or in a particular grade, or students in a particular state or even the nation as a whole, as in the National Assessment of Educational Progress (NAEP). States often break out assessment results by school district or even by individual school. Assessment information may be used to change priorities, programs, methods, or other variables; an additional use is to better understand the differences between populations, as well as changes over time.

A Growing Number of Tests and Assessments

During the last decade, there has been a significant increase in the number and types of standardized tests used in connection with elementary and secondary education in all curricular areas. For example, a decade ago there was virtually no minimum competency testing by states, yet:

> In 1985, 40 states were using student minimum competency tests for a variety of purposes and, of these, 25 used the tests for purposes of high school graduation. (CES, 1986)

As part of the movement to scrutinize teacher quality, and improve it where possible, competency testing also was extended to prospective teachers. By 1986, 35 states had enacted laws requiring competency testing for initial certification of teachers (CES, 1986).

In addition to the dozens of competency tests, there are now a host of state programs to assess educational progress, as well as a number of local assessment programs (e.g., Pittsburgh, Detroit). Although mathematics is more commonly assessed than science (an "old" basic versus a "new" basic), even the number of science assessments is large; a recent survey examining state testing in the K-8 curriculum found that 24 states had developed or expected to develop statewide assessments in science at this level (Kellogg, 1987).

Interest has also grown in comparisons among the states that provide a picture of educational achievement nationally and by state. The U.S. Secretary of Education's controversial "wall chart," as well as a proposed expansion of the National Assessment of Educational Progress, are candidates here. Growing concern about economic competitiveness has generated new interest in international education comparisons, such as the IEA studies funded by NSF.

All of this testing comes on top of typical standardized achievement tests (often administered throughout a school or school district), college entrance examinations, and advanced placement examinations. Hence, even without considering the ubiquitous teacher-made test, these trends show an increasing dependence on tests and other assessment instruments as important tools of the trade.

Intended and Unintended Consequences

Tests and assessments are a powerful force in the K-12 education system; consequently, their proliferation can have important effects. Some of these effects--but not all--occur by design. Both intended and unintended consequences need to be monitored.

The mere presence of tests may be important. For example, one researcher observes:

> One science supervisor stated that he had been trying to get elementary teachers to teach science for 23 years but that this [a new, mandated state assessment] was the first thing that had really worked. As this comment implies, testing science gives teachers a strong incentive for making science instruction important in their classroom. (Kellogg, 1987)

However, the same researcher points out that current assessment instruments are poorly adapted to measuring science process skills, such as are learned in a "hands-on" program. It is much simpler to test science knowledge ("facts") than any other aspect of science, and this fact may have a significant, although largely unintended, effect on science instruction, namely, discouraging a hands-on approach and encouraging memorization of facts.

The College Board's Advanced Placement (AP) program provides another example of intended and unintended results. The program has grown much larger than was initially expected (from 104 schools in 1956 to more than 7,200 in 1987), and the number of tests administered annually is still growing rapidly. Some observers believe the AP has helped raise the quality of course offerings in many high schools, has challenged tens of thousands of "ordinary" students (and even significant numbers in inner cities), and has helped keep many top teachers in the classroom (Mathews, 1987). Yet, within the field of mathematics, the single-minded emphasis on calculus by the AP program led to concern within the National Council of Teachers of Mathematics, which included among its recommendations for "school mathematics of the 1980s" the suggestion that "mathematics educators and college mathematicians should reevaluate the role of calculus.... If advanced placement in mathematics is encouraged, it should be a broader concept that includes options in other branches of the mathematical sciences" (NCTM, 1980). In effect, the growing use of AP exams was beginning to shape the mathematics curriculum rather than the other way around; desirable changes in mathematics education involving options other than calculus were being inhibited by the exam.

Despite such problems, many educators believe that tests and assessments play essential roles, and see the increase in testing as a positive response to the call for higher standards (Popham et al., 1985). One important function, some say, is that state legislatures and the public are more likely to support the educational system (e.g., with money) if improvements can be demonstrated using "hard" data, such as rising test results (Kirst, 1986). Other researchers, citing evidence from overseas, argue that tests can facilitate and promote experiential learning as well as encourage innovative instructional approaches (e.g., Tamir, 1974, 1985; Tamir et al., 1982).

Yet the limitations, disadvantages, and unintended consequences of tests are real. Evidently, for those who have made the decisions in recent years, the perceived benefits outweighed the perceived costs, with the result that the number of tests has increased significantly. But to maintain balance in the system, attention also needs to be paid to the problems testing brings.

Even if the purposes are clear and appropriate, tests must be carefully designed to accomplish what is intended. The most important general question that must be asked about tests and assessments is the degree of match between the instructional goals people have set and the ability of tests and assessments to measure them. If the tests and assessments are poor, they may not measure well, or at all, skills, topics, and understandings that are extremely important within a field. As another researcher expressed it:

> Large-scale testing programs tend to drive the curriculum in the direction of test specifications. To the extent that specifications are appropriate to instructional goals, then such an impact can prove beneficial; to the extent

that specifications are antithetical to goals then the results can be detrimental. (Chittenden, 1984)

In fact, it is now widely believed that inadequate tests and assessments are driving the science and mathematics curriculum in inappropriate ways (AAAS, 1986). Some mathematics teachers, for example, are reluctant to permit students to use calculators in the classroom because calculators are not permitted on most standardized tests; yet leaders in the profession believe that some calculator use should occur from the primary grades on (NCTM, 1980). In science, standardized tests and assessment instruments deemphasize laboratory and practical work, a fact that may contribute to the declining use of the science laboratory in schools. In both science and mathematics, simple skills are easier to measure than so-called higher-order skills, a fact that may lead teachers and principals who want high scores to emphasize simpler skills, such as arithmetic computation, at the expense of higher-order skills, such as solving multistep problems.

As long ago as 1975, a prominent advisory group in mathematics education warned that:

> There are unmistakable signs that the testing programs are beginning to influence the curriculum and instructional priorities in many states. Thus the substance, technical design, and use of state assessment have become a central concern for mathematics teachers across the country. (Conference Board of the Mathematical Sciences, 1975)

The gap between what assessments measure and the intended curriculum can be large, and may be a serious barrier to progress in science and mathematics education. For example, the new California mathematics framework emphasizes, among other things, open-ended problems, calculators, and increased use of cooperative learning environments (California State Department of Education, 1985). Unless the state assessment also emphasizes similar settings and measures related skills, principals and teachers may well feel pulled in two directions: teaching according to guidelines, or teaching to the test.

Improving Tests and Assessments

In virtually all subjects, interest in "higher-order skills" has grown enormously, perhaps partly in reaction to the earlier "back to basics" movement, but knowledge of how to test for such skills has grown far less quickly. In the words of an observer:

> A great concern here is the underdeveloped state of testing for science knowledge, particularly knowledge that goes beyond the recall of facts. (Fredericksen, 1984)

The format itself may be part of the problem. Current standardized tests typically involve multiple-choice "objective" items, which, according to some experts, may not provide enough flexibility to include the process of doing science, as well as other important aspects of complex subjects:

> There is an inverse relationship at present between the ease and efficiency of test administration and the extent to which a test assesses student knowledge and performance in a science valued by experts in the field. Unless the content of tests can be improved to reflect the intended learning, and particularly the more complex reasoning skills, tests may serve to reduce the curriculum to covering a broad array of facts without depth of connections. (Raizen, 1986)

In science and mathematics, a few assessments have tried to move away from paper-and-pencil-only tests. Recently, for example, the Second International Science Survey (funded by SEE) included a laboratory section in which students use actual equipment as part of the assessment. There are few such instances, in part because of the higher costs of administering them.

Current standardized tests are limiting in other ways; for example, they usually provide no room for students to construct responses based on their own thoughts. Another observer comments:

> Tests which consist solely of questions for which there is only one correct response constitute an inappropriate assessment model for science education. There is concern that testing in this form will necessarily promote the routine, formalized aspects of science teaching, but will undercut science as a process. (Chittenden, 1984)

As we change the goals of, and the learning environments for, mathematics and science instruction, we also need to change tests. This means, for one thing, that the integration of new technologies into instruction has implications for testing. For example, the state of Connecticut, which is encouraging the use of calculators for solving complex problems in mathematics, is now integrating the use of the calculator into a portion of its statewide mathematics assessment. (As yet, few other assessment programs have adopted this approach.) What will be the effect on testing of widespread use of computers for instruction? For example:

> If a student learns solid geometry in a dynamic, graphic world of a sophisticated work station, how can we appropriately test his or her mastery of this knowledge with a paper and pencil test? (Deringer, 1986)

Another of the problems with existing tests (except those developed for classroom use by good teachers) is that they do not inform instruction. In this regard, even the results of classroom-administered standardized tests are not much help to either teachers or students:

> Tests...typically are not designed to guide the specifics of instruction. We use them primarily as indicators to signal general rises or declines in school performance. They serve as an index to the standards of school, but they are not designed to shape progress effectively toward these standards. (Glaser, 1986)

Others point out the possibilities of technology in improving student and teacher learning from tests. For example, interactive computer tests and adaptive testing (in which the computer quickly matches the difficulty to the test taker's skill) could greatly improve the efficiency of testing (in terms of the number of questions required), leaving more time for diagnostic questions.

The undeniable cost-effectiveness, efficiency, and ease of current multiple-choice, machine-readable, standardized tests have also made it difficult for large strides to be made in improving testing; however, there is some evidence of progress in research and practice. The problems of mathematics and science testing have received the attention of professional societies, the testing industry and others in the science education community. Both the National Council of Teachers of Mathematics (NCTM) and the Mathematical Sciences Education Board of the National Research Council (NRC) are studying ways to produce better evaluation items and improve tests. Professional societies supporting science teachers--the American Chemical Society, the American Association of Physics Teachers, and, most recently, the National Association of Biology Teachers--have all developed model tests for their respective disciplines. In 1985, the Educational Testing Service (ETS) devoted its annual invitational conference to the theme "redesigning testing for the 21st century" (ETS, 1986). In addition, a Commission on Testing and Public Policy is being planned at the University of California at Berkeley.

Innovative testing approaches and instruments have surfaced in a few states and localities. As noted above, the state of Connecticut has developed a mathematics assessment that incorporates the use of calculators. California has experimented with interactive, computer-based testing. Some states (e.g., Michigan) have already created statewide proficiency tests that purport to measure higher-order thinking skills, although it remains unclear to many practitioners what "higher-order thinking skills" are (Knapp et al., 1986).

These are all encouraging signs. However, within the science and mathematics education community, only a few people so far have been involved, and only a very small proportion of the dozens of national, state, and local testing and assessment instruments have been affected by recent efforts. Much more work remains to be done.

The Opportunity for NSF

Efforts at the national level are needed now to improve science and mathematics testing and assessment. The field needs leadership in understanding problems, formulating potential solutions, designing better instruments, and implementing changes.

As a federal scientific agency with strong ties to the world of education, NSF has the capabilities to provide this leadership. NSF's opportunity stems from the confluence of a number of factors: a widespread perception that test and assessment instruments need improvement; their importance to education policy, notably among state policymakers; and the need for very substantial efforts, both on the technical side (designing better instruments) and in implementing and institutionalizing changes. Combined with these factors is NSF's ability to attract highly qualified individuals to work collaboratively on the problems, including subject matter experts (i.e., scientists, mathematicians, engineers, and curriculum specialists), teachers, policymakers, and experts in tests and measurement.

The problems are also of a scale that seems well suited to the resources available to SEE, assuming that SEE's funds are used mainly for R&D or for other highly leveraged activities. (Implementation costs, in almost all cases, would come from state, local, and private sources.) Federal funding could reduce the duplication and waste that might occur if numerous states, localities, and private companies invent and reinvent new test and assessment procedures or methods.

The 1980s have been a period of educational reform. It would be ironic if one set of reforms, the widespread adoption of a variety of tests and assessments intended to increase students' learning, were to inhibit or undermine the realization of goals for increased learning that are part of other reforms. In particular, any efforts to change the curriculum must also address the issues involved in testing. For example, states that have moved to include "science, technology, and society" issues in their science syllabus also need to reexamine state and local science tests and assessments to see whether the tests reinforce or undermine these new curricular goals.

In considering this opportunity, it should be noted that widespread, significant change in the area of tests and assessments may come slowly, even if NSF supports valuable work in the field. To some extent, the school testing apparatus is becoming increasingly rigid as people decide that "accountability" demands the use of narrowly focused instruments that are easily administered and that do not change from year to year--and, consequently, cannot be improved. Sudden and dramatic results are unlikely if this opportunity is pursued. But also because of the increasing rigidity of the testing apparatus, it is appropriate to make an investment in the field now, before further "hardening of the categories" takes place.

NSF (SEE) Programs in Relation to This Opportunity

In recent years, SEE has supported three types of projects related to tests and assessments: projects to undertake large-scale assessments, efforts to improve current assessments, and projects whose goal is the development of new "indicators" for science education. Most of these projects have been supported by the Office of Studies and Program Assessment (OSPA), which has as one of its goals the development and dissemination of indicators for education in science, mathematics, and technology.

This goal has led to investment in various national and international assessments, including the Second International Mathematics Study, the Second International Science Survey, and, under a 1980 grant, the national Science Assessment and Research Project (SARP), which used questions from the National Assessment of Educational Progress (NAEP). To a certain extent, each of these projects included efforts to extend the state of the art in one direction or another. For example, SARP included a broader set of questions than in the past concerning students' attitudes toward science and their knowledge of issues involving science, technology, and society.

OSPA has also made awards specifically for the purpose of finding ways to improve assessments. A 1984 grant to the National Research Council was concerned with improving national indicators for science education, including assessments. Another 1984 grant, in cooperation with the U.S. Department of Education, was to examine more effective means of measuring higher-order skills of high school students in science and mathematics, as part of NAEP. The initial results of these projects (Raizen and Jones, 1985; ETS, 1987a) have begun to influence thinking in the field.

A 1985 OSPA grant was to assess the feasibility of establishing a Mathematics Education Monitoring Center. Among other things, the Center would collect new data on key indicators of progress from a sample of schools, collect and document information about mathematics education reform efforts, and carry out a series of case studies on mathematics education in the United States. These activities could entail the use of novel or improved assessment instruments designed for teachers, students, or both.

Primary support for the National Assessment of Educational Progress comes from the U.S. Department of Education (currently in the form of a grant to the Educational Testing Service). Supplementary support for NAEP (e.g., SARP), as well as support for the American portion of current large-scale international assessments of student achievement, is clearly a priority for OSPA and for SEE as a whole. This seems most appropriate, since these assessments are one of the few national yardsticks we have that are based on large random samples, to say nothing of the richness available from international comparisons involving dozens of nations. Interest in the results remains great, and there is still much to be learned from them. These points seem well illustrated by the publicity and the scholarly symposia that accompanied the recent release of results from the Second International Mathematics Study (McKnight et al., 1987).

In addition to the Studies and Analyses Program in OSPA, several other SEE programs potentially could fund research, development, field trials, or conferences related to new testing and assessment tools. These programs include Research in Teaching and Learning; the Applications of Advanced Technologies program, and Instructional Materials Development. However, to our knowledge, none of these programs has made awards during fiscal years 1984 to 1986 for these purposes. Some instrument development may take place in connection with the development of new curriculum materials (so the developers can test the effects of the materials), but this is not noted in project descriptions, nor has SEE made it a priority in soliciting and funding development projects. SEE might consider encouraging applicants to propose development of new test items as part of the materials development process.

Although assessments are a high priority for OSPA, the only example of SEE funds being used primarily to improve tests or assessment tools (through 1986) is the grant to ETS (grantee for NAEP), which is for examining measurement of higher-order thinking skills (ETS, 1987a, 1987b). Similarly, there are apparently no SEE-funded projects that focus on tests and assessments of teachers (apart from survey research). Our knowledge of the qualifications of current and potential science and mathematics teachers is very limited; a small investment here might be fruitful, given the right project.

A careful reading of the program announcements for SEE programs shows that testing and assessment projects do not fit the guidelines very neatly, except in the Studies and Analyses program; this may be one reason why there are few such projects. In addition, SEE lacks staff with expertise in testing or test development. Another reason for the relative lack of activity by SEE in this area is that the potential applicant pool is somewhat unfamiliar. Although university-based researchers could be expected to be involved in many test-related projects, it is principally state and local education agencies and commercial test-producing enterprises that might be attracted to participate in a program in this area. SEE makes very few awards to state agencies or profit-making companies, and they, in turn, are not very familiar with SEE and its operations. To increase interest in this area, SEE might issue a targeted solicitation and send mailings to prospective applicants, such as state and local education agencies.

Promising Initiatives

In considering alternatives for investment, NSF must decide what kinds of science testing and assessment it will include in the scope of its activities. It may be tempting for SEE to concentrate (as it has so far) on large-scale national and international assessments such as NAEP or SIMS, which everyone agrees is an essential federal responsibility. Nonetheless, we believe that NSF should broaden the scope of its investment beyond this type of assessment to include state and local science testing, wherever feasible.

The argument for retaining a focus on national assessments is sound. For at least the past 20 years, the federal government has had responsibility for funding NAEP, as well as partial responsibility for international studies/assessments. Although the U.S. Department of Education is the principal funder of NAEP (for which a sizable 1988 budget increase has been requested), NSF (SEE) has supported some important related projects. Funding for international studies has come both from the U.S. Department of Education and from NSF. In these two domains, federal agencies bear responsibility for funding all aspects of the assessment process, from item development to data collection to analysis and dissemination. Because both the national and the international assessments have provided unique and useful data to policymakers and the public, continuing to support these efforts seems an important element of future policy in science and mathematics education.

In addition to their other functions, the large-scale national and international assessments, which involve hundreds of schools and thousands of students, provide a model for assessments at the state and local levels. Techniques first used at the national level (e.g., matrix sampling, or the collection of associated information on classroom interaction, as in the Second International Mathematics Study) have been adapted for use at the state or local level. This provides an additional reason for doing the national and international assessments well.

Important as these activities are, other testing and assessment practices at the state and local levels, which are having important effects on science education, ought not to be ignored. Currently, these state and local instruments (including some commercial tests that are adapted to local use) seem to provide a more limited assessment of skills and understandings than necessary and are not getting sufficient scrutiny. The instruments used vary from commercial, standardized tests (often used to rank schools in a district by aggregate mathematics and reading scores), to the products of nonprofit firms (e.g., the National Teacher Examination produced by ETS and used by many states to test prospective teachers), to unique instruments produced by states and localities. SEE can play a constructive role in this field, which would help to broaden the pool of young science learners.

NSF is well situated to bring more attention to the issues involved, using a variety of means (including supporting others who would manage the activity). The Foundation is also very well equipped to support research and development projects leading to the use of improved instruments, and to assist in disseminating widely the results of experimentation, such as new methods, instruments or procedures. These strengths of NSF correlate closely with the mission and capabilities of SEE and the needs of the field.

Three promising initiatives are described. The first is for NSF to encourage a national dialogue on tests and assessments. The second is to solicit applications for projects closely linked to improving a particular current test or assessment. The third proposed initiative is for SEE to support R&D leading to prototype instruments that test or assess important science and mathematics skills and understandings inadequately treated at present.

8.1 Stimulate a National Dialogue

The number of people and organizations involved in science and mathematics testing and assessment is enormous, including 50 chief state school officers, state legislators, state education agency staff, local superintendents, staff of testing firms (ETS, ACT), and so on. Many of these people would welcome the opportunity to learn more about how well or poorly tests and assessments measure a variety of science and mathematics skills and understandings, and how the instruments might be improved. Given the recent proliferation of testing at the state and local levels and the variety of new instruments, as well as the diverse uses to which the information is put, virtually everyone attending a conference on this subject would learn something new. Conferences, symposia, and commissioned papers are among the means SEE could use to begin a national dialogue on the uses and abuses of tests and assessments.

This initiative would not be particularly expensive. Half a million dollars annually would permit a large conference, several smaller ones, and some commissioned papers to be arranged. To focus on the issue in a sustained way, SEE would need to make this a multiyear activity, either by supporting subsequent conferences or by following the national dialogue with one of the other initiatives described below.

Important agencies that could be involved in a national dialogue include (but are not limited to) the following: ETS and the College Board; the Council of Chief State School Officers; the Education Commission of the States; the National Science Teachers Association; the NCTM; the Mathematical Sciences Education Board; the International Association for the Evaluation of Education Achievement; and some or all of the 50 state education agencies. Most of these organizations, as well as many local education agencies, have first-hand experience with tests and assessments in science and mathematics. SEE might work directly with the interested participants or (more likely) might provide funds to the NRC or some other institution to coordinate the national dialogue.

In this domain, the practices of other nations are of interest. In England, for example, the national assessment in science includes a laboratory section in which students use actual equipment. (Using the English assessment as a model, the International Science Survey, funded by SEE, has recently incorporated practical tasks, too, while NAEP is experimenting with them.) Israel has been using practical and other innovative tests in the science matriculation examinations, especially in biology (e.g., Tamir, 1974, 1985; Tamir et al., 1982). Exceptional practices such as these, whether in the United States or elsewhere, would be likely candidates to highlight in a national dialogue.

8.2 Fund Projects Linked to Current Tests and Assessments

This initiative would begin with the many existing tests and assessments in science and mathematics used at the state and local level, and the need to make them as consistent as possible with actual instructional goals. SEE would solicit applications for projects to improve science and mathematics tests and assessments, using a separate announcement (as with the recent elementary science solicitation). A commitment of \$8 million to \$12 million over a 5-year period might fund 30 to 50 projects for up to 3 years, on the assumption that projects of this type are relatively inexpensive, requiring principally the time of a few experts and some field tests. Ideally, projects would be dispersed as widely among the states as possible and would be aimed at the most visible and influential tests in use within the state (especially state-level tests, but not limited to these).

This initiative aims to bring current practice in testing and assessment up to the state of the art. SEE would need to decide whether the state of the art is sufficiently developed to warrant a large expenditure on aligning tests and assessments across the nation more closely with the best that is possible. Where the state of the art is not well developed, an initiative focused on developing prototypes (described in the section that follows) makes more sense.

Any review of current tests and assessments must begin with such basic questions as: How well is the instrument matched to the purpose it is supposed to serve? Are the results too crude to be useful? Are comparisons (with national norms, other states, other districts, over time, etc.) derived legitimately? Is the match between curricular goals (e.g., topics, skills, attitudes) and the instrument reasonable? Are there unintended consequences to using the instrument that can be remedied? Answers to these and other questions would determine what next steps are advisable for anyone wanting to improve a current instrument. The presumption seems strong that a great many large-scale test and assessment programs would not pass all of these "tests" (CBMS, 1975) and would benefit from revision.

Recipients of awards would be principally state and local education agencies. Few of the former tend to be recipients of SEE awards. For this reason, special efforts might be made to publicize the solicitation within the community of potential applicants (e.g., through the Council of Chief State School Officers).

Not-for-profit institutions, such as ETS and the College Board, would also be eligible applicants for grants. This opens the possibility of grants to improve SATs, the Achievement tests, and AP exams.

An important decision for NSF would be whether to include private, profit-making companies as potential grantees. Standardized tests used in elementary schools are typically produced and marketed by private-sector companies. SEE is not precluded from making grants to such companies, but it rarely does. To the extent that tests produced by these companies affect decisions about curriculum and instruction, it is important that their content closely match state and local education goals. However, one observer of trends in science testing has noted a widening gap between commercially available tests and current testing practice; for example, commercial tests include little on science process understanding or science attitudes (Welch, 1985).

8.3 Develop Prototype Instruments

Existing test and assessment instruments are good at capturing basic skills in mathematics and knowledge of factual information in science. How good they are at examining higher-order thinking skills, practical work, and problem solving of a non-routine sort is open to debate. Few would deny that improvement is needed if instruments and educational goals are to match.

This initiative would focus on development of prototype instruments in science and mathematics that extend our ability to test what we hope to teach. As with the preceding initiative, a targeted solicitation would be an appropriate funding mechanism. We estimate that $2 million to $3 million annually over 5 years would be necessary because R&D projects such as these are more expensive and more time consuming to develop than adapting what is already known. Furthermore, there are various forms of testing that deserve careful development to adapt them for science and mathematics applications--among them, practical tests (e.g., Tamir, 1985), interactive testing via microcomputers, adaptive and free-response testing (Ward, 1986), and school learning exhibitions (Sizer, 1986).

Whereas some projects might be highly exploratory and open-ended (leading to a general improvement in the state of the art), others are likely to be tied to specific instruments already in use. For example, a particular state, working with a local university, might propose to develop a practical and useful method for incorporating the microcomputer into its 11th grade mathematics assessment.

Eligible applicants would include not only state and local education agencies, but also any other not-for-profit institutions. These would include ETS and the College Board.

In the event that private-sector firms apply for funding, an appropriate requirement would be that results be publicly available. Although there are public benefits to be derived from the use of improved test instruments by private firms, publicly funded research and prototype development should remain public, in the absence of overwhelming reasons for a different policy, such as national security. Although specific items might remain proprietary, more general methods and procedures should be placed in the public domain.

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Opportunity 9

TO SUPPORT CONTENT-RELATED LEADERSHIP FOR ONGOING STATE REFORM OF SCIENCE AND MATHEMATICS EDUCATION

The broad array of educational reforms initiated by state legislatures and education agencies over the last few years have defined much of the agenda for improvement of science and mathematics education. However, these "excellence" reforms have often been enacted without careful attention to the substance of what students are being taught. The momentum of these reforms and the relatively short window for sustaining a reform thrust (perhaps 5 more years), combined with a vacuum in subject-matter leadership in many states, provide NSF with important and immediate chances to help direct and translate general reform energies into specific educational changes contributing to the overall goal of broadening the pool of competent and interested young science learners.

The Opportunity in Context

Following the wave of national reports urging major reforms in education, among them the NSB (1983) report *Educating Americans for the 21st Century*, many states have enacted sweeping legislation to increase graduation and accountability requirements, alter teacher certification procedures, raise teacher salaries, and revise and update curricular frameworks, to cite some of the most common actions. In the eyes of one observer:

> State governments have become what some have described as the fulcrum of the reform movement. (White, 1983)

Although typically affecting many aspects of education, these reforms have often zeroed in on mathematics and science as a high-priority concern. For example, since 1980, 45 states and the District of Columbia have changed the requirements for earning a standard high school diploma: 42 states increased the number of years of mathematics study required for graduation; 34 states did the same in science. Requirements for mathematics and science increased more than those for any other subject, leading to an increase of about 20% in the number of course sections in science and mathematics between school years 1982-83 and 1984-85 (Kirst, 1986). Furthermore, for the first time six states enacted a computer literacy requirement for high school graduation (Pipho, 1986).

In addition to this legislative activity, state boards of education have also been extremely active; more than 200 state-level task forces have been in operation since 1983 focusing on education issues. Two major themes in this buzz of activity are more rigorous academic standards for students and greater recognition and higher standards for teachers (Pipho, 1986).

The Need for Follow-up to State Reform Initiatives

New regulation or legislation, however, is only a first step toward local improvement of education. For example, the new increases in high school graduation requirements in science and mathematics will not, by themselves, improve science and mathematics curricula, instructional practices, teacher quality, or the motivation of students who would otherwise have dropped these subjects. If local districts do not have an understanding of what is needed and how to achieve it, as well as financial and other support for educational reforms, states' actions will not be translated effectively into useful changes in the nation's classrooms.

Leaders at the state level are very well aware of the limitations of mandates. The State Superintendent of Schools for Maryland, also the current President of the Council of Chief State School Officers, recently remarked:

> At the state level, we have created the structure of a difference in the schools, but not yet the substance. That lies ahead. (Hornbeck, 1987)

The very fact that substantial change lies ahead, and is needed, presents NSF with an opportunity. Furthermore, some state departments of education are hard pressed to implement and monitor the multitude of reforms mandated from above, working, as one observer suggests:

> on a shoestring budget with a staff that was often hired to monitor the flow of federal dollars rather than to [work with and] track the implementation of reform at the district level. (Pipho, 1986)

Very rapid change such as has occurred at the state level also leads to a bandwagon effect; for example, one former state supervisor we spoke with was convinced that many states instituted residential science and mathematics high schools as a direct result of the creation of such a school by the state of North Carolina. (The bandwagon effect may have good or bad effects, depending on the quality of the model and the needs of other states.) The fact that there has been nearly simultaneous reform activity in most of the states means that many states are less likely to learn from others' experiences, and may instead simply adopt what is popular or spend time reinventing existing wheels. Rapid change may also be more likely to lead to adoption of dubious practices, such as the creation by one state of a computer data base to be used by local schools, consisting of thousands of "validated" test items in science whose quality has been questioned by some observers.

Because the state reform movement is largely a product of the last 5 years, relatively little is known about the individual or collective effects of these efforts, the interaction among reform provisions, or how localities are responding to the situation. (A good example would be how state mandates on the uses of calculator and computer technologies in mathematics in California and Connecticut are affecting instructional practices and student outcomes.) More importantly, state educational agencies are often at a loss as to how to proceed and express eagerness for help and advice. Certain basic information is available--for example, descriptive surveys of the states' legislative reform provisions have been done (e.g., *Education Week*, 1983; Education Commission of the States, 1983; Armstrong et al., 1986), and the Council of Chief State School Officers has a data base to coordinate information about the progress of state reforms, as have several of the states. But the diversity of these reforms adds to the questions about appropriate courses of action, and highlights the need for additional studies (Hurd, 1986).

Outside state governments and the educational system itself, there are various efforts to support state reforms, but few are initiated by groups or agencies concerned about the nation as a whole. True, the U.S. Department of Education allocates to states block grant funds for the full range of school improvement activities (under Chapter 2 of the Education Consolidation and Improvement Act) and also for mathematics and science teacher training, specifically (under Title II of the Education and Economic Security Act). Beyond that, the efforts of national-level groups have typically focused on policies in the federal arena or on local concerns--for example, through various services offered by professional societies like NSTA and NCTM to their membership. Within states, locally based foundations, citizens' groups, and professional societies have often rallied to the cause, but typically with very broad education reform goals in mind, rather than with attention to one specific segment of the instructional program, such as state-level policies in science or mathematics.

A few national-level professional groups have been active in monitoring state education reform, among them the Council of Chief State School Officers, the Education Commission of the States, the National Association of State Science Supervisors, and the National Governors Association. Also, the U.S. Department of Education followed the course of state reforms for several years in such publications as *A Nation Responds* (U.S. Department of Education, 1984), but has not done so for some time. However, these groups are generally unable (or unwilling) to grapple with needs on a state-by-state level, or to study any state or group of states in detail. (One exception is that Title II of the Education for Economic Security Act requires states to submit to the U.S. Department of Education assessments of their needs for teacher training in science, mathematics, and computer education; some of the submissions are very informative, although uneven.)

Despite the unfinished character of state reform and the paucity of information that is available about outcomes, the importance of state-level actions cannot be overestimated. In addition to their legislative activity, in 1979 states for the first time became the primary funders of public schools, exceeding even the role of local districts (Center for Education Statistics, 1986). Taking together the power of the purse and the mandates for reform, it is clear why states now dominate the agenda of education reform (White, 1983).

As states assume a more assertive posture in this area, their ways of interpreting, enforcing, and reinforcing new requirements will have a great deal to do with the way local science and mathematics teachers are selected, how they set their priorities (e.g., by choosing material that most closely approximates the state curricular scope and sequence), and how they conduct instruction (e.g., by emphasizing the topics or skills that state assessments and accountability tests cover). States' actions also have profound indirect effects, most clearly seen in the way state science and mathematics frameworks, which set forth curriculum expectations, serve as guidelines for textbook publishers (Capper, 1986).

In addition, states' requirements pose new dilemmas for local science and mathematics programs, such as how to organize course offerings at the high school level so that the full range of students may benefit from increased requirements. Many localities need a great deal of help, and the science and mathematics education personnel and resources at the state level are often a logical place for them to turn. Because state personnel represent a high-level entry point, NSF can gain significant leverage by providing assistance to key groups and individuals at the state level. These include not only state supervisors of science and mathematics, but also staff from the governors' offices, state boards of education, and associations of local school superintendents, to name a few key groups.

The Opportunity for NSF

As the most prominent federal-level supporter of science education improvement, NSF has the opportunity to contribute greatly to the state science education reform movement in several ways:

- By supporting individual states with aspects of reform for which some lack expertise (e.g., the revision of state science curricular frameworks, or provision of assistance to districts who wish to expand their use of educational technology in mathematics and science instruction), particularly in cases where these states could serve as models.

- By helping states learn from one another's experiences and from the natural variations across states.

- By helping to identify and demonstrate the aggregate effects and gaps in the collective efforts of the states.

Although NSF cannot intrude on the states' constitutionally defined prerogatives in managing public education, the Foundation has a chance to support leadership activities in this area.

NSF exhibits four qualities that make it well suited to assist and facilitate state efforts in science, mathematics, and technology education. First, by virtue of its grounding in state-of-the-art developments in both science/mathematics curricula and the disciplines themselves (including engineering), the Foundation can support people who have content-related information that is needed for decisions related to curricula, testing, assessment, and other concerns. Most important, through the curricular work it supports (see Opportunities 1, 2, and 7), the Foundation can help develop a statement of what in science and mathematics is important to teach and what pedagogy is appropriate. Second, NSF's prestige and concern for excellence provide its awardees with particular respect within both the science and the education communities. A former state education agency specialist observed:

> "NSF is very respected among state-level education people. The Foundation doesn't realize how much local and state educators want it to tell them what's good. There is little sense that NSF is a government agency."

Third, the Foundation's central position and national analytic capability in science education (both within SEE and among the analytic projects it supports) enable it to assemble, compose, interpret, and distribute appropriate information across states. Fourth, the Foundation commands more flexible discretionary resources than most states or the relevant national associations have at their disposal for carrying out the difficult technical or developmental aspects of the reform effort.

National reform movements afford a relatively narrow window of time in which positive energies are mobilized toward goals. To the extent ambitions overreach perceived accomplishments or progress is slow, the public may become disillusioned. We estimate that state-initiated science education reforms have perhaps up to 5 years in which substantial changes can be brought about before the necessary energy dissipates. Already, attention within states and local districts is shifting from making policy to implementation. The most appropriate time for NSF to act is early in this process, before curricular frameworks become set, mandatory testing procedures are in place, teacher certification requirements have been established, and in general each state's implementation process is too far along to change very much.

Nonetheless, the Foundation's role in support of state reform in science, mathematics, and technology education must acknowledge the limits on federal involvement in state educational policy and operations and the differences that distinguish NSF's functions from those of other national-level entities, particularly the U.S. Department of Education (ED) and the Council of Chief State School Officers (CCSSO). Many aspects of the state reform movement are outside the mission of any federal agency to regulate or determine, such as the setting of hiring standards, graduation requirements, course content, and the like. Some other aspects are best left to ED (or other agencies); for example, ED's multi-million-dollar block grant funds for school improvement are allocated by formula to all states, whereas NSF is prohibited by law from dispensing funds in this fashion. Finally, NSF must keep in mind that state-level initiatives may be a long way from the classroom; its first priority should remain on contributions to activities that most directly affect classrooms, teachers, and children.

Acting to support leadership in state educational reform of science and mathematics is largely a new role for NSF. It is an important, timely role--and one that NSF is well qualified for--but it is a role that NSF is only beginning to perform.

NSF (SEE) Activities in Relation to This Opportunity

To date, NSF has done relatively little to support state science education reforms directly, beyond the initial stimulus to reform represented by the NSB (1983) report. The few projects in the last few years that have aimed at the state level emphasize network development and information gathering. One unusual example of direct support for state reform is the "Minnesota Mathematics Mobilization," funded in fiscal year 1986, which is an effort to bring together teachers, academics, leaders in research and industry, and government officials to increase support for mathematics education in the state. A large variety of activities, ranging from a statewide newsletter to a speakers' bureau, are supported. Support is also provided by NSF for a project being undertaken by a similar, preexisting state network, the Colorado Alliance for Science. A 1987 grant to the state of Virginia for some statewide assessment procedures in science provides a third example.

A few projects have been supported by NSF to set up monitoring systems at the national level that may also have implications for states. For example, support has been provided to establish a School Mathematics Monitoring Center at the University of Wisconsin for the purpose of "gathering, analyzing, and reporting data on the response of schools to current reform efforts." The degree to which data will be provided at the state level is as yet unclear. Similarly, the National Academy of Sciences is developing a coordinated monitoring system for precollege science and mathematics education, which is also not explicitly tied to state-level data. NSF has also supported the Council of Chief State School Officers in its efforts to coordinate state assessments of needs for teacher training in science and mathematics (needs that are met, in part, by the Title II funds distributed by the Department of Education) and to set up a data base for tracking the progress of state reforms in science and mathematics.

Finally, a few grants under SEE's Science and Mathematics Education Networks program are helping to expand the information-sharing capacity among states--for example, a grant to the National State Science Supervisors Association to establish a telecommunications network among state science education specialists (and ultimately with local districts). Examples of information available via this network include abstracts of curriculum guides for all 50 states, up-to-date legislative and judicial activities relevant to science education, messages, and surveys. Other network development projects are building state or regional linkages between a variety of actors--the private sector, professional societies, etc.

Collectively, these efforts provide some data (or the mechanisms for gathering and interpreting data) and a few demonstrations of useful networks. These activities, particularly the state-level network development efforts, are effective as far as they go. However, the Council of Chief State School Officers project to coordinate states' needs assessments has proven quite difficult, and the monitoring systems are not yet producing state-level data. Most SEE grants involving the states (except those involving monitoring) are to assist individual states, rather than to support work with many or all of them. Yet grants to assist states remain rather unusual; other entities, notably colleges and universities, receive the bulk of SEE's funds.

But even if these investments in networking and information collection were more extensive, they would not constitute the "content-related leadership" that is at the heart of this opportunity. NSF (SEE) has yet to engage significant actors at the state level in dialogue about science education goals, promising approaches, or solutions to the policy dilemmas confronting them. Only by doing so will the Foundation exert the kind of state-level leverage that is needed. In the words of one state science supervisor, his counterparts in many states are "begging for this kind of help." NSF has yet to exercise the leadership necessary to mount an adequate response to this demand. To be sure, SEE's plans for the future show a growing awareness of the importance of educational reform, which is one of the stated priorities for future grants in the Studies and Analyses program. But state-level people want--and deserve--more than the results of these studies are likely to yield.

The low level of NSF's funding in this area has reduced its ability to assist the state-level reform effort significantly. NSF's approach to date is explained partly by lack of familiarity or engagement with the key state-level actors. Also, state education agencies do not often apply to SEE for funds and are not always sure how to do so. Whatever the explanation, there is now an opportunity for NSF to help broaden the pool of competent young science learners by supporting additional projects aimed at leadership in state reform.

Promising Initiatives

We describe below three promising initiatives that address this opportunity. All three initiatives represent attempts to improve the current system, rather than being longer-term investments in knowledge or model development (although some longer-term understanding will result). Long-term investments make little sense for NSF here, even though the intended impacts of state reforms themselves are both fundamental and long-term.

Each of these investment initiatives attempts to reach all states, rather than to demonstrate approaches in one or a few. Nonetheless, as we have indicated, because of states' tendency to "follow the bandwagon," there are times when investing resources in a few states can help bring about change in most of the rest.

9.1 Promote a National Dialogue on State Science and Mathematics Education Policies

NSF can make a significant contribution to the momentum and direction of the state reform movement, with only a modest investment of resources, by supporting public debates and discussions of state science and mathematics education policy issues in national forums. Some of this information exchange and debate happens naturally, but unless efforts are made to examine specific state-related issues relevant to science and mathematics education, they are unlikely to be brought into sharp focus for the variety of actors who determine state education policy (e.g., governors, chief state school officers, science advisors, state education agency personnel, state legislators).

NSF might form a State Science Education Issues Task Force and/or host, or fund others to host, a series of well-publicized forums (perhaps on a "League of Women Voters" debate model) for discussing issues and policies affecting science education at the state level. There are a great many such issues, including:

- The design of state science and mathematics assessment programs.
- Testing programs in science and mathematics, including those for teachers and for students.
- Science and mathematics teacher certification standards.
- State incentives for schools and districts to achieve excellence in science and mathematics education.
- Science and mathematics for students not in the academic track.
- Support for districts on the appropriate use and integration of technology in science and mathematics programs.

Examples of broader themes appropriate for the forums or task force to explore include these: "Four Years After the NSB Commission Report: The View from the States" or "State Economic Competitiveness and the Quality of Education in Science, Mathematics, and Technology."

This kind of activity draws on NSF's central position and its acknowledged leadership role in science and mathematics education. The activity fills a vacuum that no state can fill (although certain states like California and Connecticut clearly exercise leadership). National groups are not likely to fill the void either, since organizations with the best ties to the states (e.g., the National Governors Association, Council of Chief State School Officers) tend to focus on issues broader than these. If undertaken soon, this kind of activity can bring considerable visibility to these issues with a small investment of funds.

Nevertheless, NSF must proceed with caution in any activities that thrust it into the public eye. Some aspects of state science and mathematics education policy are controversial to the point that NSF might be hurt by association with them--for example, the debate over creationism vs. evolution in the biology/life sciences curriculum. Discussion of topics such as textbook adoption policy, which is so clearly within the realm of state and local discretion, should be approached in a way that does not place NSF, as stimulator of debate or funding agent, in the position of advocating particular content.

Sponsoring activities such as these to stimulate and focus discussion does not require great sums of money. Estimated costs are between $4 million and $5 million over the next 5 years (assuming $3 million to $4 million for the ongoing activities of a national task force, and up to $1 million for periodic public forums).

9.2 Support Technical Assistance to State Science and Mathematics Education Planners, Specialists, and Policymakers

The state-level people who translate reform legislation into programs, guidelines, and resources of various kinds--people who are typically located in the state department of education--are pivotal figures in the state reform process, and in many states they are very much in need of help. Various types of people should be included in the activities supported by this initiative. In addition to science and mathematics specialists, other mid-level staff (e.g., those responsible for research and evaluation, staff development, educational technology) have an important influence on science and mathematics education policy. Above them, top-level policymakers (e.g., the state superintendent, state board of education members) determine the broad contours of policy that affect the teaching of science and mathematics. Finally, governors and their staffs are increasingly involved in educational policy matters, not only in initial reform legislation but in the ongoing to-and-fro concerning the implementation of reforms. Collectively, these types of individuals must deal, directly or indirectly, with questions such as:

- What does "science for all" mean in terms of state curricular frameworks? How can students with varying abilities and in very different programs best be served? How many substantively different science and mathematics courses should be offered?

- What are the best available materials for junior high school life science or high school physical science (including textbooks, supplementary modules, films, computer software, etc.)? What criteria should be used in choosing materials?

- What should be the content of mandated state assessments, competency tests, or other statewide examinations? How should content be selected, and by whom? (See also Opportunity 8, on testing and assessment.)

- How can states help localities to adapt the new technologies they acquire to specific levels and topics in current science and mathematics instruction?

- How can reliable data about the qualifications, supply, and demand for science and mathematics teachers be gathered and updated? How can states best help districts to meet needs for inservice teacher training?

These are clearly difficult questions. By strategically funding appropriate intermediaries (e.g., professional associations representing national-level groups, regional consortia), NSF can engage in the following kinds of activities to help these people do their job:

- Continue and expand network development (as SEE is now doing).

- Conduct ongoing national "seminars" (or other forms of technical assistance) for all state science/mathematics education personnel engaged in content-related issues in science and mathematics.

- Support the review of state curricular frameworks--for example, by supporting a referral service of experts in content and curricula.

NSF's particular strength in all these activities is to draw on and facilitate the exchange of ideas across states. There, the Foundation's national perspective comes into play. It may also work with individual states but is most justified in doing so when implications for other states arise from such assistance.

Through this initiative, with modest resources, NSF can affect many of the key state-level education personnel in all or most states at a time when these individuals are increasingly influential in determining the kind of science/mathematics instruction that takes place in the classrooms across the state. For example, to the extent that NSF can help states ground their science/mathematics education policies in the best current thinking about curriculum content or translate increased graduation requirements into courses useful to all students, it will have achieved something with far-reaching ramifications. Also, there are likely to be important spin-off effects; for example, the connections made at seminars or forums may lead to exchanges of assistance or materials that go far beyond the agenda topics.

This initiative has several important drawbacks, including:

- State science/mathematics education planners and specialists may be at a bottleneck of sorts--there are limits on how much they can do to influence local districts.

- Not all states place a high priority on mathematics and science education. In such cases, NSF's support may accomplish little.

These kinds of activities could be done effectively in a large number of states with an investment of between \$6 million and \$9 million over a 5-year period (assuming up to \$1 million annually for network activities, and up to \$4 million across 5 years for national seminars or other forms of assistance).

9.3 Take Advantage of the Natural Laboratory of State Reform: Learning from the States' Experiences

The rush of activity by the states opens up a new and timely line of inquiry that has immediate usefulness to the states and to others participating in the reform process. NSF can help states learn about what is and is not working by inviting a series of studies that (1) compare alternative approaches to similar reform measures across states (e.g., develop case studies of how six to eight sample states have implemented new science and mathematics teacher certification policies); (2) identify successful alternative approaches to the full range of state science/mathematics education policies; or (3) aggregate and synthesize information about each state's efforts into a larger picture of the states' contribution to meeting the national challenge in science and mathematics education.

A question remains regarding how we will know what states have accomplished in the improvement of science and mathematics education. Although one might assume that the states are carefully monitoring the effects of the various reforms, in fact one experienced observer of states' activities in education is concerned that far too little is being invested in assessing the outcomes of education reforms, noting that "only a few states, such as South Carolina and Tennessee, have earmarked significant money for in-depth analyses of the impact of the reforms" (Kirst, 1986). There is, then, a definite need for closer examination of outcomes across the states.

This initiative takes advantage of the unusually rich variation among the states in approaches to persistent and difficult problems in science and mathematics education. Although the "experiment" is unplanned and precise comparisons cannot be made, a great deal can be learned from comparative research of this nature, just as international comparisons of achievement in science and mathematics have provided new insights into American education. In fact, a recent study of educational reform in seven states concluded (among other things) that "there remains an important state government need for applied research assistance to guide policy decisions" (Chance, 1986).

Disadvantages of undertaking this initiative include the chance that it will be difficult to draw sound conclusions from the comparative data, and the possibility that states will not respond even to clear and positive findings, either because their own reforms are firmly in place or because conditions from state to state differ so greatly.

These kinds of studies require a relatively low investment of funds: over a 5-year period, $2 million to $3 million for aggregating and synthesizing data across states; $2 million to $3 million for in-depth comparative studies across states; and $1 million for investigating and documenting exemplary state approaches, for a total of between $5 million and $7 million.

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Opportunity 10

TO EXPAND INFORMAL SCIENCE LEARNING RESOURCES AND ENHANCE THEIR CONTRIBUTION TO SCHOOL-BASED PROGRAMS

NSF's decade-long involvement in promoting informal science education through broadcast media, museums, and other institutions has helped to stimulate the development of learning resources that make science ideas and activities more accessible to a broad audience. In addition, these resources provide important alternative opportunities for motivated young learners to pursue their own science interests.

The Foundation faces an opportunity that is partly of its own making--it can continue and extend the work it has already done in informal science education, with special emphasis on further supporting innovations, broadening the impacts of current successful programs, and cultivating new arenas (e.g., youth groups and recreational associations). In addition, as informal science learning experiences become more widely available, their potential as a resource to school-based science and mathematics programs increases. NSF has the chance to help explore ways to make these resources complement school programs more effectively.

The Opportunity in Context

As noted in the introduction to this volume, the way most young people are introduced to mathematics and science in our educational system does not successfully lead them to develop an interest in, or a positive attitude about, the study of these subjects. Growing up in a family environment and a culture in which discussions, activities, and interest in scientific ideas are largely absent, most young people fail to develop a foundation for learning about the natural world. Worse, many learn at an early age to avoid anything that has a scientific or mathematical flavor.

The sequence and nature of learning experiences in school has much to do with students' attitudes and performance. At the elementary school level, students have relatively little exposure to the natural sciences (see Opportunity 2a); in middle school, they typically encounter more science but it is often inappropriate to their needs and interests (Weiss, 1986). Students in high school make choices among science courses that are typically aimed at individuals preparing for college-level study in the sciences (see discussion under Opportunity 2b). The pattern in mathematics is similar, even though some aspects of mathematics, such as arithmetic computation, are taught extensively at the elementary school level (see discussion under Opportunity 1). These early experiences do not give students a good grounding in mathematical thinking, nor an interest in acquiring it.

The Importance of Informal Science Learning

These failures are a basic reason why the pool of competent and interested science learners by the age of 18 is so small. But, it is a mistake to lay the blame solely at the schoolhouse door. For many individuals, out-of-school learning experiences may play at least as important a role as in-school learning in fostering scientific interests and literacy.

> There are at least as many opportunities for youngsters to learn science outside of school as in.... Further efforts outside of school may be more productive than in school. A strategy of using existing programming structures (such as 4-H, public television, public parks programs) and finding personnel already strongly committed to (informal) science education appears to have untapped potential for improving science education in America. (Stake and Easley, 1978)

The problem of students' opting out of science and mathematics can be restated in broader, more cultural terms. One science educator we interviewed put it this way:

> "We live in a scientifically and technologically driven economy, and we live in a culture that throughout this century has been identified with science--the atomic age, the space age, the computer age, etc. The total resources (formal and informal) for science education become a question of the education of children for living in a science-technology culture. This makes science education a matter of acculturation--so far a little-recognized goal. Formal and informal education are ways (properly conceived) of making it possible for children not to be foreigners in their own culture.... (For these reasons) I cannot be unbiased about the importance of informal education in the sciences."

Informal learning experiences are the basic mechanism of any acculturation process. Children that grow up in families in which science and mathematics interests are fostered gradually learn the basic elements of the culture. The importance of the family and immediate culture in determining lifelong motivation and achievement of America's youth is being increasingly demonstrated in the research literature (e.g., Bock and Moore, 1986) and in regard to science and mathematics in particular (e.g., Stevenson et al., 1986).

A recent NSF publication--*Profiles in Excellence* (NSF, 1986)--outlines the background of first-year graduate students chosen for the prestigious NSF graduate fellowships. What is most striking about these profiles is the extent to which parents and out-of-school experiences (and, occasionally an exceptional teacher) play a large part in these students' determination to pursue scientific careers.

The rationale for this opportunity rests on an understanding of the important, even critical role that informal learning experiences can play in the acculturation process. More specifically, a rich environment of informal science learning resources might help bridge the present gap between the science-deprived background the schools.

The Opportunity for NSF

NSF is an appropriate agency to support work in this domain. The Foundation has a national perspective and a mandate that is compatible with the nature of many large informal science education efforts (particularly the development of science broadcasts) that are inherently national in scope. Indeed, some informal science projects (such as national PBS science series for children) are very difficult to sustain without NSF support because they require very large levels of funding and don't appeal to local funding sources. The informal education arena is also one in which NSF's unique scientific and educational strengths may be applied. Most informal science efforts require the collaboration of scientists, educators, and media specialists (see Opportunity 6)--a collaboration that NSF is ideally positioned to arrange. Finally, as a result of its two-decade history of working in this area, NSF has developed a unique expertise and sophistication in funding informal science education projects (NSF, 1981).

By comparison with the difficulties and challenges the Foundation faces in improving school-based science programs, informal science education may be easy for NSF to influence and improve, for various reasons:

- Investments that fund exhibits or broadcast productions, for example, are "close to the consumer," with funds going directly for learning resources that are immediately and widely available to the learners.

- The informal education arena involves few intermediaries and thus offers a more straightforward and efficient way to provide people with high-quality science resources.

- Because the resources are to be used in a public, free-choice environment, there is greater freedom and latitude available than in producing materials for the school setting.

- The level of resources that NSF can draw on are of the order of magnitude needed to have considerable impact on the practices and capabilities of the informal science education community.

NSF's support for informal science educational opportunities is timely. For the last decade, public interest in science and use of informal science resources have risen dramatically. The number of science centers in the United States has more than doubled in 10 years. Science and nature broadcast shows now abound on public television. Science periodicals and tradebooks are increasingly popular. A recently completed study (Riccobono, 1986) noted that informal learning about science, health, computers, and nature rank highly across all age groups. For all of these reasons, national studies of science education in the United States have increasingly pointed out the potential of informal science education resources (NSB, 1983; Weiss, 1986; Stake and Easley, 1978).

Informal science education is an appropriate focus of NSF investment because it plays an important role in fulfilling another of the Foundation's goals: developing an adequate supply of scientists and engineers. The early experiences of children and adolescents are crucial to their decisions to enter scientific work. Physicist Richard Feynman's interest in fixing radios as a young boy (Feynman, 1985) or Seymour Papert's early fascination with gear ratios (Papert, 1980) did not emerge from direct instruction in the classroom, but from curiosity nurtured through informal learning. In fact, informal learning experiences are sometimes cited by scientists as important antidotes to negative school experiences. As a biologist explained to us:

> "For me and other scientists, museums and libraries were places where we could sustain our interest in science while we survived the poor exposure we got in school.... Many scientists I know have stories about the importance of these refuges."

Recent studies (e.g., Bloom, 1985) also emphasize the critical importance of the home environment (especially to the child between the ages of 8 and 13) in defining the interests of future scientists and mathematicians. Basic attitudes are already in place by the time science courses begin in earnest in junior high school, with gender differences well established (Bloom, 1985; Haertel et al., 1981; Hueftle et al., 1983). More extensive investments by NSF may be able to "penetrate" the home and family environment (Diamond, 1980) and infuse positive values toward science and mathematics into areas of a child's life where there was previously no or little reinforcement. Altering family and cultural dispositions toward science is a long-term and ambitious undertaking--one fraught with difficulties, but one also of immense importance (Stevenson et al., 1986; Walberg et al., 1984).

Informal science education, with its ability to communicate widely the images of modern science, could potentially serve as an effective outreach and communication tool for the entire Foundation. Television, museums, and print media all offer scientists vehicles to convey the essence of their work to the public. Professional scientific societies, for example, fund television and radio science broadcasts as a way of helping the public develop a more accurate (and positive) view of their work. Properly conceived, NSF, in funding informal science education projects, could serve its scientific as well as its educational purposes.

However, there are limits and caveats to NSF's support of informal science education activities. Primary among these is the fact that out-of-school resources, although popular, affect people in ways that are largely unknown. It is relatively easy to track the number of people who watch a television show and who go to a museum. It is very difficult to determine the net "learning" (changes in attitudes, skills, or knowledge) that has occurred as a result. To date, NSF has relied on largely anecdotal evidence and needs to do much more exploration of the impacts of its projects (see Opportunity 6).

Also, by its nature informal science education is a part of people's recreational experiences. Informal science experiences are associated with pleasure and are undertaken for intrinsic interest. Informal science educators know how readily their audiences "vote with their feet" when they are not interested. Thus, these educators must artfully balance entertainment value with the desire to convey science content. Erring on one side, informal science education may result in "diluted or simplistic" science; erring on the other side, these activities may be pedantic, unattractive, and ignored. The science education community has yet to determine how much middle ground there is--where meaningful learning takes place in enjoyable ways.

NSF'S Programs in Relation to This Opportunity

NSF's current and projected investments in informal science education must be understood as an outgrowth of a pattern of support spanning more than two decades. In 1959, NSF established the Public Understanding of Science (PUOS) program to provide modest support for projects across the country directed at improving public knowledge of the potential and limitations of science. This program was the first major NSF effort to support a wide range of educational efforts in informal settings. The PUOS program continued through 1982 (with interruptions), expending a total of $27 million.

In the 1970s the PUOS program concentrated much of its support on projects that dealt with the interrelationship of science and public policy issues. The program also supported the then novel idea of a television science series suited for national broadcast. "Nova" was initiated with NSF funding and served as a model and proof of feasibility for many subsequent series. PUOS was also instrumental in helping science museums advance their abilities to develop high-quality exhibits.

Other programs were created in the 1970s, still with a primary focus on the adult population. From 1976 to 1981, the Ethics and Values in Science and Technology (EVIST) program was established to address ethical and social dilemmas that arise in the work of scientists and engineers, through workshops and studies aimed at the academic community. From 1977 to 1979, the Science for Citizens (CFS) program was established to fund projects that could make scientific and technical information and expertise available to citizens and to stimulate their informed participation in issues of public policy. The program awarded public service residencies to scientists and engineers to spend up to a year working with citizens' groups and other organizations in need of their expertise.

Following the reinstatement of the SEE Directorate in the early 1980s, programmatic attention shifted more heavily to the younger population. In 1984, the Informal Science Education (ISE) program was founded to "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 education system" (NSF, 1984). The distinguishing differences between this and the earlier PUOS, EVIST, and CFS programs are: (1) a shift away from a public policy emphasis, (2) a decision to make younger audiences a much higher priority, and (3) an emphasis on projects that achieve widespread national impacts in a direct and cost-effective fashion. An increasing amount of funds has gone to this area of activity; the FY 1987 budget for the ISE program is $11.5 million, up from $8.5 million in FY 1986 and $7 million in FY 1985.

NSF's current activities in the informal education domain are centered largely in the ISE program. However, several other SEE programs are encouraging projects that involve the informal field. The Instructional Materials Development (IMD) program, for example, has several projects that fund informal institutions to develop curriculum materials for use in informal and formal settings. The Teacher Enhancement program funds teacher training projects in informal education institutions, and the Science and Mathematics Education Networks (SMEN) program funds projects that foster the crossover between formal and informal domains.

Three salient characteristic of SEE's overall approach in informal science education are its proactive funding stance, its emphasis on general and younger audiences, and its support of different media and kinds of activities.

The emphasis in the ISE program has been on making direct, incremental impacts on the general student population and on reaching large numbers of young people in a cost-effective way. Consequently, the approach has shifted away from the earlier PUOS strategy of funding numerous local and model projects (many of which were high in quality and quite innovative) toward the current ISE strategy of funding large national broadcast productions and large museum exhibit projects. This shift in approach has resulted in a different pattern of investment, as a SEE program officer explained:

> "SEE will never have more than 1% of what it needs to do the job it has. What then are the priorities? The 'hidden criteria' we are now using in funding decisions is Nielsen ratings. Or more generally it is how many impressions produced at what cost? As long as NSF is in the position of triage, it will fund projects with the larger numbers."

Particularly in the broadcast media, SEE is funding large projects of relatively long duration (3 to 5 years). This shift to larger projects is dictated by the nature of the media and SEE's goal to affect large audiences via broadcast:

> "We are now funding the 'big boys' to do TV and to some extent museums. There is no point in funding small local broadcast projects. The bigger the audience, the tougher the audience is to hold, so you need a blockbuster type to do the job.... Big projects simply mean that if you are going to do it, you have to do it right. This is why the number of grants in the informal domain has gone down while the size of the grants has gone up." (SEE program officer)

SEE's domain-wide approach to informal science education has been and continues to be structured around media. A PBS television science show, a network newscast, a newspaper, a trip to the museum, or an Audubon field trip all provide different types of experiences. Ideally, the different media can be used to reinforce each other:

"You don't learn in the informal area from *one* media. You learn because there is some impact from seeing something on television, then from getting another impact hearing it on radio, from reading about it in the newspapers or a magazine, another impact from going to a museum, another kind of impact when you go and do something in a club.... None of these media alone is a way to teach. It is important to us to try to build the multiplicity of impact. You want a rich environment so that wherever someone turns there is redundancy in the system." (SEE program officer)

At present, the following patterns occur in the distribution of SEE's funding across the different media:

- SEE has been investing heavily in television.
- SEE has been funding a wide range of development projects that rely on exhibits and curriculum materials, or some combination of them.
- By comparison, SEE has placed little emphasis on support of radio, the print media, or computers.

Moreover, because of its ability to reach a wide segment of the population, the informal science arena is felt by SEE to have a high potential for influencing the attitudes of audiences that otherwise are difficult to reach (e.g., young women and minorities). Approximately two-fifths of funds invested in informal science education in 1984-86 supported programs aimed at special groups (e.g., minorities). Informal channels are used in diverse ways to gain access to special groups, including the funding of special organizations (e.g., Girls Clubs) to do science with their members, the development of exhibits aimed at special groups (e.g., the blind), and the emphasis on women and minority role models in national TV series.

Overall, SEE appears to have been productive in concentrating its main efforts on supporting innovative, high-quality projects aimed at having a wide and immediate impact on the population. Most promising are SEE's efforts to support the broadcast of science series (in a wide range of formats), the infusion of science into broadcast (radio and television) journalism, and the development of and experimentation with approaches to amplify the effects of a wide range of informal institutions.

In terms of the riskiness of its investments, SEE is funding many innovative and experimental projects--more than half of the projects involve new approaches, deal with new topics, or bring science into new arenas. We heard no claims, nor did we find any evidence, that SEE is either too innovative or too conservative in its approach in the informal domain.

The ISE program, building on the history of the PUOS program, has been able to develop a coherent approach strategically aimed at improving and strengthening informal science education resources:

- The program has concentrated its resources on matters of a scope and significance proportionate to its resources and special capabilities.

- The program has generated a staff capability within SEE that has a competence and knowledge of the informal science field.

- Program staff have taken a proactive role, designing their own initiatives and promoting appropriate experiments.

- The program has promoted a sense of mission and commitment in pursuing informal science education, thereby generally raising the stature of the enterprise.

When one examines the different types of investment more closely, there are important differences and unresolved questions, which we review below by the four main areas of investment aimed at young audiences: broadcast, informal education institutions (e.g., museums), linkage with school programs, and national recreational organizations.

Broadcast Investments

More than any other vehicle, television is able to reach large national audiences.* Television plays a major part in most people's daily lives; the Public Broadcasting System (PBS) is attracting an increasing share of viewing time. The average household watches 10 hours of PBS a month (up from 7.5 hours 10 years ago) and in a given month 80% of American households will watch at least one PBS show.

There are questions about whom the series are reaching. Interviews with staff in Corporation for Public Broadcasting indicated that the adult viewing audience is made up of:

- Households of all income levels and all types of occupations in roughly the same proportion as they exist in the population, except that the very poor (under $10,000) are underrepresented.

- [illegible] roughly the same proportion as they are found in the population, [illegible] black households are slightly underrepresented.

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* Typical ratings for PBS science shows run from a high of about 17% of all (86 million) households for National Geographic Specials to around 2% for children's science shows. Because science shows are about the general ideas, issues, and people of science, they can be rerun several times over several years, greatly increasing the number of viewers they reach. By rough estimates, all of the television series currently funded (or partly funded) by SEE will ultimately reach millions of viewers and will provide well over 1 billion interaction-hours of science television viewing.

- People with all levels of education in roughly the same proportion as found in the population, except that those who did not graduate from high school are underrepresented.

NSF supports educational broadcasts aimed at adults as well as children. Because all science shows coming into the home tend to influence the science "culture" of that home, it is not completely possible or wise to separate the two In terms of the adult audiences for science shows, research suggests that PBS ows like "Nova" and "The Brain" are unlikely to reach significantly beyond the "scientifically attentive" audience that comprises, at most, 20% of the U.S. population (Miller, 1986). These data suggest that SEE can reach a broad and diverse cross-section of the population with PBS shows if they appear to be more than strictly "science" shows. Documentaries, docu-dramas, and interdisciplinary shows may be appropriate formats to explore in the future.

In addition to increasing the number of science shows, NSF's investments have contributed to a steady rise in the quality of science shows over the last decade. Broadcast production standards are now very high; there is a core of experienced, talented people making science shows; and the genre of a national science series has become an accepted and popular mainstay of the PBS world. Also, increasingly, cable television channels are showing previously produced science series (e.g., The National Geographics Explorer Series).

Broadcast investments play a major role in SEE's overall strategy for reaching younger audiences. In its first 3 years, "3-2-1 Contact!" reached 7.4 million children, aged 2 to 11, during an average week between 1980 and 1983 (Chen, 1984), or 23% of all children in that age group in the United States.

Preliminary results of a large-scale study of the viewers of "3-2-1 Contact!" (Crane, in progress) show very high recognition levels among children--the show is beginning to become part of the children's culture (in the same way, although to a lesser extent, as "Sesame Street" has). In tests of sample shows done within the home environment, children express interest in, and can verbally recall, much of what they watch. Even the youngest watchers appear to concentrate on the visual images presented. However, the study raises other questions about the educational impacts of the show:

- The audience that actually watches the show is determined by the time slot of the showing. The afternoon PBS audience is much younger than the targeted audience--almost twice as many 2- to 5-year-olds watch the show as the intended 8- to 12-year-old audience. The verbal recall of the children varies inversely with their age--the younger audience gets much less (at least in verbal information) than the older group. This finding has implications as to how important it is to design these shows to be suitable for a wide age range. In addition, the fixed 4:00 to 6:00 p.m. time slot for PBS for children's shows suggests that there is a limit to the number of science shows that can air simultaneously, and already there are signs that the new

"Square One TV" mathematics series may be competing for time with "3-2-1 Contact!" at some PBS stations.

- The ratings of "3-2-1 Contact!" have declined in recent years, suggesting that the show has becomes "passe" and/or that the marketplace of competing shows has expanded. As with commercial shows, there may be a need to produc new shows for each "season" (unlike the more stable days of Mr. Wizard).

- Although children may watch the show several times each month on the average they may not reach a threshold level of viewing where long-lasting substantive learning occurs. Also, in light of other activities taking place at the same time in the household, the quality of the typical viewing time is questionable.

Earlier formative research efforts have pointed out the potential of these shows to interest younger audiences:

> Viewers...were able to express newly acquired familiarity with a wide range of scientific concepts, phenomena, and ideas contained in the shows.... There were some indications from children that the shows motivated an interest that continued after viewing.... Some viewers were able to note shifts in their own feelings about science...from a perception of science as boring...to a sense that science can be fun.... (Chen, 1984)

The debate about the approach to presenting science on television raises questions about what people are learning and the attitudes they are forming as a result of watching science shows. Although there is evidence that large numbers of people are watching the SEE-sponsored science series, very little is known about what impact the shows are having. (See Opportunity 6 for a discussion of the need for a thorough research effort in this area.) There is a consensus on the need to know more about the nature and quality of the viewers' experience as they watch science shows. A producer of science broadcast shows told us:

> "The problem with the TV industry mentality is that only numbers count. Large-scale projects have good coverage but do they have only superficial impact? We need to be much more precise about audience segmentation, and about which groups of viewers are watching and getting something from it."

In almost all of our interviews with informal science broadcast producers, we found strong tensions between the perspective of the producer (who wants to keep the viewer entertained) and the perspective of the science educator (who wants to show good science). The producers are careful to maintain the integrity of the media and to protect viewers from being turned off. The producer of a PBS science series put it this way:

> "We don't care what people are learning. We don't make our programs to teach (as you do in the classroom); they are made to entertain. Our programs can only reach those people who want to see them."

On the other side of the issue, the scientists and science educators who work on the shows worry about "overdilution or sugar-coating" of the science. As the content specialist of a children's science show observed:

> "We are producing these shows for kids who are losing interest in science. But what are we doing for those who are already interested? Our shows are too superficial for them. The science is not overt enough.... In TV, the entertainment tail wags the dog. The science content tends to underestimate the kids. The way to interest people in science is to show interesting science."

Many questions still remain about the nature and overall effectiveness of television as a medium for science learning. In interviews, three producers expressed reservations as follows:

> "Voluntary viewing relies on an initial motivation to view the show. And sequential viewing from day to day cannot be assured. TV does not meet the need for hands-on experiences. TV cannot generate the same degree of monitoring, those personally inspiring experiences, that promote learning."

> "Our series also may contribute to a view of science as disjointed--a lot of facts with no organizing themes or framework.... The themes are clear to us but they don't get communicated to the kids."

> "Television cannot teach math or science by itself. We should think more globally--television plus museums plus teacher training."

Whatever their effectiveness, SEE's broadcast investments are undeniably cost-efficient. "3-2-1 Contact!" provided programming at an average cost of approximately $.05 per household per week over its first 3 years (Chen, 1983). As a rough benchmark, children's television is costing NSF about $.01 per interaction-hour, which is significantly less than any other medium.

Another part of the cost-efficiency argument is that, after a decade of success, a PBS science series can attract matching corporate funding. Thus, NSF can shift its role from serving as sole funder to serving as a "seed" funder. For example, SEE is funding only 7% of "The Ring of Truth." Although there is substantial leverage in this approach, there are also dangers. SEE risks, on the one hand, funding projects that never get off the ground, and on the other, funding projects that might well have succeeded without any SEE funds.

The potential to date, however, for leveraging the funding of children's series appears less optimistic than that for the adult science series. "3-2-1 Contact!," "The Voyage of the Mimi," and "Square One TV," all aimed at a younger audience, have had difficulty in drawing and sustaining corporate sponsors. Recently, the U.S. Department of Education, which has co-funded these television projects with NSF, has considered dropping its commitment to children's science and mathematics television. Thus, NSF is likely to be the primary, perhaps even sole, supporter of these and similar enterprises.

Investments in Informal Science Education Institutions

Over the last decade SEE has invested heavily in informal science institutions, with a strong emphasis on science museums. The ISE program has concentrated on projects aimed at amplifying the abilities of science centers to make the ideas and activities of science available to the public in interesting and innovative ways. The teacher enhancement and material development programs have supported other projects that attempt to use the resources of informal institutions (staff and exhibits) to serve the schools' efforts.

NSF has carefully delineated the kinds of support it offers informal science institutions. It has not, for example, offered support for the initiation of new centers; it has not funded local efforts unless they have wider implications, and it has not helped to support normal operational expenses. Primarily, NSF has sought to leverage its funding by seeking to raise the standards and widen the impact of institutions by (1) supporting the development of innovative exhibits, and (2) engineering collaborative efforts between institutions that help to share innovations across the field.

NSF continues to support the development of experimental exhibits that can serve as models as well as have a significant impact in their own right. Experimental exhibits address new topics (e.g., quantum mechanics, cell biology), aim at filling a gap in the communication of a major topic of public interest (evolution, rain forests), or aim at providing science for new audiences (e.g., the very young, the visually impaired). SEE's efforts at developing models that can serve the field widely can be seen in its pattern of funding a higher proportion of large museums than small ones. Science museums vary greatly in size and talent; there are a half-dozen museums serving as leaders for more than 100 newly founded and smaller science centers. Within the category of large museums, however, NSF does not necessarily fund those with the largest numbers of visitors, but rather concentrates on those centers that take the lead in educational innovation.

Those working in the science museum field argue that SEE's funding is needed for further innovation:

> "NSF should fund high-risk model exhibits like 'The Quantum Atom.' Industry will fund more standard, more applied type exhibits (like electricity, nuclear) but won't touch something as basic and fundamental as the quantum atom....
>
> "NSF should fund major topics and approaches not done before: the downside of this kind of funding is that you cannot prove that you affect more than one institution...." (Director of a major science museum)
>
> "NSF's most important priority in supporting museums, I believe, should be in supporting new major exhibitions. No one else will provide this kind of support...and you shouldn't minimize the importance of the stamp of approval that NSF funding gives a project--it makes it much easier to go out and get matching funds...." (Director of a small science museum)

The success of such "models" appears to be mixed. The prototype exhibits are often, in fact, innovative and of high quality. Also, unlike model curricula, these exhibits reach large numbers of learners even if the projects do not act as a model for other museums. But, as with model curricula, there are few mechanisms available for smaller museums to benefit from these large, expensive developments.

SEE has recognized the difficulty in spreading innovation from the large to the small museums and has sought to develop mechanisms for facilitating this process, each with benefits and drawbacks:

- *Multiple copies of new exhibits*. Offering copies of well-designed exhibits to smaller museums extracts more value out of the heavy costs of developing good exhibits. On the other hand, it may discourage smaller museums from understanding the exhibits or developing their own.

- *Collaborative arrangements between large and small museums*. Engineering collaborative efforts between institutions is one way to connect large and small museums, and can lead to a much more efficient sharing and dissemination of good ideas. It also has the important side effect of helping develop the skills of the staff of all the museums involved. On the other side of the coin, collaborations require great amounts of staff time and energy. Often, there are institutional barriers and territorial issues to overcome in trying to establish a cooperative arrangement. As a science museum director told us, "It can bring out the very worst of the bureaucracy of the two institutions involved...but joint exhibits can work when each institution does what it can do well...." Finally, by targeting its funding toward collaboration and by having excessively restrictive criteria, SEE may end up attracting "false collaboration" and may discourage the truly creative individual exhibit developer.

- *Traveling exhibits*. Traveling exhibits have recently received about one-third of ISE's total funding for museums. Through this mechanism NSF has attempted to increase the power of informal institutions to reach large numbers of people and to facilitate further cooperation between institutions. The advantage of this mechanism is that it can help museums change their static image and draw locals back to the museum for "special events." The down side of traveling exhibits is that they may be of lower quality, used inappropriately, and/or create logistical costs greater than their benefits.

Overall, through its support for innovative exhibit ideas and their wider dissemination, NSF has played a major role over the last decade in helping science museums become a public educational resource, promoting the educational possibilities of these science centers, and helping to raise their educational standards.

Investments Aimed at Linking Informal Resources with the Formal Education System

Of the current projects funded by SEE in the informal science education domain, almost one-third focus on linking the resources of the informal and formal science education settings. For the most part, SEE is supporting informal science institutions to carry out teacher training and curriculum materials development. Many museums and other institutions have resources in their exhibits and in the expertise of their staff that make them well suited for the task of upgrading local teachers' science knowledge and science teaching skills. Exhibits are a natural material resource, and some staff have had years of experience in communicating science in ways that attract and hold people's interest. In addition, many museums are well equipped to help with the design of hands-on materials, with curriculum development, and even with logistical support through development and distribution of materials.

Historically, a few large museums have had small teacher training programs and have helped schools develop materials for their classes (Danilov, 1982). However, it is only in the last 3 years that SEE has broadened its teacher training strategy to include the funding of informal institutions.

To date, these investments have produced a few promising programs that provide interesting models for linking informal science education resources with the schools. But the projects remain somewhat ad hoc--a temporary support for teachers and students--and are not being established as an institutionalized resource to school programs, except in a few instances. Teachers may also view their participation in museum-based training as a temporary departure from the realities of the classroom.

Investments in National Recreational Organizations

This category of investment fosters the development of science activities in large organizations that traditionally do not focus on science or that are only peripherally organized to carry out science activities for young people. The present SEE strategy is to fund projects that are models with the potential of being applied nationally. NSF's efforts to infuse science activities into the the Girls Club and 4-H organizations illustrate the size of the potential numbers involved:

- 4-H claims to be the largest youth organization in the world. It has 4,657,784 members nationwide. It is made up of 165,711 local units. There are more than 40 million alumni. There are 82 countries around the world with similar youth programs.

- The Girls Club has more than 200,000 members--young women aged 6 to 18. Almost three-quarters of these girls are from families with incomes under $15,000 per year. About half the members are minorities.

Not only does the strategy of helping national organizations have a potential of reaching many young people, it also provides SEE with a very good opportunity to have a significant impact on difficult-to-reach audiences, particularly young women and minorities.

To date, SEE has supported only a few projects of this sort--for example, a grant to the Girls Club of America to pilot science programs for potential national inclusion in the club's activities. This area is one of the priorities for future funding, as described in SEE's recently updated long-range plan (NSF, 1987).

However, although national recreational organizations present an opportunity for exposing young people to science, they also present serious problems. It is very difficult for trained teachers to carry out high-quality science programs. How will untrained organization staff and volunteers be able to do as well or better? Leaders of youth groups who are uncomfortable with science may do more harm than good. Also, organizations such as the Girls Club, 4-H, and the Audubon Society are national organizations with local chapters that have strong local control. It is not a trivial task to disseminate high-quality science programs throughout the structure of such an organization. The strategy has the advantage of bringing national associations and local community groups into a relationship with NSF, which could create new and potentially powerful allies. On the other hand, the move into nonscience arenas may make it more difficult for NSF to attract scientists, who may have difficulty viewing this as "serious science."

Promising Initiatives for Expanding Informal Science Learning Resources

NSF's work in informal science education over the last two decades provides the base for various investment opportunities. Well connected to the field, knowledgeable about the nature of the informal setting and the processes of informal learning, and increasingly sophisticated in its funding strategies, NSF (SEE) is now in a position to extend and broaden informal science learning opportunities in an intelligent and cost-effective way.

10.1 Extend and Modify the Broadcast Strategy

NSF has successfully supported the development of several PBS science series for both adults and children. This experience provides a good base for extending current successes and for experimenting with new approaches. Several emphases are suggested below.

Providing a stable base of children's science programs--In accordance with the importance of reaching a diversity of young people and of interesting them in scientific pursuits, a heavy investment in children's television appears to be warranted (with the proviso that such efforts receive intense study). The development and production of children's shows should be undertaken with a 5- to 10-year life cycle in mind, with such plans including contingencies for using the materials in multiple ways and settings. NSF should continue to develop and support innovative efforts like "3-2-1 Contact!" and "Square One TV," with future efforts being informed by thorough studies of these existing shows.

Extending the use of existing broadcast materials--The broadcast strategy is limited by an over reliance on PBS. It is difficult to get air time on PBS, and the requirements of the PBS format may constrain the types of broadcast shows that can be produced. Further, exposure is limited when only one outlet is used. The amount of work and investment that goes into a series like "3-2-1 Contact!" or "The Ring of Truth" is enormous. The show may be aired three or four times on PBS and then shelved. There are many possibilities for extending the use and increasing the benefit of such high-quality materials. Some existing shows are distributed through cable networks, but this method has involved relatively few viewers. It may be possible in the future for SEE to work out a collaboratively funded showing of previously produced major science series on major cable networks (as National Geographic has done).* (See Initiative 10.5 below for more detail.)

Providing seed money and credibility--In its funding of "The Ring of Truth" and "The Search for Mind," SEE contributes only 7% of the total funds required for the project. The leveraging effect of SEE's funding in these cases is very high. SEE may wish to solicit and support proposals for other high-quality science series (and other innovative formats) where SEE can provide start-up funds and offer its imprimatur to create credibility for the show. Indeed, some projects (such as national PBS science series for children) probably would not survive at all without NSF support because they require very large levels of funding, are national in scope, and demand the collaboration of scientific, educational, and media experts.

Infusing science into existing popular broadcast shows--Another avenue for getting science into homes via broadcast is to "piggyback" onto existing shows. Suggestions include supporting "Sesame Street" to include more science (as SEE has done with "Reading Rainbow"), supporting commercial shows (such as "Quincy") in presenting science/medicine in a realistic light, and funding miniseries or plays on the lives and work of scientists. Again, the generally high rating and wide demographic spread of PBS shows argue for broadly based shows integrating science with other material and forms.

The broadcast initiative would require $8 million to $10 million per year, or $40 million to $50 million over the next 5 years. These funds could ensure a core of children's science programming (a minimum of two daily shows), as well as provide seed funding for other innovations and experiments.

10.2 Support Informal Science Education Institutions

For many years SEE has focused its support for informal science education institutions on a small number of science and technology centers that are capable of carrying out high-quality development efforts. SEE's support of science centers is still

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* In addition, SEE may be able to fund the "repackaging and repurposing" of selected science shows for use in the classroom or the home.

encouraging high-quality work, yet the development of science centers may have reached a plateau or steady state (in terms of the state of the art, as opposed to the numbers). Interactive exhibits have become widely accepted, and no new paradigms for science center activities are unfolding. Science centers are strong and are actively exploring ways to broaden their funding base. SEE still has an important role here in helping these institutions continue to innovate, consolidate gains, and expand their audiences. However, SEE should not constrain itself to a narrow focus on science centers alone.

Broaden support for interactive science learning in other types of informal institutions--Whereas science centers received 81% of the museum funding from PUOS and ISE, natural history museums, zoos, aquaria, and parks together received only 19% of museum funding. More concentrated funding of these institutions by SEE could have far-reaching impact, for several reasons:

- Zoos and parks, in particular, reach a large audience. Each year more than 400 million people visit the national parks and more than 100 million visit zoos.

- There are far more zoos and natural history museums than science centers. According to the American Association of Museums (1982), there are 368 natural history museums and 150 zoos, compared with only 72 science and technology centers nationwide. There are a few large natural history museums and zoos that are highly visible, providing an important research and development role for the others. This distribution of large and small institutions is similar to that found in the science center community, where major funding of a few influential institutions has led to a great impact on the overall field.

- These institutions have great potential to bring young audiences into contact with some of the most significant scientific public issues. Zoos, aquaria, and natural history museums are well suited to educating people about some of the major biology, ecology, and conservation issues confronting the nation today. Biological diversity, genetic resources, impacts of genetic engineering, toxic waste, and infectious disease are among the issues that now receive wide publicity and concern. The biological expertise on the staffs of large natural history museums and zoos are a valuable resource for the development of education materials on current biological topics.

- Zoos and aquaria are increasingly interested in education. One zoo director put it this way: "Zoos have taken on a *crucial* role in conservation biology.... We do not know, however, how to use this as an educational opportunity." Whereas zoos long have been cognizant of their entertainment value, they are now showing increased interest in how they can communicate to their visitors about their efforts in research and conservation.

- Natural history museums are changing their long-term emphasis on research and are increasingly redefining themselves as educational institutions. There is a strong decrease in interest in natural history collections, and several institutions have recently given away or sold their collections. As a result, natural history museums are increasingly viewing public education as the key to their future. However, a new design philosophy for natural history exhibits has not yet emerged to take the place of the diorama.

SEE could use its experience with science centers to help these institutions begin to realize their potential in science education. A major thrust could help these institutions increase their educational effectiveness. As an example, consider the tours offered by buses and monorails at major zoos. The San Diego Zoo has more than 3.5 million visitors on its half-hour bus tour each year, as does the Bronx Zoo, yet neither has widely involved scientists or science educators in writing the scripts of the tour speech. Interviews with staff from both institutions suggest that a project to upgrade these tours could bring large educational returns.

Support for continued innovation in science museums--NSF has played, and should continue to play, a leadership role in helping science museums develop innovative educational practices. Exhibits and educational programs developed and tested with NSF funding often do influence the conventional wisdom and practice of the field. NSF's support of the San Francisco Exploratorium, for example, has had a long-term impact on the practice of most science museums across the country. In addition, NSF can continue to experiment with mechanisms (e.g., copies of exhibits, traveling exhibits, collaborations) for disseminating high-quality practices throughout the science museum community.

The resources required to support informal institutions under this initiative would require an annual investment of $5 million to $8 million from NSF, or $25 million to $40 million over 5 years. Approximately half of these funds would go to furthering and spreading innovation in science centers; the other half would go to experiments in assisting other types of informal institutions (zoos, aquaria, parks, etc.).

10.3 Create New Arenas for Science Activities (e.g., National Recreational Associations)

Funding attempts to infuse science activities into national recreational organizations is a new strategy for NSF. Some study and systematic exploration of the potential of this strategy would be useful. NSF could use what it learns from its present projects to determine the viability of, or direction for, future investments of this sort. To carry out such an investigation, SEE might concentrate on the following questions:

- How effective are national organizations in establishing high-quality programs in their local chapters?

- What kinds of organizations (youth groups, amateur science societies, clubs, semi-educational groups) are most likely to succeed? Supporting amateur science groups to broaden their activities and to create special programs for young people, for example, may be more feasible than working with nonscience organizations.

- What resources or knowledge is available from past efforts to introduce science activities into nonscience settings? The experience with past curriculum projects such as Outdoor Biology Instructional Strategies (OBIS), for example, can provide a rich basis for understanding some of the difficulties in this area.

In undertaking any new strategy, we suggest that SEE experiment with a few promising projects and monitor them closely. This could be the emphasis of SEE's activities until it has gained a broader perspective on the field.

Only a modest level of support is needed to try out ideas in new arenas of informal science education. We estimate that this strategy could be reasonably funded at a cost of $1.5 million per year, or approximately $7.5 million over 5 years (which would cover four to eight trial programs). A significant portion of that funding ought to be reserved for evaluative activities or research on the potential for this area of investment.

Promising Initiatives for Integrating Informal and Formal Science Education

As the potential of informal science resources is recognized, NSF could help to integrate broadcast, informal science institutions, and journalism with formal education in public and private schools. NSF is already supporting the use of science museums as teacher training institutions, and broadcast series are now being designed for in-classroom use as well as public airing. A long-term NSF effort to link informal resources more closely with science and mathematics programs in schools could have a significant impact on the learning of science in this country.

The following two initiatives discuss two broad areas in which NSF could help foster links between the formal and informal domains.

10.4 Link Informal and Formal Education Institutions

The interest of schools in using out-of-school science and mathematics resources is growing, and the potential for establishing symbiotic relationships between the two now exists (NSF is currently funding projects that begin to explore that potential).

Informal science institutions are an obvious resource for teachers (Danilov, 1982). Not only are the exhibits, fish, or animals learning resources for both teachers and students, but the education staff of these institutions have had to develop expertise in making science understandable and interesting to the public. This expertise may be very valuable to teachers.

In projects it has funded to date, SEE has shown that science museums can work well with teachers in the schools. A science museum director argues:

> "The informal [setting] can profoundly affect the formal.... NSF should help connect museums with the schools. This has to happen on an individual person-person basis.... Most importantly, museums can play an integral part in creating and supporting teacher professionalism...and universities do not fill the bill. The museum is perceived as a friendly and local real teaching resource.... We can establish personal relationships with teachers which are ongoing working relationships...."

Evidence we gathered from museums that were working with teachers suggests that SEE programs are highly appreciated by the teachers.

But a larger vision is needed to guide NSF's teacher training and curriculum development efforts centered within informal institutions. Rather than funding short-term, one-time projects in museums, NSF could adopt a longer-term goal of helping informal institutions gain ongoing financial support as part of the formal system. At present, for example, science museums are seen by the schools as an outside, independent, and auxiliary resource. NSF could work to establish connections so that museums would be considered part of the educational system; some states are already beginning to support science museum teacher training programs as part of the regular educational budget. More might be persuaded to do so, as might large school districts.

The potential of this strategy lies in its ability to create a new way of thinking about informal institutions and their role as a resource to the school systems. One museum director explained it this way:

> "First, you have to understand that power and money are moving to states and local communities. This leaves the federal agencies with the important role of doing seminal funding.... To really serve the museums, NSF has got to assist museums in changing their image and status in the eyes of the local community.... Presently museums are thought of as places to go on a rainy day.... They are not taken seriously as educational institutions.... We have got to become thought of as an integral part of the educational system...."

The connections proposed here are institutional and not curricular in nature. That is, it is not the intent of this initiative to make schools more like museums or vice versa. Informal science educators should not try to duplicate in-school objectives or approaches. Instead, the idea of this initiative is to draw on the best of both worlds and to let their different environments complement each other.

We estimate that the cost of efforts to link informal resources with the schools will cost NSF approximately $4 million to $5 million per year, or $20 million to $25 million over a 5-year period. This level of funding would be best allocated to extensive support ($400,000 per year) for a few (say 10) institutions to allow them to develop strong programs as well as community ties that increase the likelihood of the institutionalization of their efforts.

10.5 Adapt Informal Resources and Materials to Formal Settings

Although the way that science is taught in the schools has not changed dramatically during the past decade, the media environment has undergone rapid transition. In addition to textbooks and the broadcast television media of the 1960s and 1970s, new electronic media, such as cable, videocassette, videodisc, and computer software, as well as new print resources in the form of specialty tradebooks and science magazines, have entered the educational marketplace for use in schools, homes, and other settings.

The growing array of high-quality informal science education materials opens up new possibilities for school programs. This initiative involves repackaging, reediting, or reformatting existing materials, which were designed originally for informal science education settings, for use in the schools. Some updating of older materials to remain current may also be required. Some "repurposing" of goals and materials may also be needed, that is, taking materials designed for one set of purposes or one medium and redirecting them for new purposes or media.

One bright prospect is the repackaging of educational TV programs, filmstrips, or other video materials for videotape, to be sold or rented for classroom (and home) use. The possibilities for capitalizing on VCRs in the schools are great, as indicated by the following findings of a recent study of technology in the schools (Riccobono, 1986):

- 74% of all schools had VCRs. Six years earlier this figure had been 40%.
- Nine out of 10 high schools had VCRs.
- VCRs were used for science more than for any other subject.
- The most viewed instructional television series was "Nova" (94,000 teachers; 10,000,000 students) and National Geographic Specials (77,000 teachers; 7,000,000 students). These shows were seen by twice as many students as the next most viewed series.

Because VCRs are becoming as common a technology as television, they are likely to become a useful tool in the classroom if programs are appropriate (e.g., topic-oriented videotapes about 5 to 15 minutes long). SEE's funding of the use and distribution of "The Mechanical Universe" for high school classrooms is a first example of an effective way to support teachers with good materials in this new medium.

Print materials in the informal domain also can be repackaged for use in the classroom. Increasingly, there are very good popular books about nature, science, and mathematics that have great educational potential in the classroom. Articles from science magazines could be collated and reformatted for use in high school science classes. Nature groups, informal institutions, and amateur science societies all have publications that could be adapted by the schools.

NSF can also fund projects that design innovative materials that are simultaneously compatible with in-school and out-of-school use. The SEE-funded "The Voyage of the Mimi" is an example of a program that begins to do this: videos, software, readings, and laboratories are woven together in an integrated curriculum unit for upper elementary or middle school grades. The "Mimi" is not so much a replicable model as a test of a new approach that seeks to bring inquiry-based activities into the classroom.

The introduction of materials like "The Voyage of the Mimi" into the classroom forces a teacher to teach differently:

> "Our goal is to thaw the formality of the classroom. We get teachers to explore a topic in many ways; we cut across curriculum boundaries; we teach teachers to go off in different directions. Informal education can cross boundaries at will and it acknowledges the need for messiness.... Formal education is too tidy now.... In this sense, I am a subversive...." (Staff member of "The Voyage of the Mimi")

Also promising is the repackaging of in-school science curriculum materials such as the Elementary Science Study (ESS) and the Science Curriculum Improvement Study (SCIS) to be used outside the classroom, as in the home, museums, zoos, aquaria, youth organizations, or by naturalist or hobbyist organizations.

The repackaging of materials raises complex design issues paralleling those involved in the original development process:

- The same careful attention to science content and pedagogy required in the initial development of materials will still be needed in considering redesign and reformatting issues, or quality may be reduced.

- Distribution through new channels or media may face problems of "market readiness." One of the challenges for groups seeking funding will be to demonstrate that the market exists and is ready for these redesigned materials.

The development of informal resources that support science education in both informal and formal settings could be accomplished at a funding level of $3 million per year, or $15 million over 5 years. This would support five "reformatting" projects at $200,000 per year, as well as one or two large development projects (like "The Voyage of the Mimi") at $2 million per year.

10.6 Explore the Home and Family Environment

Recent studies (e.g., Stevenson et al., 1986) accent the importance of the family, home, and larger cultural environment in the development of individual achievement and motivation. The home and family environment thus has a great deal to do with efforts to broaden the pool of science learners, but also it is an area that is very difficult to influence. For NSF it is an area that merits exploration and experimentation. The Family Math Program, investments in science museums, upgrading science journalism, and science television productions are all examples of current SEE investments that could have at least a small impact on this domain.

NSF should consider additional efforts to bring ideas and activities of science and mathematics into the family and home environment. Experiments might include:

- Ways to create and market science videos for home use.
- Software that is suitable for both home and school use.
- Community efforts (perhaps centered in science museums) that are designed for adults and families.
- Efforts to support libraries in serving the science interests of children and adults.
- Efforts to expand the activities of informal science and craft societies for children and families.

These suggestions are meant only to indicate the broad arena in which NSF should consider exploring promising opportunities. How to infuse science into the family and home environment is an open question--and one that NSF should continue to explore in an open-ended fashion.

An initial level of exploratory work could be carried out in this area by investing between $12 million and $16 million over 5 years (assuming 30 to 40 projects at an average of $400,000 per project).

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Appendix A

PROMISING INITIATIVES, BY OPPORTUNITY

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The following table lists initiatives we developed for NSF (SEE) to take advantage of the 10 opportunities for improving K-12 science education. Each initiative is numbered according to the opportunity to which it relates (Initiatives 6.1 and 6.2 address Opportunity 6, etc.).

Resource estimates indicate the scale of investment that would be necessary to achieve the targets of opportunity, under the following assumptions:

(1) Estimates indicate the level of SEE investment over the next 5 years, even though some initiatives would require longer to complete.

(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.

Table A-1

PROMISING INITIATIVES, BY OPPORTUNITY

Area of Opportunity/Initiative		Estimated Resources (Over 5 Years)
Opportunity 1:	*To reconceptualize K-12 mathematics content and associated instructional approaches*	
1.1	Develop comprehensive prototypes for middle and high school mathematics	$40-50 million
1.2	Develop national standards for mathematics education, K-12 (expand current efforts)	$5-7.5 million
1.3	Develop software tools for learning mathematics, K-12	$20 million
Opportunity 2a:	*To rethink the approach to, and settings for, elementary science education*	
2a.1	Support studies and research on the mission for, constraints on, and possibilities for enhancing the science learning of younger children	$8-12 million
2a.2	Support large-scale field experiments with alternative approaches to school-based elementary science education (demonstration of alternative instructional systems at work)	$40-50 million
Opportunity 2b:	*To recast the content of middle and high school science curricula*	
2b.1	Support national task forces with a mandate to redesign high school and middle school curricula	$15-20 million
2b.2	Fund field-based experimentation with alternative conceptions of science education (demonstration of new curricula and approaches)	$40-50 million

Table A-1 (Continued)

Area of Opportunity/Initiative		Estimated Resources (Over 5 Years)
Opportunity 3:	*To match science and mathematics education to the different needs in a diverse student population*	
3.1	Mount targeted experiential program for secondary students from underrepresented groups	$5-7.5 million
3.2	Fund research focused on underrepresented groups in science education (e.g., to increase understanding of these groups' learning styles and pre- or mis-conceptions of science)	$4-6 million
3.3	Develop curriculum materials and instructional methods for selected groups	$15-20 million
3.4	Promote exemplary models for serving students from underrepresented groups	$10-15 million
Opportunity 4:	*To bolster the "support cadre" serving science and mathematics teachers*	
4.1	Develop a pool of teacher resource fellows at the secondary and middle school levels (to provide continuing teacher education and support)	$100-150 million
4.2	Develop science/mathematics district leadership at the elementary level (training and support for leaders to implement grass-roots innovations)	$100 million
Opportunity 5:	*To help attract and prepare the next generation of well-qualified science and mathematics teachers*	
5.1	Experiment with incentives to attract qualified individuals into science and mathematics teaching (support for experiments to change existing conditions and provide new incentives)	$20-30 million
5.2	Fund research to increase understanding of teachers' pedagogical content knowledge in science and mathematics (aimed at improving teacher preparation programs)	$10-15 million

Table A-1 (Continued)

Area of Opportunity/Initiative		Estimated Resources (Over 5 Years)
Opportunity 5:	*(Continued)*	
5.3	Support alternative teacher education programs to attract and certify qualified teacher candidates from a nontraditional pool (especially women and minorities)	$15-20 million
5.4	Stimulate innovative development aimed at "trouble spots" in the teacher preparation process	$20-25 million
5.5	Support and upgrade the community of science and mathematics educators	$15-20 million
Opportunity 6:	*To strengthen the informal science education community*	
6.1	Foster professional development (training for new professionals and opportunities for present practitioners to increase knowledge and skills)	$15 million
6.2	Develop profitable lines of research and evaluation (understanding the nature and impact of informal learning; evaluation of informal science programs and projects)	$10-15 million
Opportunity 7:	*To engage and expand science and mathematics education publishing capabilities*	
7.1	Repeat and extend solicitation for publisher partnerships (e.g., to middle school)	$40-50 million
7.2	Form a consortium to explore and support alternative publishing capabilities	$18-25 million
7.3	Support R&D on the science or mathematics "textbook of the future" (extend and apply the state of the art)	$15-20 million
7.4	Stimulate a new generation of science textbooks (seed money support for manuscripts for tradebooks)	$10 million

Table A-1 (Continued)

Area of Opportunity/Initiative		Estimated Resources (Over 5 Years)
Opportunity 8:	*To improve science and mathematics testing and assessment*	
8.1	Stimulate a national dialogue (e.g., conferences, symposia, commissioned papers to learn how tests and assessment practices can be improved)	$2.5 million
8.2	Fund projects linked to current tests and assessments (to improve current practices and make tests and assessments consistent with instructional goals)	$8-12 million
8.3	Develop prototype instruments (to extend ability to test what is taught)	$10-15 million
Opportunity 9:	*To support content-related leadership for ongoing state reform of science and mathematics education*	
9.1	Promote a national dialogue on state science and mathematics education policies	$4-5 million
9.2	Support technical assistance to state science and mathematics education planners, specialists, and policymakers	$6-9 million
9.3	Take advantage of the "natural laboratory" of state reform: learning from the states' experiences (comparative research on current state reform measures and alternatives to them)	$5-7 million

Table A-1 (Continued)

Area of Opportunity/Initiative		Estimated Resources (Over 5 Years)
Opportunity 8:	*To improve science and mathematics testing and assessment*	
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