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ABSTRACT

In 1988, the Office for Undergraduate Science, Engineering, and Mathematics Education (USEME) convened a series of disciplinary workshops designed to obtain a better understanding of the conditions and trends in undergraduate education in the United States in seven critical areas: Biology, Chemistry, Computer Science, Engineering, Geosciences, Mathematics, and Physics. Each workshop was comprised of about 20 leaders from the appropriate disciplines in academia and industry. This report describes the findings of these workshops and their recommendations concerning actions that should be taken to improve undergraduate education in the United States. An executive summary and individual reports are included. Each individual report provides a list of participants, a summary, background information, and recommendations. (CW)

Report on the National Science Foundation Disciplinary Workshops on Undergraduate Education

Recommendations of the disciplinary taskforces concerning critical issues in U.S. undergraduate education in the Sciences, Mathematics and Engineering.

Division of Undergraduate Science, Engineering, and Mathematics Education

Directorate for Science and Engineering Education
National Science Foundation

April 1989

National Science Foundation

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Report on the National Science Foundation Disciplinary Workshops on Undergraduate Education

- BIOLOGY: June 1-2, 1988
- CHEMISTRY: May 18-19, 1988
- COMPUTER SCIENCE: March 10-11, 1988
- ENGINEERING: April 25-26, 1988
- GEOSCIENCES: March 28-29, 1988
- MATHEMATICS: February 25-26, 1988
- PHYSICS: April 14-15, 1988

Recommendations of the disciplinary taskforces concerning critical issues in U.S. undergraduate education in the Sciences, Mathematics and Engineering.

Division of Undergraduate Science, Engineering, and Mathematics Education

Directorate for Science and Engineering Education
National Science Foundation

April 1989

National Science Foundation
Directorate for Science and Engineering Education

April 3, 1989

Erich Bloch
Director,
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Washington, D.C. 20550

Dear Erich:

I am pleased to submit to you the reports of the experts who participated in the National Science Foundation workshops on the state of U.S. undergraduate education in Biology, Chemistry, Computer Science, Engineering, Geosciences, Mathematics and Physics. These Disciplinary Workshops are a follow-up to the National Science Board Task Committee Report on Undergraduate Science and Engineering Education, March 1986 (Homer A. Neal, Chairman). With the 1988 series of workshops, considerable insight was gained into the conditions and trends in undergraduate education in the U.S. in seven distinct and critical disciplines of science, engineering and mathematics.

The Disciplinary Workshops were organized as a cooperative effort between SEE and NSF's Research Directorates (BBS, CISE, ENG, GEO and MPS).

All of the Disciplinary Workshops reflect serious needs for support of undergraduate education and they are consistent in their recommendations to NSF for increased activities in undergraduate education.

Bassam Shakhashiri
Assistant Director,
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INTRODUCTION

In March 1986, the National Science Board (NSB) released its report "Undergraduate Science, Mathematics and Engineering Education" (NSB 86-100) that described the outcomes of a year-long study conducted by the NSB Task Committee on Undergraduate Science and Engineering Education. The NSB report identifies serious problem areas in U. S. undergraduate education and suggests remedial actions that should be taken by academic institutions, the private sector, states, the National Science Foundation (NSF) and other Federal Agencies.

In response to the NSB undergraduate education report, the NSF created, in July 1987, the Office for Undergraduate Science, Engineering, and Mathematics Education (USEME), within the Directorate for Science and Engineering Education. The USEME Office (subsequently designated an NSF Division in September 1988) is charged with responsibility for managing and initiating new programs that support improvements in undergraduate education in Science, Mathematics and Engineering. USEME is guided in its activities by a Steering Committee comprised of representatives of the NSF Research Directorates. The members of the USEME Steering Committee are listed inside the back cover of this report.

As an additional follow up to the NSB 1986 Report, the NSF, through its USEME Office and with the cooperation of the Research Directorates (Biological, Behavioral and Social Sciences, Computer and Information Science and Engineering, Engineering, Geosciences, and Mathematical and Physical Sciences), convened a series of Disciplinary Workshops during the period of February to June 1988. These Disciplinary Workshops had the objective of obtaining a better understanding of the conditions and trends in U.S. undergraduate education in seven critical areas: Biology, Chemistry, Computer Science, Engineering, Geosciences, Mathematics and Physics. Each workshop was comprised of about twenty distinguished leaders from the appropriate disciplinary research and educational communities. The participants represented all types of academic institutions and industry.

While the Disciplinary Workshops were convened and charged independently, there was, nonetheless, a remarkable degree of consistency in their findings, in their call for NSF actions, and recommendations for specific NSF initiatives.

This report, edited by Anita J. LaSalle (USEME), describes the findings of the NSF Disciplinary Workshops on Undergraduate Science, Engineering, and Mathematics Education and their recommendations concerning actions that should be taken to improve undergraduate education in the U.S.

Robert F. Watson, Director
Division of Undergraduate Science,
Engineering, and Mathematics Education

I. EXECUTIVE SUMMARY

Background

Between February and June 1988, seven workshops were initiated by the National Science Foundation (NSF) to examine the condition of U.S. undergraduate education in a series of science, engineering and mathematics disciplines. The convening of these Disciplinary Workshops followed the Fall 1987 direction of the National Science Board (NSB) Executive Committee. They were a timely follow-up to the 1986 NSB Report on Undergraduate Education (the NEAL Report), and three 1987 related workshops in mathematics, engineering, and the basic sciences. The 1988 Disciplinary Workshops were a cooperative effort of the Directorate for Science and Engineering Education, with the Biological, Behavioral, and Social Sciences Directorate, the Mathematical and Physical Sciences Directorate, the Computer and Information Science and Engineering Directorate, the Engineering Directorate, and the Geosciences Directorate, respectively.

"...undergraduate education in science and engineering in the United States is in a state of crisis..."
(Chemistry Workshop)

The workshops focused on the disciplines of Biology, Chemistry, Computer Science, Engineering, Geoscience, Mathematics, and Physics (including Astronomy and Materials Science). Each workshop was comprised of about twenty distinguished leaders from the appropriate disciplinary research and education communities. All types of U. S. institutions of higher learning and industry were represented among the participants.

"...inadequate pre-college instruction, declining enrollments, deteriorating instructional facilities and lack of funding for research efforts involving students are particularly evident..."
(Geosciences Workshop)

NSF's objectives in these workshops were to obtain a better understanding of the condition and trends in U.S. undergraduate education and its importance to the total science and engineering enterprise, and to receive the community's advice and recommendations for NSF action in this area.

Common Themes

There was a remarkable level of commonality across the workshops, despite their independence one from the other and the character and personalities of the individuals involved. Certainly, many different views, experiences, and recommendations were voiced, both within and across the workshops; and the reports contain a wealth and variety of ideas, many aimed at problems specific to a particular discipline. But most notable is the consistency of the major observations and findings. Consistency in:

- Concern for the condition of undergraduate education
- Need for NSF action
- Recommendations for NSF action

"...The (Geoscience) Committee strongly agrees with the NSB report, Undergraduate Science, Mathematics, and Engineering Education, which identifies basic deficiencies in undergraduate education in the United States, and recommends NSF action ..."

Concern for the Condition of Undergraduate Education

Uniform high concern was expressed for the state of affairs in U.S. undergraduate education in the sciences, mathematics, and engineering, with particular reference to the findings of the Neal Report.

"...as never before, quality of life requires technologically enlightened business and civic leadership..."
(Engineering Workshop)

There was considerable feeling that undergraduate education, in particular the lower division component, suffers from lack of attention, even neglect. Deficiencies were found in the laboratories (their condition and their absence), in the curriculum (inappropriate for many and often too narrow), in the materials and texts (dull, uninspiring, consisting too frequently of huge compendia of facts), and in the students (decreasing in number, and in some disciplines in quality). These concerns extended not only to the "pipeline" student, but also to those many individuals in college who will be society's future leaders, that is, those who must be scientifically literate.

Many reasons were given for this condition, but perhaps the most ubiquitous is also the one most significant to NSF: the pre-occupation of the faculty with their research to the detriment of their teaching.

"...In the United States, we see at least three basic problems underlying the present poor condition of science education and scientific literacy:
(1) Teaching is considered to be a second-class activity compared to research,
(2) Science is isolated from the broad body of knowledge expected of the well-educated person,
(3) There is not enough interchange between the research and teaching communities."
(Physics Workshop)

All participants stressed that they are strong advocates of research, but even the most research oriented pointed to the lack of comparable support for innovative teaching-related faculty effort.

The workshops also pointed strongly to the condition of precollege education as a major concern and contributing factor to the status of undergraduate education. They acknowledged NSF's programming at this level but called for greatly enhanced attention there as well.

Need For NSF Action

NSF leadership and support is felt to be an essential ingredient to a healthy and dynamic system of undergraduate science, engineering, and mathematics education. It was pointed out repeatedly that NSF sends strong signals to the academic community about what is important and what is not important, and that the community responds.

The workshops emphasized their support for the findings and recommendations of the NSB Report on Undergraduate Education, and praised the NSF for the initial responsive steps that it has taken. They pointed to the new Office of Undergraduate Science, Engineering, and Mathematics Education, and the beginning programs in faculty enhancement, instrumentation, curriculum development in calculus and engineering, minority centers, and research experiences for undergraduates. But they then proceeded to call for significant expansion of these activities including wholly new programs.

"...the (NSF) response thus far... has been insufficient to even stem the tide let alone begin to resolve the issue."
(Engineering Workshop)

Recommendations For NSF Action

The workshops urged that NSF expand or initiate programming in the following major areas:

- Laboratory
- Course and Curriculum
- Faculty
- Underrepresented Groups
- Students

"...The laboratory infrastructure is not in place to support undergraduate computer science as a laboratory science. There are difficulties in four basic infrastructure areas: equipment, software, staff, and operations."
(Computer Science Workshop)

• Laboratory

All are agreed that the laboratory (meaning herein also field experiences) is the most critical element of instruction in the disciplines; even the mathematics workshop placed a primary emphasis on the drive to become a laboratory science, and the need to bring technology into the undergraduate instructional process. The laboratory is where students gain true insight into the scientific process and is thought to be crucial in stimulating students to major in the discipline. In most disciplines, the greatest concern lies with the introductory laboratories, thought to be more proficient at turning-off and eliminating students than attracting them to the disciplines.

"...There are widespread, fundamental, and longstanding problems in laboratory instruction in chemistry. The problems are most acute, affect the largest numbers of students, have the greatest effect on retention of students in the study of science, and offer the greatest opportunity for NSF action, in the first two years of the undergraduate curriculum's laboratory courses..."
(Chemistry Workshop)

The workshops called for broad based support of laboratory development and improvement activities at all types of institutions: 2-year and 4-year colleges and doctoral universities, in addition to the continued or enhanced support of instrumentation presently provided.

Support should be available to study the needs and debate issues with regard to the laboratory portion of the curricula, to design and develop undergraduate laboratory experiments, to emphasize hands on activities, to incorporate new technologies, and to create open-ended laboratories that challenge and excite students.

• Course and Curriculum

The expository portion of the instructional process, the curriculum in its broadest sense, was viewed as needing serious attention. This view was expressed by all disciplines, Biology, Chemistry, Physics, Engineering, Mathematics, Geosciences, and Computer Science. As with the laboratory, the greatest concern is with the lower division courses.

"...The main target of reform must be introductory biology..."
(Biology Workshop)

The effort should encourage and assist the communities to both analyze and restructure courses and curricula. NSF should assist the professional societies to provide leadership within the disciplines to examine and implement activities that address the needs.

"...(NSF should) fund the development of a variety of freshman/sophomore courses focusing on the integrative nature of engineering..."
(Engineering Workshop)

Types of support called for include both small unsolicited grants for individual or small groups of faculty modeled after traditional NSF project grant support, as well as substantial group efforts, involving expertise across the scientific disciplines and including such areas as cognitive science. The Computer Science Workshop proposed that Centers be established to serve as focal points for curricular development, training, and dissemination.

• Faculty

The Workshops identified the faculty as the keys to solution of the perceived problems and to a healthy undergraduate enterprise. They recognized also that the faculty are the primary operatives through which NSF programs of any kind work. In general two types of programs related to the "faculty problem" were identified: Those intended at least in part to attract and motivate research-oriented scientists and engineers to work on improved teaching, and those aimed at helping teaching faculty to achieve and maintain continuing technical competence.

"...The most important thing NSF can do for science education is to increase the prestige and respectability of teaching. To accomplish this, we recommend that the NSF establish grants for teaching and curriculum development, analogous to the influential grants now given for research, and that the NSF award prizes and fellowships to outstanding teachers."
(Physics Workshop)

Possibly the most systemic need identified in the workshops relates to changing the balance in the faculty incentive and reward system for teaching and research.

Several workshops produced similar recommendations including the concept that NSF establish "Presidential Teacher (young and old) Awards" analogous to the Presidential Young Investigator Awards for research. High value was placed on the importance of NSF recognition of the significance of creative activity related to teaching by initiating both recognition grants and dispersed project support.

"...(the Committee) recommends summer science institutes and other more extended renewal opportunities than presently available for faculty of primarily undergraduate institutions..."
(Geosciences Workshop)

The need for expanded and more flexible support of faculty enhancement activities was also cited by most workshops.

Particular concern for the needs of two-year college faculty was expressed in some workshops.

"... (the Committee) recommends the development of exchange programs between faculty at colleges (two and four-year) and universities, with an aim toward the sharing of instructional and technical ideas..."
(Mathematics Workshop)

- **Underrepresented Groups**

There was a high level of recognition of the importance of improving access to careers for women, minorities, and the disabled. Several workshops pointed out that the problem of shortages of mathematicians, scientists and engineers can be solved if underrepresented groups participate in these fields in proportion to their presence in the population. Typical of the recommendations of the workshops were:

"...(there are) major changes in the racial and ethnic composition of the U.S. population..."
(Engineering Workshop)

Develop a means for identifying and nurturing, early in their education, women, minorities and disabled who have potential in mathematics, science or engineering; create a program that makes "role models" available to underrepresented groups early in their careers; create programs aimed at retention of underrepresented students in science, engineering and mathematics courses and curriculum; develop recruitment materials directed towards women, minorities and disabled; increased support for programs that involve undergraduate women, minority and disabled students in research programs with faculty.

"...several population groups of significant size in the U. S. are under-represented in science. Their contributions and support are needed if the potential of the country is to be realized..."
(Geosciences Workshop)

- **Students**

The Workshops addressed not only the undergraduate cohort but also the pre-college interface and the advanced degree interface. There was strong support for the improvement of pre-college preparation of students in the sciences and mathematics and the nurturing of young people to enter careers in science, engineering and mathematics, particularly women and other underrepresented groups.

"...NSF should strengthen its existing programs for undergraduate research experiences, especially to populations now underrepresented or for which appropriate role models do not exist..."
(Biology Workshop)

It is clear that the academic scientific community regards the involvement of undergraduate student majors in meaningful research and related scholarly activity with faculty mentors as one of the most powerful of instructional tools. The workshops sense of urgency here was less than in other areas as they regarded the Research Experiences for Undergraduates (REU) program as a strong response to this need. They recommended that REU be continued and expanded; they did, however, raise at least two important issues. First, they indicated that REU is a good technique for increasing the involvement of women and minorities in the pipeline, and urged that this aspect of the program be continually stressed. Second, they called for an expansion of the program (or a new program) to include a much wider array of project types with support located across the spectrum of institutional types, i.e., nondoctoral institutions, not just at major research universities.

Summation

All workshops expressed concern about the low level of importance to which undergraduate education seems to have fallen and the urgency for restoring it to a position on the campus comparable to that of graduate study and research.

The program recommendations described above represent the major thrust identified with remarkable consistency across the workshops and with equally remarkable agreement among the individuals within the workshops. An additional point seems worthy of comment. Several workshops called for NSF consideration of policies for instructional components as part of the regular support of basic research. These might be either funded or unfunded, universally required or not, but would all be intended to underscore NSF's commitment to undergraduate education.

"...that NSF awards to faculty . . . include an emphasis on the commitment to combined teaching and research . ..."
(Engineering Workshop)

Finally, as mentioned earlier this summary does not begin to cover the wealth of individual ideas for strengthening undergraduate education across the disciplines contained in the reports, or more so, discussed at the workshops. Many of the ideas were more in the form of project proposals that might be examples of support under the programs listed above. For example from Geoscience, the pairing of a minority institution with a majority university in curriculum development; from Chemistry, faculty enhancement leaves at industrial or national laboratories; from Biology, improvement of graduate teaching assistants' instruction of undergraduates; from Engineering, study of international aspects of engineering and the curriculum; from Mathematics, exploration of the use of technology in mathematics instruction; from Computer Science, research into new instructional technologies; and from Physics, a summer science institute for humanists and social scientists. These and many more testify to the richness of the potential in the academic scientific community for assuring the long term health of collegiate education in the United States.

"...NSF should be actively involved in the planning and direction of undergraduate science, engineering and mathematics education..."
(Geosciences Workshop)

II. FINDINGS OF THE DISCIPLINARY WORKSHOPS ON UNDERGRADUATE EDUCATION

A. Workshop on Biology

1. Biology Workshop Participants

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2. Report of the Biology Workshop

Report of the NSF Workshop on Undergraduate Biology Education

June 1-2, 1988

Executive Summary

The workshop on undergraduate education in biology concluded that there are three main areas that require attention: **laboratories and course development, enhancing the quality of teaching, and recruitment and retention of students.** The three areas taken together constitute the type of *balanced* program needed to make progress. In recognition of the realities of limited resources, but without specifying hard priorities, there was a consensus that attention to **ensuring the quality of what was taught in biology, and the quality of instruction were essential to recruitment and retention of students.**

Leadership, Laboratory and Introductory Course Development

Problem: Because of the diversity of biology, there is no central leadership in matters of education as with other disciplines such as chemistry.
Solution: NSF should stimulate the total professional community in biology to carry out its leadership responsibilities.

Problem: Deterioration of role of biology laboratory and field experiences.
Solution: NSF should initiate a program of support for development of laboratory and field experiences and requisite skills in biology courses.

Problem: Introductory biology courses are confusing, aimless, and generally negative stimuli to career choice or selection of electives. Curricula don't address increasing multidisciplinary nature of biology.
Solution: NSF should support the development of introductory biology courses, and programs designed to strengthen multidisciplinary approaches in teaching biology.

Problem: The role of instrumentation, both simple new approaches as well as sophisticated instruments, is hindered by lack of resources.
Solution: The NSF should continue strong support for instrumentation necessary for both laboratory instruction and undergraduate research experiences.

Enhancement of the Quality of Teaching

Problem: Teaching is not rewarded.
Solution: NSF should initiate a program to recognize excellence in undergraduate teaching and support efforts to increase teaching prowess.

Problem: There is insufficient communication and transfer of ideas, etc. among teaching, research and undergraduate students.
Solution: NSF should fund programs that foster connections among active research groups, students and teachers.

Recruitment and Retention of Students

Problem: There is keen competition to recruit presently underrepresented groups in all sciences.
Solution: NSF should strengthen its programs for women, minorities, and handicapped in relation to the biological sciences.

Problem: Undergraduate research experiences are important in making science career choices.
Solution: The NSF should strengthen its existing programs for undergraduate research experiences, especially to populations now underrepresented or for which appropriate role models don't exist.

Introduction

The problems in undergraduate biology education have been well-documented in a variety of studies indicating the relatively poor performance of American students compared to those in other countries. This problem must be viewed with considerable concern since biology education is the foundation for training physicians, biomedical researchers, biology teachers, and agricultural researchers and technicians; the skills and expertise of these individuals have a direct impact on our nation's economic competitiveness and the well-being of our citizens. Moreover, undergraduate biology education provides the support base for the nation's research and technological application efforts — both in terms of providing education and enlightened citizens who can understand the need for research and technological benefits and in providing competent graduates who will become the researchers and technicians providing tomorrow's scientific expertise.

On June 1 and 2, 1988 an *ad hoc* panel met in Washington, D.C. to provide advice to the National Science Foundation on undergraduate education in biology. The charge to this panel was threefold: to consider the needs in undergraduate education in biology and the barriers to meeting or otherwise resolving these needs, to review the range of programs in undergraduate education in biology currently funded by the National Science Foundation, and to suggest ways in which the activities of the Foundation in the area of undergraduate biology education could be made more effective and responsive to national needs.

Three general points were emphasized throughout the discussion. Taken together they comprise the context in which undergraduate education must be examined. First, the issue of leadership in biology comes into particularly sharp focus when viewed in the context of undergraduate instruction. Unlike the situation in chemistry, physics, mathematics, or geology, there is no unified group that speaks with one voice for all of biology. This problem is complicated by the lack of unity and coordination across the variety of educational institutions including two-year and four-year colleges and universities. A combination of professional societies, perhaps, could play this role, but has not, in our opinion, risen to this opportunity. As a result of this lack of leadership, no one appears to be capable of presenting an appropriate curriculum for biology overall, or of representing the needs of the field or its potential to the general public. In order to achieve the objectives we have outlined below, some degree of unification is necessary, and we would strongly encourage the NSF to bring the major coordinating societies together for these purposes.

Second, biology is, to a greater extent than the other sciences, a composite and complex field. Biology has gained a new vitality from the infusion of chemical methodology, especially the ready availability of the means for sequencing and synthesizing macromolecules and of new kinds of instrumentation. Systematic and evolutionary biology, conservation biology, and ecology, also with progress propelled by advanced methodologies, are central to solving critical natural resource problems that appear with an alarming increased frequency. An increased emphasis on biological diversity is well justified in an age of extinction of species, and the role of the NSF in this field, as the major source of federal support, must be considered. NSF must be sensitive to the importance of including these diverse fields in undergraduate biology education and achieving an appropriate balance realistically representing the breadth of biology.

Finally, a prerequisite condition to enhancing the quality of undergraduate education in biology is the preparation of the students K-12. The tradition of offering progressively watered-down versions of college-level biology at these levels of instruction is not optimal. The need to improve college education in biology can not be totally separated from general improvement of instruction in earlier grades. Within this context, it is important to recognize that two-year colleges provide a large portion of introductory biology education and must be incorporated in mainstream efforts to improve biology education. For this reason, the Committee commends NSF for its support of biological education K-12, and reemphasize the importance of this area. In addition, the general difficulties of elementary and secondary education in the U.S. are such that college students are often poorly prepared in analytical reasoning skills, including those in language and mathematics, that are so essential to success at the college level. These problems are not peculiar to biology, but they are of such central importance that we feel that it is necessary to emphasize them in this context.

Our analysis of problems and solutions concludes that there are three main areas that require attention: **laboratories and curricula, enhancing the quality of teaching, and recruitment and retention of students.** Within each there are grouped specific concerns and recommended courses of action. The three groupings taken together constitute the type of balanced program specific to biology education that we feel is needed to make progress. Recognizing the real limitations to proceeding on every front at once, but without specifying hard and fast priorities, there was a consensus that attention to ensuring the quality of what is taught in biology, and the quality of instruction, is essential for successful recruitment and retention of students.

Analysis and Recommendations

• Laboratories and Course Development

Laboratory and Field Exercises. A central objective of undergraduate biology instruction for majors and non-majors alike is to help students acquire scientific, critical and creative reasoning skills. These include the ability to explore nature, to raise questions, to generate multiple tentative answers, and to test these through the deduction of their logical consequences and a comparison with evidence. These skills are not only essential tools of the professional scientist but are patterns of thought which serve people well in all walks of life and are essential for an informed and effective democratic citizenry.

Because these skills develop through attempts to use them in the exploration and explanation of nature, the laboratory and field experience play a crucial role in biology instruction. Regrettably, too few laboratory and field exercises sufficiently challenge college students' abilities to inquire. Thus, we see a pressing need for projects that would:

- create open-ended (non-cookbook) laboratory and field exercises that challenge college students' ability (1) to explore biological phenomena, discover patterns of regularity, propose alternative explanations and (2) to design and conduct experiments in which these alternatives are tested;
- integrate the laboratory and expository elements of instruction in ways that retain the exploratory nature of the laboratory and allow the lecture to build upon laboratory exercises;
- develop methods of teaching that allow for student exploration, argumentation and critical thinking, yet enable the orderly introduction of important biological concepts;
- re-think the laboratory component of mass enrollment, non-majors, introductory courses and develop experiences which require simple, inexpensive apparatus and instrumentation and design, pilot-produce, and test such devices;
- re-think the laboratory and field component of majors introductory and advanced courses in ways that enable students to acquire skill in using modern laboratory and field apparatus and instrumentation in the context of designing and conducting personally meaningful inquiries;
- design and test measures of evaluation compatible with the emphasis on higher order creative and critical thinking skills.

The NSF should initiate a program of support for the development of laboratories and field experiences in biology courses. Laboratory skills are fundamental to an understanding of biology as a science, and are being neglected for many different reasons. Teaching laboratories is time-consuming and not highly rewarded; students may find laboratories boring and not related to their own educational purposes. The Committee generally agreed, however, that no more effective way of appreciating biology exists than the laboratory experience. For this reason, we recommend that the Foundation support studies of effective approaches to laboratory instruction for courses throughout the undergraduate biology curriculum, including supporting workshops, the development of model laboratories, and associated activities. We also recommend a program of released time for selected faculty members, on a competitive basis, for the development of laboratories associated with different courses in the biology curriculum, as well as other innovative activities in this area.

Introductory Biology Courses. Biology has become the dominant science of the last quarter of the 20th century. Knowledge of its basic findings and methods is essential for the applied fields of medicine and agriculture. Biological knowledge is also essential for an understanding of ourselves, the natural world, and the history of life over time. It must be presented at the core of a liberal arts education.

While recognizing the centrality of the biological sciences, we must accept, also, that there is a pervasive feeling on the part of teachers, students, and critics that, in many respects, the teaching of biology is inadequate. Both courses and textbooks come under censure. There is little likelihood that many acceptable courses will spring independently on campuses throughout the nation. It is essential, therefore, that the NSF undertake a rigorous program to assist development of undergraduate biology courses that are both worthy of the science and essential for national needs.

The main target for reform must be introductory biology in the colleges and universities, for this may be the terminal course for those who will become our national leaders, scientists in other fields, informed citizens, and those who aspire to a career of teaching in our nation's schools. Overt efforts must be made to address courses at two-year colleges where many college students will receive their preparation in the discipline and which for many others is their only exposure to college biology.

New approaches to the teaching of biology at all levels must emphasize the conceptual framework of biology, reduce the excessive terminology that characterizes so many courses, consider the strengths and limitations of the scientific process, and deal explicitly with human problems for which biological data and methods can suggest solution.

The more advanced undergraduate courses should combine the fundamental principles of biology developed over time with the astonishing new information emerging from the biological revolution in molecular biology, organismal biology and ecology. The vastness of modern biology is such that effective reform of the undergraduate curriculum must have the informed support of the NSF.

The NSF should support the development of introductory biology courses. This important goal could be accomplished through workshops, special projects, and similar activities which draw together faculty from the variety of two-year, four-year, and university level institutions as well as respected researchers. It is recommended that such courses should be organized along "inquiry" lines, and specifically so that the students might gain a sense of how science operates. Whether or not they become professional biologists, such knowledge will be of great importance to them. Existing textbooks were viewed by the committee as largely unsatisfactory, their problems reflecting the ferment that is characteristic of the field of biology and the consequent lack of agreement on what constitutes a satisfactory outline of basic principles for the field. There is probably no perfect answer to this dilemma, but the approaches that might be developed collectively would be extremely useful for improving the existing texts. The Committee was divided on the question of whether or not there should be a different introductory biology course for undergraduate majors and non-majors, but did agree that this question deserved further study and thought. Special attention should also be given to the meaning of A.B. and M.A. degrees in biology in the contemporary world: these degrees currently have little meaning as compared with comparable ones in engineering, for example. Biologists should consider this problem in more detail, especially in view of the clear need for more trained biologists in the future in industry, for example.

Undergraduate biology education must address a variety of instructional issues which are common to the diverse sub-disciplines comprising biology. Such issues include the curriculum and course design for majors and non-majors, laboratory needs, and analytical skill development in undergraduate students. At present, there is a lack of leadership which can effectively focus and direct efforts to respond to these issues. **The NSF should support professional associations trying to provide cohesive leadership in identifying and implementing activities to improve undergraduate education.** Associations may wish to form study groups and/or assemble teams of appropriate professionals to examine specific issues, and are expected to provide promotion, dissemination, and assistance for adoption of specific potential solutions.

Instructional Instrumentation. It is well known that America's stock of instruments for both research and instruction needs to be replenished in order that these activities can be carried on at an appropriate level. **The NSF should continue strong support for appropriate instrumentation both for laboratory instruction and for undergraduate research participation.**

Multidisciplinary Courses. Biology as a discipline has increased in complexity at all levels, ranging from greater understanding of the mechanisms underlying biological phenomena to the interactions among cells and whole organisms with their biotic and abiotic environments. Many of the technological advances permitting this explosion of knowledge in the biological sciences have come from applying concepts and advances from the disciplines of physics, mathematics, computer science, and engineering. However, the development of biology course curricula and laboratory technology and exercises has not benefitted from this multidisciplinary interaction. **The NSF should initiate programs designed to strengthen multidisciplinary approaches in teaching biology.**

• Enhancing the Quality of Teaching

Recognition of Excellence in Teaching. America is unique in its dependence on universities for its research enterprise, a system that works well for research but that often places undue strains on the educational capabilities of the same institutions. **The NSF should initiate programs of recognition for excellence in undergraduate teaching of biology and should support released time for faculty members primarily engaged in instruction to allow them to improve their teaching.** National and state-level awards for outstanding biology teaching that carry with them high recognition and a substantial stipend would directly benefit the recipients and indicate to all biologists the emphasis that NSF places on teaching as a crucial part of a faculty member's university or college responsibilities. Grants allowing faculty leave time and financial support—in the academic year and/or the summer—to improve teaching either through curricular redesign or research experience would have a beneficial effect. This is especially important for two-year and small four-year college faculty where there is frequently little opportunity to interact with researchers or be exposed to teaching innovations. Just as NSF research grants have been decisive in the restructuring of the American university in science to a primarily research-oriented institution, so could NSF grants primarily aimed at instruction help to redress the balance and restore the traditional function of instruction, properly valued, to the American university.

Training for Student Teachers. The training of graduate student and talented undergraduate teaching assistants in the principles and practice of teaching biology should receive NSF funding. Teaching assistants, particularly in large institutions, often have significant responsibility for the conduct of laboratory and discussion sections. In fact, they often have quantitatively and qualitatively more contact with students than do instructors. They may be coached in the biological principles and the techniques appropriate to specific labs and demonstrations, but rarely do they receive instruction in teaching. Their lack of experience and of training can result in situations that alienate their students and cause the students to have a negative perception of the subject.

General training programs, such as one-day or one-week sessions as sponsored by some college and universities, are not adequate to meet the specific but diverse needs of biologists teaching different materials at different levels to different student clienteles. Specific information on techniques of teaching labs and discussions in biology, as well as testing, grading, evaluating student problems, and related matters, is needed.

The NSF should initiate programs to enhance the teaching abilities of graduate and undergraduate students. Funding of training programs in the teaching of biology, supplied to biological science departments, would: (1) raise the level of undergraduate instruction in biology; (2) increase the expertise and therefore the confidence of teaching assistants, (3) potentially attract good undergraduates to the teaching of biology and therefore to careers in biology teaching and research, (4) facilitate more effective teacher-student interaction, and (5) demonstrate to administrators and the public of the commitment of both federal agencies and college faculties to effective teaching.

Networking Teaching, Research and Students. Special attention should be given to collaborations between 2-year college faculty, 4-year colleges, universities, and industry. Biologists are trained at all these institutions, often for positions in industry. Cooperation among them is certain to improve the quality of education for all.

The NSF should fund programs that foster connections between active research groups and individual scientists and teachers. NSF is encouraged to develop programs to support workshops, summer stipend requests, and grants that facilitate interactions among excellent research scientists and teachers who have the goal of expediting information transfer to lecture and laboratory aspects of biology course curricula. NSF support for laboratory equipment acquisition and exercise development should mandate the marriage of excellent researchers and teachers to evaluate current information and technology to be judiciously intertwined for the benefit of short-term as well as long-term teaching effort.

- **Recruitment and Retention of Students**

Underrepresented Groups. The manpower needed in biology from the latter half of the 1990s onward will not be attained without the full participation of all segments of American society. In addition, science and engineering education is a major focal point for changing the traditional employment patterns. More women than ever presently are enrolled in the biological sciences. In contrast, the number of ethnic minorities enrolled in biology has shown a decrease during the period 1977-1986 of approximately 28% at the undergraduate level. Even though there has been an increase in the number of women entering these fields at the university level, the number actually entering employment in these fields has not kept pace with the increased number that are being trained at the graduate level. One of the problems in this area is the lack of employment opportunities for those with an A.B. degree in biology, as mentioned above. Furthermore, there are essentially no special opportunities available for the handicapped for graduate study or employment in biology. **The NSF should strengthen its programs for women, minorities, and handicapped individuals in relation to the biological sciences.**

During the past 15 years several initiatives for addressing the critical problem indicated above have been proposed by several federal agencies. The most notable examples are the two models that have been quite successful at the N.I.H.: the MARC (Minority Access to Research Centers) Undergraduate Honors Program and the Minority Biomedical Research Support Program (MBRS). We propose that the NSF make a serious commitment to allocation of funds for similar programs. Initially, it is recommended that the MBRS format serve as a start-up for this effort. This model will place a great deal of emphasis on the recruitment of minority students under the NSF-RIMI program Historically Black Colleges and other institutions. Minority students at majority institutions would be eligible for support under any existing research program. Quality control under this type program will be prescribed under a minimum G.P.A. that would be consistent with the aims and goals of the research program.

It is anticipated that under the MBRS type format that at least 40 institutions would probably qualify for awards. The first year budget is estimated as follows:

Phase I: 200 students at $3600 per year = $720,000

The maximum number will not exceed five students at a given institution.

The awards will be made for periods up to 4 years. If 200 students are added per year, the cost will rise to just under $3 million per year by 1995.

It is imperative that the NSF address the involvement of minority students throughout the "pipeline" (primary, secondary and college levels). Since minority students do not tend to go on to science (e.g., only 6 doctorates in biochemistry for 1986) this is an urgent problem that requires NSF's participation. A particularly important contribution can be made by community colleges where large numbers of minority and disadvantaged students start their academic career. Cooperative programs and partnerships between two-year colleges and universities aimed at attracting and developing minorities for scientific careers could be especially effective.

Undergraduate Research Experiences. An appropriate goal of the NSF is to build up the national effort in the field of biology to reflect the current revolution in the field and resulting rapid expansion of our knowledge of biological systems. One of the most effective ways of stimulating interest in careers in biology and in educating future professional biologists and teachers of biology is through programs to introduce students at the undergraduate level to active research laboratories. There is widespread agreement that research experience is an essential adjunct to formal lecture and laboratory curricula to train future biologists. The question is how to most effectively provide research opportunities both for those already committed to biology and, even more importantly, those who are potentially interested but have not had the opportunity to experience the exciting possibilities of a career in biology.

The existing REU program has several components and a flexibility that allows utilization of our current research community. The first major category of opportunities now in place, the REU supplements, are simple ways to add undergraduates to on-going research efforts. The only problem is that this aspect of the program is limited to investigators with NSF grants and leaves out a large portion of the biological community, particularly the biomedical sciences that do not hold NSF grants.

The second major category, REU sites, allows for greater diversity. The committee offered several suggestions for further improvements. Allowing on-going undergraduate summer research programs such as the long-established Woods Hole and Cold Spring Harbor biology programs, the newer site at Princeton and the more interdisciplinary program at Caltech, to compete for support was endorsed. One important aspect of such programs is that they allow undergraduates at small institutions to broaden their experience of biology by moving for an entire summer to a new scientific environment. Expansion of such programs to other universities should be encouraged.

Second, the program should not be limited to Ph.D. universities and major research faculties, however. It should be encouraged at smaller 4-year colleges with on-going research operations and demonstrated overall excellence. This is a particularly important mechanism for developing the major, currently untapped resource of future biologists that exists in our women's and minority colleges. Students at these institutions are attracted to the professions (law and medicine) rather than biology because they are unaware of the rewards of careers in research/teaching or even the nature of these careers.

Finally, various professional organizations have programs in place for providing individual summer research fellowships for talented individual applicants. Such programs should be allowed to submit proposals to NSF programs to support additional students. Such fellowships could be viewed as individual achievement awards so that students begin to identify themselves as talented biologists, again particularly important for women and minorities. Summer experiences have the obvious advantages of long-term, in-depth development of research projects. However, projects during the academic year should also be encouraged in individual laboratories to provide individuals their first contact with research.

The NSF should strengthen its existing programs for undergraduate research participation as suggested in the foregoing analysis. The Committee was unanimous in its view that no experience is more valuable in the training of undergraduates in biology than participation in research activities. We recommend that supplements to research grants to include undergraduates in these activities be increased, that centers of biological research be encouraged to incorporate undergraduates in their activities, and that primarily teaching institutions be supported in providing research activities for their undergraduates, whether on campus or at another institution. We view activities of this sort as extremely cost effective and of great importance.

B. Workshop on Chemistry

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2. Report of the Chemistry Workshop

WORKSHOP ON UNDERGRADUATE EDUCATION IN CHEMISTRY

May 18 - 19 1988

Outline

Summary

Impending personnel shortages in the chemistry workforce and the lack of public understanding of chemistry and its role in society threaten to undermine the fragile structure of chemical and allied industries that have provided this Nation with over 10% of its gross national product. To turn this situation around, the participants in the Workshop on Undergraduate Education in Chemistry have concluded that our educational system must provide both scientifically literate decision makers and citizenry and a sufficient pool in the United States of capable scientists and engineers. For this to occur, chemistry undergraduate programs must (1) educate non-scientists about chemistry to an extent that enables them to understand and appreciate the role of chemistry in their lives, (2) motivate students for careers in science and technology, (3) supply the needs of chemical and allied industries for professional chemists, and (4) prepare chemists for teaching at the secondary school level. To achieve these goals, the participants strongly urge the National Science Foundation

- to enhance laboratory instruction through programs that address the widespread, fundamental, and long-standing problems in the first two years of the undergraduate laboratory curriculum,
- to establish a broad-based curriculum development program and to support the formation of a Commission empowered to generate up-to-date instructional materials in order to revitalize introductory courses in chemistry,
- to catalyze direct interactions involving industrial/ national laboratories and undergraduate students/ faculty that enhance student motivation for careers in chemistry,
- to establish Centers for Instructional Research and Development to implement continuing developments in chemical education,
- to broaden faculty exchange programs to include research in chemical education,
- to initiate teaching internships and Presidential Young Teacher/Researcher programs, and
- to establish a program of research participation targeted to handicapped, minority, and women undergraduate students to stimulate their increased involvement in chemistry.

Preface

Undergraduate education in science and engineering in the United States is in a state of crisis. Despite the importance of science and technology to competitiveness in present-day and future world markets, the United States has failed to invest adequately in building the technical workforce and educated citizenry needed to assure a secure future. This workshop report provides a potential solution to the well-known and soon-to-be- devastating problem.

Responding to calls for action articulated in "A Nation at Risk" and other reports, the National Science Board's Task Committee on Undergraduate Science and Engineering Education (Neal Report) has recommended specific, appropriate roles for the National Science Foundation, as well as for other institutions and organizations in both the private and public sectors. The Workshop on Undergraduate Education in Chemistry, whose recommendations to the NSF are presented here, was one in a series of workshops, organized at the behest of the Foundation's Director, to translate the recommendations of the Neal Report into workable NSF programs.

Problems in undergraduate education in chemistry are similar to those in other fields of science and engineering:

- there are too few students motivated to pursue careers in chemistry;
- too many undergraduate laboratories are struggling with inadequate and obsolete equipment, and
- too few teachers of the necessary caliber are available to replace those who are retiring.

It is precisely because most college students begin their careers in science and engineering from introductory courses in chemistry that the problems in undergraduate chemical education are deserving of close scrutiny and immediate resolution.

The chemical community represented by the participants in the Workshop on Undergraduate Education in Chemistry strongly supports the initiatives that are presented in this Report. Our recommendations address long-standing and pervasive problems in undergraduate chemistry education that require well-funded comprehensive programs at the NSF. The NSF has only recently reinstituted focused attention on undergraduate education, but without the funding necessary to have substantial impact on the rapidly eroding infrastructure. Significant increases in NSF support for undergraduate education are essential to the success of the recommended chemistry initiatives, let alone those for all of science and engineering.

1. Introduction and Overview

The Neal Report has already documented the serious threat to our economy and society posed by impending personnel shortages in the scientific and engineering workforce and by a lack of public understanding of science and technology.[1] Erosion in the quality of education as well as the declining pool of college age students signal alarming developments that are impeding this nation's ability to compete effectively in the global economy during the coming decades. These problems are compounded by the relative absence of women and, especially, underrepresented minorities in the science and engineering workforce;[2] if these groups were to participate in proportion to their presence in society, the problem of shortage would be solved at a single stroke!

Moreover, there are suggestions that our society is becoming increasingly skeptical of, and even hostile to, some aspects of industry and technology. Young people are consequently discouraged from following careers in science and many areas of engineering. Public interest groups, public officials, and the public at large exhibit insufficient understanding of the scientific method, quantitative concepts, and risk assessment to allow scientific and engineering information to be properly factored into the political decision-making process. Furthermore, scientists and engineers need to speak clearly to the public about scientific and technological issues so that decision makers can reach well-informed conclusions. The alternative, not really far down the road, is separation of science from the society that supports it, and the alienation of just those young people whom we want to join the science corps.[3] If our technological industries are to prosper and our economy to grow, our educational system must provide both:

- scientifically literate decision makers and citizenry; and
- a sufficient pool in the U.S. of the most capable scientists and engineers in the world. Essential to this goal is the attraction of both women and underrepresented minorities into science and engineering professions.

In order for the disciplines of chemistry to share in the renaissance of science education, chemistry undergraduate programs must:

1) educate non-scientists about chemistry in its broadest sense to an extent that enables them to understand and appreciate the role of chemistry in their lives;
2) provide an intellectually challenging introduction to modern experimental science in order to prepare students for advanced study in science and engineering;
3) supply the needs of chemical and allied industries for professional chemists; and
4) prepare secondary school science teachers competent to teach chemistry as a modern, laboratory-centered science.

Undergraduate education in chemistry has entered an alarming decline. Whereas the percentage of students receiving a bachelors degree in chemistry was 1.56 of all Bachelors' degrees in 1970, that percentage declined to 1.17 by 1978 and continued steadily downward to 0.97 in 1986.[4] From 1978 to 1986, the total number of students who annually received bachelors degrees in chemistry declined by an alarming 13 percent,[4] and even greater erosion is anticipated during the next 10 years. This erosion is reflected in graduate school applicant pools and in the availability of new job applicants for chemical industry and, especially, for academia. The number of chemical engineers graduating from U.S. universities has also dropped dramatically (from 7021 in 1983 to 5229 in 1986) with resulting shortages in the workforce. Projected retirements of high school chemical educators and college/university faculties in chemistry are anticipated to require a significant infusion of new talent in the 1990's which, according to current predictions, will not be available. Severe shortages in the chemistry workforce are expected.

As the central molecular science, chemistry plays a special role in our understanding of nature, in the education of scientists and engineers, and in our nation's industrial base. The traditional chemical industry contributes to the very fabric of our material lives as well as to a substantial credit in our balance of payments.[5] Chemicals and chemical principles are the foundations of development in structural materials, biology and medicine, electronic materials, energy generation, and numerous other areas upon which our society is dependent. Understanding the chemistry of our natural environment and predicting the effects of human activities on the environment are crucial to our future on this planet.

Chemistry provides the underpinning for nearly all of science and engineering and thus has a pivotal role in the undergraduate curriculum. It is the first course, along with calculus and English, for most students in science, engineering, and health fields. This first course in chemistry can be a thrilling, motivating experience, but as often as not it is boring. The result of a boring course is a total lack of enthusiasm for a career in science or engineering.

To reverse the current national trends in science education in general, and chemistry education in particular, there is an urgent need to address the problems of undergraduate chemistry education, especially at the introductory level. In beginning chemistry classes, it is incumbent upon chemists to provide an exciting introduction to the scientific method along with the principles and practice of structure, synthesis, analysis, and dynamics. There is a critical need to incorporate into freshman and sophomore chemistry courses the applications of chemistry to biology, to materials of all sorts, and to environmental problems. By viewing the frontiers of science early in their educational experience, students will be challenged and stimulated to consider science for their future careers.

2. Laboratory.

Chemistry is an experimental science, and for the student of chemistry a laboratory experience is an essential part of learning chemical concepts and how new knowledge in chemistry is generated. Hands-on manipulations of chemicals, chemical reactions, and instruments are indispensable elements of an undergraduate education in chemistry. The quantitative nature of chemistry as a science, whether the topic is a discussion of a chemical structure, elucidation of a chemical reaction rate, or a description of molecular composition demands that the student appreciate in an intimate way how measurements in the chemical sciences are accomplished.

Undergraduate research involvement is well recognized as a stimulus to career commitment in chemistry. The NSF has instituted important and effective undergraduate research programs (REU and RUI) which must be maintained and strengthened. However, undergraduate research is only one part of the laboratory component of a successful chemistry laboratory program. It cannot reach most first- and second-year college students, where career choices are often made. Yet it is precisely at the introductory level where laboratory experiences are generally inadequate. A poor laboratory experience caused by inadequate facilities, outmoded and unreliable instruments, and chemical content of no discernable purpose (to the undergraduate), can deflect the best young minds and talents from science careers. Conversely, an excellent laboratory can stimulate a choice of science careers because the student views scientific investigation as exciting and worthwhile.

It is appropriate, therefore, to articulate the characteristics of an excellent laboratory experience. This can be done by stating a set of *goals*, of what should be accomplished for the student, whether he/she be a chemistry major, a science major, or a non-science major. These goals include:

- designing experiments that serve to stimulate the student's interest in science and in chemistry;
- designing experiments that develop the student's skills in manipulating chemicals and chemical reactions in the contexts of synthesis, structural characterization, chemical dynamics, and analysis;
- providing the student with an appreciation of the underlying purpose of chemical experimentation;
- teaching the student how to interpret and carry out a set of written experimental instructions, and how to convey experimental results in a scientific report;
- teaching the student basic elements of the safe handling and disposal of chemicals.

As reported by the NSB Task Committee on Undergraduate Science and Engineering Education,[1] the undergraduate experiences of students in chemistry courses in the U.S. do not achieve the above goals. There are widespread, fundamental, and long-standing problems in laboratory instruction in chemistry. The problems are most acute, affect the largest numbers of students, have the greatest effect on retention of students in the study of science, and offer the greatest opportunity for NSF action, in the first two years of the undergraduate curriculum's laboratory courses. The needs of these laboratory courses mainly fall into two categories: **instructional laboratory equipment and the design and content of experiments.**

- Instrumentation is out-moded, unreliable, or not present at all in the first two years of the undergraduate laboratory curriculum at most colleges and universities.[6] The primary reason for this lack of modern instrumentation is limited financial resources. The need expressed here recognizes that freshman and sophomore level instruments need not be state-of-the-art to be effective pedagogical tools.

- The content of the chemistry laboratory experiments that students encounter, especially in the first two years, tends to be stagnant and restricted by lack of experiment development efforts and by severe limitations in the availability of necessary instruments. The laboratory experiences in these years generally fail to capture student interest, and laboratory exercises rarely give the impression that chemistry is important in modern society.

There are other problems in laboratory instruction, such as poor equipment maintenance, insufficient support staff, and inexperienced graduate teaching assistants. The first two of these are legitimately institutional obligations; the third should be a continuing part of laboratory development efforts in chemistry departments.

Recommendations Regarding Laboratory Instruction.

We recommend that the problems of undergraduate laboratory instruction in chemistry be addressed through two programs that expand and enhance existing efforts both monetarily and in scope:

- Undergraduate Chemistry Laboratory Development
- Instructional Laboratory Instrumentation for Chemistry

These programs should provide opportunities to the full spectrum of educational institutions, ranging from two- and four-year colleges to universities.

The purpose of the *Undergraduate Chemistry Laboratory Development Program* would be to support the design and development of undergraduate laboratory experiments, especially those for courses in the first two years of the chemistry curriculum, including both major and non-major courses. The design and development should aim to achieve the overall goals stated above for modern laboratory instruction in chemistry.

The purpose of an expanded *Instructional Laboratory Instrumentation Program* is to continue to assist educational institutions in the acquisition of modern and/or innovative equipment for undergraduate instruction, begun through NSF's ILI program, and to support the design and development of pedagogically effective instruments and widely applicable instruments of low cost.

We recognize and applaud existing efforts at the NSF in the above directions and make these proposals not to supplant but to enhance them both financially and in scope.

Additional Objectives

- Laboratory development should incorporate new technology into the design of experiments, including digital systems and modern measurement devices — with the aim of providing better instruction and instruction at lower cost.
- Laboratory pedagogy should encompass a balanced combination of hands-on laboratory experiences and the use of new technology based on digital simulation and computational systems.
- Desirable features of proposals would be plans to transfer/publish innovative steps, procedures, designs, etc., accomplished in laboratory experiments and with instrumentation such that they become accessible to other institutions.
- Attention should be given to development of the teaching skills of graduate assistants who actually provide much of the laboratory instruction to undergraduates in universities.
- A larger cadre of advanced undergraduates should be involved in chemistry laboratory instruction to stimulate their interest in teaching and to provide a sense of community and role models for beginning students.
- Instruments of potentially low cost should be developed and marketed by the private sector so that pedagogically sound, but inexpensive instrumentation can be made available to a greater number of educational institutions. Low cost teaching equipment has, when such equipment has been marketed, had a beneficial effect on undergraduate laboratory instruction (*e.g.*, mass selective detectors, capillary gas chromatographs).

3. Curriculum.

Chemistry instruction at the introductory level has resisted change despite numerous exciting advances and a substantial broadening of the discipline. The result has been a virtual fixation with topics and foundation concepts that served chemistry well during its early development as the central molecular science, but which today do not allow us to present chemistry as the dynamic, exciting enterprise that we know it to be. If the present course is followed to the limit, chemistry, like Latin, soon could be regarded as a "dead" language.

The constraints on curricular change are enormous. Standardized examinations for professional school admissions (MCAT,DAT, for example) rely on the specific format of unchanging topics for introductory courses in chemistry. Even certain initiatives of the American Chemical Society restrict curricular changes, although its Committee on Professional Training allows considerable flexibility. As a result, students often perceive chemistry as an unchanging scientific discipline in which all of the important discoveries have already been made.

The problems we have defined are amenable to resolution; the leadership required to effect needed changes will be taken by influential members of the chemical community with the support of the National Science Foundation. In the area of curriculum development, where special efforts will be required to bring about effective restructuring of the introductory programs for chemistry, we recommend the formation of a Commission and establishment of a curricular development program by the National Science Foundation

- to generate comprehensive content and curricula for undergraduate exposure to the chemical sciences that meet the national needs to educate scientists and engineers and to broadly educate students who as citizens are expected to participate in and influence decisions regarding applications of the chemical sciences in an increasingly complex technological society, and
- to establish the means to introduce the curricula into colleges and universities for the broadest possible impact.

The absence of any major change in the curricula employed for chemical instruction during the past 30 years, and the resistance in private publishing ventures to substantive textual changes for the introductory courses, suggest the need for the implementation of this program by the NSF. The success of these initiatives will be dependent upon

- primary funding by the National Science Foundation, which recognizes the importance of this effort,
- multi-year dedication to this program by a highly select group of chemical scientists whose visibility and leadership will certify program development and implementation, and
- endorsement of the mission by chemical societies, associations, and industries, and by leaders in the chemical professions with a commitment to assist in materials development.

The goals of the Commission should include

- providing a link to educational testing services that could immediately begin discussions on ways in which curricular flexibility could be incorporated into test formats,
- heightening awareness of the need for curricular changes in chemistry. The Commission would determine the impact of proposed changes on disciplines that utilize introductory chemistry, and facilitate understanding of that utilization,
- developing the charge for Task Forces to be created to implement broad curricular developments and establishing guidelines for their timely and comprehensive efforts, and
- facilitating implementation of curricular developments to insure wide distribution and impact.

The Task Forces would be expected to develop materials, especially textual and related materials, for adoption at colleges and universities, and to integrate, as much as possible, both the essential elements and the exciting new frontiers of chemistry. The National Science Foundation should provide multi-year support for broad curricular developments that offer diversity in effective instruction, consistent with established guidelines.

4. Industry/Academic Coupling.

Undergraduate research involvement is well recognized as a potent stimulus to the initiation of career commitment in chemistry. The Neal report strongly endorses undergraduate research participation and specifically recommends the summer placement of undergraduates in industrial research laboratories. In chemistry, we are fortunate to have a large established industrial research structure which is a potentially enormous resource for undergraduate research. National Laboratories provide additional opportunities. Moreover, there is significant untapped potential for interactions between faculty who teach undergraduates and the staff of industrial or national laboratories.

Additionally, there is a significant curriculum/counseling need for increased knowledge of industry and industrial career opportunities on the part of both undergraduate faculty and students. Direct exposure of students and faculty to industrial and national laboratories will help address this need.

NSF should take the lead in catalyzing direct interactions involving industrial/national labs and undergraduate students/ faculty. For students, early exposure (from the freshman year on) to research often gives strong impetus to the selection of a career in chemistry. Knowledge of the real interests and needs of industry and national laboratories in chemistry can strongly encourage students to become chemistry majors.

In the area of undergraduate research we recommend that

- NSF should jointly fund summer research programs for undergraduate students with industry/national labs. [Alternatively, NSF could support university facilitators to initiate these programs or fund "demonstration projects" at specific institutions.]

The resultant reinjection of excitement into the corridors of chemistry departments about opportunities for students at all levels will encourage students to consider careers in chemistry.

In the area of faculty/university relations we recommend that

- NSF should jointly support programs of faculty leaves or visits at industrial institutions/national laboratories.

The involvement of faculty at industrial labs can have a tremendously broadening effect on the faculty member and enhance his/her ability to connect chemistry to the real world for his/her students. If done creatively, the faculty/industry relationship can be continuous, long term, and could even involve collaborative research at the college after the visiting period or between visits. The "faculty" in question could be from research universities, undergraduate colleges, community colleges or high schools. Funding for the program could be shared between industry and the NSF (at first). The program could involve summers or sabbatical terms, and would reward outstanding teachers and expose them to state-of-the-art science/technology, which further enhances their ability as teachers.

In combination with the student-oriented programs, the faculty programs could help establish ongoing industry/university relations that would facilitate curriculum development in the university and student recruitment by industry.

5. Centers for Instructional Research and Development.

- The NSF should establish a program to support state or regional Centers for Instructional Research and Development.

Such centers should be designed to bring together enthusiastic, effective, dedicated chemists to work on curricular experimentation, application of various technologies to the teaching/learning of chemistry, development and testing of new experiments or apparatus, and other specific projects. Special emphasis should be placed upon involving a mix of persons from Ph.D.-granting universities, other universities, four-year colleges, and two-year colleges in collaborative efforts, and upon maintaining contacts among participants and institutions after a project has been completed. Centers could involve a single institution that would draw participants from others in the area, but would preferably involve consortia consisting of all of the types of institutions enumerated above.

Centers would require a small permanent staff to direct and manage their programs and maintain long-term contact among participating individuals and institutions. NSF-supported fellowships should be available on a continuing basis to support both academic-year and summer participants in projects undertaken at the discretion of the center. In addition, such centers could serve as a focus for larger-scale projects that would be supported by separate grants from both public and private sources as well as other NSF-SEE programs.

Centers for Instructional Research and Development would be able to contribute to most of the high-priority items identified in the Neal report:

- laboratory development;
- faculty professional development;
- course and curriculum improvement;
- comprehensive improvement in chemistry education, and
- collection, study, and analysis of data on undergraduate education (on a regional basis).

They would provide the following additional benefits:

- increased utilization of the talents and experience of teachers in two-year and four-year colleges;
- long-term contacts and networks that provide cross-fertilization of ideas among all types of institutions;
- Increased professional awareness and better identification with the discipline of chemistry among participants;
- Improved articulation among source (e.g., two-year) and acceptor (four-year) institutions[7] that will result in recruitment of more and better students in chemistry and the chemistry-related sciences.

6. Faculty Exchange

Exchanges of faculty between educational institutions is an established and proven strategy for transferring knowledge and educational skills from one type of institution or faculty to another. Traditionally, this has meant that faculty from small schools spend time at large research institutions, learning about the latest methods in research, and then return to their "home" institution to apply their new knowledge (*i.e.*, ROA program of the NSF). While this can and should be an important aspect of this program, there are other components of faculty exchange to be considered. Research-based exchanges should be broadened both in scope and in types of faculty involved.

- Research in chemical education as well as in innovative teaching methods and delivery systems should be considered as viable objectives for faculty exchanges.

7. Teaching Internships and PYTR

Chemistry faculties are aging. The impending increases in faculty retirements exacerbate the predicted shortages of qualified faculty members. Thus, every effort must be made to attract young, dedicated members to the teaching profession at all levels. The NSF has established the importance of quality research for the scientific community through its funding for such programs as the Presidential Young Investigators (PYI). Now NSF needs to become the leader in conferring a parallel importance to the involvement of faculty in institutional development and teaching activities. By overemphasizing research among our young faculty, we risk creating institutes out of universities with consequent deemphasis of the teaching function of the college professor. Teaching and research internships for students planning academic careers should be designed to allow them to experience innovative teaching methods under the guidance of a mentor.

- The NSF should establish a new category of postdoctoral fellowship that would allow recipients to experience research participation, course design, the direction of undergraduate research students, the presentation of course lectures, and other relevant activities.

The "research plan" should be designed in conjunction with a proposed institution and mentor to ensure a truly beneficial, balanced pre-teaching experience. Because the intent of the fellowship would be to introduce the young teacher/researcher to the many facets of a teaching career, the choice of mentor, the institutional environment, and the commitment of the host institution, in addition to the qualifications of the applicant, should play a decisive role in the review process. The place of residence should also be commensurate with the ultimate career intentions of the applicant.

These fellowships should be prestigious. They should offer a good stipend, allow travel to educational and scientific meetings, and carry a start-up commitment for the fellow when he or she assumes an academic position.

- The NSF should establish a Presidential Young Teacher/Researcher (PYTR) Program to encourage young faculty appointees to be involved in curricular developments and teaching as well as research.

By supporting such a program, NSF would be giving national recognition to the importance of the teacher-scholar. Advantages of this program include introduction of new curricular developments, stimulation of innovative teaching methods, and reinforcement of the importance of the teaching role for young faculty.

8. Special Focus on Undergraduate Women, Minorities, and Handicapped.

Women, minorities, and the handicapped with interests in science, and chemistry in particular, need to be identified early and nurtured for advanced undergraduate study in chemistry. At present, too few *who have the potential* opt for study in this area. A program of research participation for these students, modest in the early years, but expanded at junior and senior levels, would contribute to increasing the retention of students who have early expressed interest in chemistry.

We, therefore, recommend that

- the NSF establish a program to fund academic year and summer research participation in chemistry by women, minority, and handicapped undergraduate students to foster early identification of those students who have an interest in chemistry.

References

1. National Science Board Task Committee on Undergraduate Science and Engineering Education, *Undergraduate Sciences, Mathematics, and Engineering Education*, National Science Board, Washington, DC 1986.
2. S. L. Coyle and Y. Bae, *Summary Report 1986: Doctorate Recipients from United States Universities*, National Academy Press, Washington, D.C., 1987.
3. R. Hoffmann, *American Scientist*, **1987**, *75*, 418.
4. NSF Data provided by Dr. R. Watson and Reports of the American Chemical Society Committee on Professional Training, *Chemical and Engineering News*, July 4, 1988, p. 49.
5. G. C. Pimentel, *Opportunities in Chemistry*, National Academy Press, Washington, D.C., 1985.
6. American Chemical Society, *Instrumentation Needs of Academic Departments of Chemistry*, Washington, D.C., 1984.
7. American Chemical Society, *Critical Issues in Two-Year College Chemistry*, Washington, D.C., 1985.

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2. Report of the Computer Science Workshop

UNDERGRADUATE COMPUTER SCIENCE EDUCATION

March 10-11, 1988

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EXECUTIVE SUMMARY

Computer science is a relatively new and dynamic field. In just over forty years, it has become a central technological influence in our society and a key element in our continuing economic development, international competitiveness, and national security. To use computers effectively, the nation must have a continuing supply of well-educated computer professionals. Further, an understanding of the central ideas concerning computers is essential to all college graduates, who will increasingly use computers. Therefore, excellence in Undergraduate Computer Science Education must be a matter of high priority for our nation.

Computer science and the computer industry have experienced explosive growth. There have been staggering advances in the depth and breadth of our knowledge of computer science and nearly exponential growth in the number of computer science degree programs. Computers have improved in capacity and performance and fallen in price at an extraordinary pace.

New computer science knowledge has necessarily led both to a need for continuing revision of curricula and instructional materials, and to a need for retraining and revitalizing many current faculty. An expanding number of undergraduate degree programs and insufficient rewards for undergraduate educational activities have caused serious shortages of qualified faculty, especially in non-Ph.D. granting departments.

Although computer science Ph.D. production has recently improved, it still falls far short of satisfying the nation's demands. For example, there are over 1,000 computer science degree programs in the nation's colleges and universities. Most of these programs are in four-year institutions, do not offer the Ph.D., and have no or only a few faculty who themselves hold a computer science Ph.D. Yet in 1986-87, only 41 of the 466 new computer science Ph.D.'s took teaching positions in the non-Ph.D. granting computer science degree programs [GRI88]. This contrasts, for example, with the 202 of 845 new mathematics Ph.D.'s who took teaching positions in the non-Ph.D. granting mathematics degree programs [NSF87a]

Computer science is a laboratory science, yet many undergraduate computer science departments have not yet been able to establish instructional labs. Even where labs are in place, the advent of powerful workstation computers means that many existing labs need to be modernized. Instructional materials need to be created to take advantage of new opportunities for better instruction. Opportunities for using new media or improved instructional strategies to improve instructional delivery in a wider educational context should be exploited.

To identify solutions to these concerns, this NSF-sponsored workshop brought together 32 computer scientists who organized their efforts by focusing attention on problems in four separate areas of concern: curricula, faculty, laboratory infrastructure, and instructional delivery. Solutions which were both highly-ranked and for which there was a broadly-based consensus are listed below; order does not imply priority.

In the area of **curricular development**, we recommend that the National Science Foundation:

—Establish two National Centers to serve as focal points for computer science curricular development, training, and dissemination. These centers will focus the energy and attention required to create and maintain the curricula, instructional materials, and training opportunities needed to bring undergraduate computer science instruction up-to-date and to maintain it in the face of continuing rapid change.

To focus m ore **national and faculty attention on teaching,** we recommend that the National Science Foundation implement:

—Presidential Young Teacher awards, which will provide incentives and rewards for creative and successful teaching of undergraduates, indicate to administrators, faculty, and students that both teaching and research are significant, and bring national attention to the importance of educational excellence.

To provide **adequate laboratory infrastructure,** the National Science Foundation should:

—Significantly expand the Instrumentation and Laboratory Improvement Program to create and maintain effective laboratory infrastructures in a substantial fraction of the nation's undergraduate computer science degree programs.

To improve **instructional delivery,** the National Science Foundation should support:

—Research into new Instructional Technologies, to realize the opportunities that computer science has to lead the academic community in a general enhancement of instruction through computer technology.

The workshop participants are pleased that NSF has recently begun to respond to the need for increased emphasis on undergraduate education. Some of our proposals call for expanding existing programs; others, for fundamentally new programs.

The importance of computer science undergraduate education to the nation dictates that additional funding be found to support the initiatives proposed in this report. Our recommendations address updating and maintaining curricula, enhancing faculty knowledge, developing and improving laboratory infrastructure, creating and maintaining instructional materials, and using new computing equipment to improve instructional delivery.

1. INTRODUCTION

Undergraduate education in science, engineering and mathematics serves two essential ends. First, it serves as a bridge between colleges and universities and the nation's technology-oriented organizations. Second, it strengthens the capacities of all individuals to function knowledgeably and effectively in our increasingly complex and technologically demanding society. Despite recognition of its importance, there is mounting evidence that undergraduate education in science and engineering has serious weaknesses and that insufficient numbers of students will be entering these fields to meet the future needs of the nation.

Rapid advances in computing technologies are a driving force in creating the information society. These advances are revolutionizing many aspects of science, engineering, and mathematics. Because computer science is the core discipline of computing, it is important that computer science education be strengthened.

The March 1986 National Science Board [NSB86] report of the Task Committee on Undergraduate Science and Engineering Education recommended that NSF take the lead in improving undergraduate science education in the nation. Since the appearance of the NSB report, NSF has increased both the budget for and the variety of programs targeted at improving undergraduate science education.

Later in 1986, NSF used a workshop format to solicit advice on implementing the NSB recommendations. Discipline-specific workshops were used because various disciplines differ in their needs. The background material for the present Workshop on Undergraduate Computer Science Education included a draft of NSF's strategic plan for undergraduate NSF programs [NSF87b] and copies of the Report of the NSF Workshop on Undergraduate Engineering Education [NSF86a], the Report of the NSF Workshop on Undergraduate Science Education [NSF86b], and the Report of the NSF Mathematics Workshop [NSF86c].

This Workshop on Undergraduate Computer Science Education is one of several held in early 1988 to provide further guidance to NSF. In its charge to the workshop, NSF was concerned with quantitative issues such as the size of the student and faculty pools, as well as qualitative ones such as those dealing with the ability of the faculty to remain current in their fields; the adequacy of instructional materials; and the quality and extent of professional education in research and non-research institutions.

NSF asked the workshop to produce a report identifying the major problems of undergraduate computer science education, possible solutions to these problems, and opportunities that computer science has to lead the academic community in a general enhancement of instruction through computer technology.

The workshop participants prepared position papers concerning issues facing undergraduate computer science education, and reviewed the papers prior to the workshop. The participants, listed in Appendix A, gathered for two days of intensive discussions at The George Washington University on March 10-11, 1988. The report contributors then prepared preliminary versions of material which were subsequently integrated into this report. The report contributors reviewed multiple drafts of the report to ensure that it reflects the consensus of the entire workshop.

As suggested earlier, there have been major changes in computer science and computer technology over the past years. Workshop participants deliberated in the context of these continuing changes, which are: (1) rapid growth of the field both in breadth and depth, as evidenced by growth in the number of research areas and the content of each; (2) a need to update the curricula, both to incorporate significant advances in knowledge and to impose new, improved structures of organization, particularly in the fundamental areas; (3) substantial improvement in the price, power and capacity of computers, including desktop workstations; (4) expansion of the range of computing applications to affect most areas of human activity.

While these changes are positive in that they indicate substantial progress in the field, they also cause obsolescence of equipment, faculty knowledge and curricula. On-going strong demand for faculty, greatly exceeding the supply of qualified computer science Ph.D.s, continues to limit growth and retard needed improvement in the quality of existing programs.

Computer science continues to be a rapidly changing field. The Computer Science and Engineering Research Study (COSERS) [ARD80] commenced in 1974; in 1980 it published a volume detailing the then-current research areas and frontiers of computer science. The striking aspect of the report is that virtually all these research topics and areas from 1979-80 are incorporated into well-designed undergraduate computer curricula of 1987-88. Indications are that the rate of growth is currently even greater. This clearly illustrates the dynamics of computer science. The needs of the discipline within the academic community might be compared to the needs of a teenager who is in that phase of rapid growth which requires frequent feeding, new clothes which fit, and a supportive environment in order to become a healthy and productive adult.

While computer science continued to expand, research expenditures failed to keep pace. The issues have been well-documented by the Computing Research Board and others [DEN81, GRI86b, HOP87, TAR85]. Consequently, funding for graduate student support, particularly Ph.D. students, is deficient. The Taulbee studies clearly chronicle the consequences [GRI86a, GRI87, GRI88]. For example, in 1986-87, only 466 computer science Ph.D.s were produced. This is low when compared to other disciplines. For instance, 845 Ph.D.'s were awarded in Math [GRI88].

A countervailing trend has been a downturn in interest in computer work as a career. The percentage of college freshmen interested in careers as computer programmers or system analysts dropped from approximately 9% in 1982 to about 3% in 1988 [AST87]. From 1985 to 1987, 53 computer science departments had a decrease in majors of 29%, and a decrease in entering freshmen majors of 33% [McB88]. In many cases, this reduction has permitted departments that were previously stretched too thin and were overworked to rebalance their teaching loads and begin to consider offering computing courses for specialists in other sciences and survey courses to educate a computer-literate citizenry. It has not, however, reduced the need for more Ph.D.s. This view is reinforced by current studies of supply and demand [GRI88], which show that cumulative demand for new computer science faculty has not been fully satisfied, and even though Ph.D. production in computer science is up, there are still not enough Ph.D.s to satisfy demand. The problem is especially severe for the primarily undergraduate institutions: of last year's 466 new Ph.D.s, 218 took faculty positions, but only 41 of the positions were with non-Ph.D. granting computer science departments [GRI88].

The intellectual ferment occasioned by expansion and change in the depth and breadth of computer science has resulted in a series of curriculum developments by professional societies, universities, and working groups. The Association for Computing Machinery developed the influential "Curriculum '68" [ACM68], which impacted most of the undergraduate computer science programs and many textbooks of the era. The subsequent "Curriculum '78" [AUS78] revised the prior curriculum. The IEEE Computer Society made important recommendations for the four-year undergraduate program in computer science in their 1977 model program [CSE77], and the updated 1983 model program [CSE83]. An ACM project to identify core material which should be included in all undergraduate computer science programs [DEN88] is leading to a "Curriculum '88" effort. Curriculum design has also taken place outside the professional societies: Shaw et al [SHA84] and Berztiss [BER87] proposed new organizations for traditional majors, and Gibbs and Tucker [GIB86] describe a model liberal arts curriculum developed by a group funded by the Sloan Foundation.

The growth of the field and inadequate supply of trained educators led to concerns about the quality of computer science programs. This led the IEEE Computer Society and ACM to form, in 1984, the Computing Science Accreditation Board (CSAB). A description of the program and its development [MUL84], current criteria for accreditation [CSA87], and a report on the first year of activities [BOO87] document this activity. The CSAB accreditation effort is having a positive impact on the quality of undergraduate computer science education.

Because of these trends in computer science, several needs are apparent: (1) computer science curricula are in need of substantial revision, (2) there is a need to upgrade the skills of current computer science faculty, particularly those who switched into computer science from some other discipline (3) laboratory infrastructure needs to be upgraded (or in some cases created and then kept current), (4) instructional materials need to be brought up to date, (5) new materials need to be created to support instruction in new curricular areas and to take advantage of new media and instructional strategies, and (6) a broader range of students than ever before require some sort of computing education.

The workshop participants developed a series of solutions to address these needs. Direct grants and Centers are recommended to foster creation and update of curricula, lab infrastructure, and instructional materials. Direct research grants are needed to support research into new instructional technologies and better assessment mechanisms. Workshops, Centers, and Clearinghouses are recommended to provide better dissemination and sharing of information and to perform needed training. The objective of some of the proposals for direct grants is to involve faculty more closely in undergraduate teaching and to redress the imbalance between research and teaching that has grown over the past years [NSB86]. The specific proposals are presented in the following sections.

2. CURRICULA

The Curricula working group began by identifying the audiences served by computer science departments - the kinds of students who take CS courses and the needs of those students. We identified an emerging pattern rather different from the traditional one. We then turned to questions of content of the computer science curricula and identified further problems and recommendations in those areas.

A substantial number of students continues to major in computer science, but the wild growth in majors seen in the 1970's and early 1980's appears behind us. Recent studies [McB88] indicate signs of stabilization, and even decreases in CS majors. On the other hand, there is an increasing demand for teaching of computer science as part of the basic science education of every college student. In addition, a significant component of the demand for bachelors and masters level computer professionals may soon be for computer specialists - students who acquire advanced technical competence in computing as an integral component of computing specializations within disciplines other than computer science. This trend probably contributes to the documented shortage of computer professionals at all levels, from practitioners to researchers. This shortage is projected to continue through the 1990's [GRI76, NSF80].

In addition to changes in the needs of undergraduates, there is an evolving need to educate high school students about computing. Although pre-college education was not a primary focus of this workshop, we noted a widespread problem with the articulation between high school education and undergraduate programs, and we make a recommendation on that subject.

Problem 2.1 - Evolution of Undergraduate Curricula in a Changing Discipline

Computer science is developing so quickly that it is not possible to keep the undergraduate curricula up to date. Unlike more established science and engineering disciplines, most of what was taught to undergraduates a decade ago is now largely superseded by new results. For the foreseeable future, computer science will face the need for continual curricular revision.

This need has been partially satisfied by the efforts of professional societies, as discussed in the introduction. The strengths of these efforts lie in the group participation, the discussions, and the wide consensus usually built around their recommendations. However, these efforts typically codify current thinking; the compromises needed to build consensus can lead to conservative recommendations. Nor do these efforts create the necessary instructional materials such as case studies, work books, instructional software, and solution sets.

On occasion, other groups develop innovative curricula on their own initiative as was done by CMU [SHA84] and the liberal arts community [GIB86]. Because these groups are not required to satisfy numerous constituents, they can achieve more internal coherence and set future goals; but by the same token they do not automatically have widespread support.

The curricula working group discussed several alternative solutions such as funding a new curriculum effort. The group concluded that one-time efforts might help the immediate problem, but they would not address the long-term problem, which requires provisions for continual curricula renewal. At the same time, there was recognition that it is too early to consider a single standard curriculum. The core of computer science knowledge may be converging (though this is not proved yet), but the field must maintain pluralism in overall curricula and non-core content for a while.

Dissemination of curricula to teachers in the over 1000 colleges and universities which teach computer science is as important as the content of the curricula. The current mechanisms are textbooks and ACM SIGCSE activities. These mechanisms are not adequate to train or retrain faculty, nor do they address the need for the production and dissemination of teaching support materials such as detailed outlines, case studies, worked examples, software demonstrations, ideas for projects, and artifacts for study.

Solution 2.1 - National Centers for Computer Science Curricula Development

The National Science Foundation should dedicate resources to continual renewal of the computer science curricula by establishing two national centers for the development and dissemination of computer science curricula and high-quality teaching support materials. The centers can bring together computer science educators to develop content and support materials with the goals of making high-quality materials available to all computer science educators. The centers' projects can initiate new curricula, course designs, or material; they can also refine and improve existing material. The permanent staff of the centers will provide an environment to facilitate the development process, to involve technical leaders in content review, to arrange for collaborative activities, and to assist in dissemination.

The centers will be charged with keeping curricula recommendations current and stimulating the academic community to make new recommendations as the body of knowledge evolves. They also should facilitate the production and dissemination of curricula recommendations for secondary schools and two year colleges and keep them current. The centers need to identify and recommend activities to improve and maintain the skills of faculty in those institutions. They should also work together with professional societies to fully utilize the capabilities of the centers and the societies.

Each center should be located at a university which has a major commitment to undergraduate computer science education, and which has a quality library and state-of-the-art equipment. Each university should agree to let the developers use their classes and students to pilot-test innovative approaches and new materials; the centers should make arrangements with other colleges and universities for early testing of the material on different campuses with a variety of students.

The advantages of such centers are many. At most research departments, only a very few people are actively involved with keeping the undergraduate curricula current. Faculty who are not tenured are often warned not to focus too much on teaching activities. As long as curricula development and related activities remain fragmented and distributed, the current university system will not adequately recognize or reward this important work. National centers where people must apply to participate can provide additional prestige and recognition necessary to advance a faculty member's career. The working group felt that industry and government may find it in their best interest to help support such centers. The centers might even make recommendations on continuing education and practitioner training.

To assure diversity, there should be two centers, loosely coupled to foster interaction, where desirable, and to avoid excessive duplication. Each center would have about 5 permanent professional staff, plus associated support staff including librarian, graphic artists, technical writers, and software experts; each would host approximately 10 visiting educators during the academic year and 20 during the summer.

Problem 2.2 - Education Computing Specialists in Many Disciplines

The advent of computational paradigms in disciplines other than computer science has led to a need for professionals who know enough about both disciplines to bring significant amounts of computer science to advanced problems of the second discipline. This requires a good grounding in both. Scientific computation has changed considerably since scientific programmers learned programming and numerical analysis. They now need also to know subjects such as data structures, algorithms, graphics, and databases.

Our analysis of the audience for computer science education showed a growing population of students who will become professionals in these computational specialties, in areas such as astronomy, communications, economics, geography, geology, physics, chemistry, statistics, mechanics, architecture, and mathematics. We see a need for intermediate-to-advanced computer science education for these students. Professional specialization of this sort requires genuine competence in both fields - unlike applications programming of the past decade.

We see a need for joint majors with closer cooperation between departments than is usually associated with a minor or a double major. Students pursuing these joint majors should take at least the fundamental courses in computer science, the fundamental courses in a second discipline, and additional courses that deal with computing specialization within the second discipline. However, they need not necessarily satisfy all requirements in both departments.

Double majors, or majors with minors in computer science, do not serve the need adequately. First, minors and double majors do not usually involve direct cooperation between departments. Yet, advanced courses in the computational specialties should rely on a computer science background, and may require cooperation between the departments to adapt the content of the computer science courses. Second, double majors often require extra effort of students; they usually consume all the flexibility elective courses are designed to provide. Because (as discussed in Appendix C) we believe that a liberal education is important to a computer scientist, the double major alternative falls short. Finally, minors may require too few courses in the minor discipline.

Appendix B describes several computer specialist programs at three universities represented at the workshop: Carnegie Mellon University, The George Washington University, and the University of Illinois. We are aware of other programs, at the University of Colorado and the University of Toronto, which have been established based on the need for computing specialists.

This is not to say that computing specialties can be created only at schools with large computer science efforts or at large schools. We see the opportunity to create specialized programs in, for example, computational mathematics or computational physics at schools without even full-fledged computer science departments if faculty expertise permits. Further, this provides an opportunity for liberal arts schools to follow their traditional strength in creating cross-disciplinary programs to meet their students' needs.

Solution 2.2 - Curricula for Computing Specialists

The National Science Foundation should support the development of interdisciplinary programs involving computer science or advanced computation. This support would provide design and startup funding for programs that involve joint developments between computer science and other departments, with both departments being willing to yield on the usual requirements and the other department having faculty well-versed in the computational paradigms of the other discipline. The joint programs would typically have as their content the fundamentals of computer science, the fundamentals of the other discipline, general college/university requirements, advanced material in the computational paradigms of the other discipline, and enough electives to remain liberal.

Support should cover the design of interdisciplinary programs suitable for introduction at many universities and the particular effort associated with starting programs at individual universities. It should also support design of adaptations of computer science offerings for this purpose and for the design and development of the advanced disciplinary computation offerings.

The cost of this effort is relatively modest, and there is high leverage in preparing computing specialists to serve the needs of the nation. Students who take these programs may outnumber computer science majors by the turn of the century. The success of this endeavor can be measured by the number of programs which are developed and the demand for program graduates.

Problem 2.3 - High School Preparation for Computer Science

Many students now entering colleges and universities have been exposed to computing, either through high school courses or through individual initiative. However, the preparation they bring to the college or university is often ad hoc or misdirected.

Workshop participants felt that a solution to this problem must involve both improving the material being taught, better preparing teachers, and increasing the number of qualified teachers. They recognized the contributions of the Advanced Placement Examination to improving the teaching of computer science, but there was a general sense that more needs to be done.

Solution 2.3 - Develop High School Curriculum Materials

The National Science Foundation should consider a project modeled after the Physical Science Study Commission (PSSC) project of the late 1950's. NSF should start such a program of high school curriculum development, design of laboratories, and extensive teacher training. A recent ACM task force report [TAS85] could be one starting point for this project.

Additional problems and solutions

Other problems and solutions the curricula group discussed are included in Appendix C. They are:

—The need to provide computer science education for all citizens, not just those in high school and undergraduate programs.

—The need to maintain a diverse set of curricula, to meet the needs of different styles of undergraduate education-liberal arts, engineering, business.

—The misperception that different undergraduate curricula are needed for those preparing for industrial positions as opposed to those preparing for graduate school.

—The need to pay close attention to the relations between computer science curricula and preparatory material from other disciplines, particularly math but also psychology (user-computer interfaces) and electrical and computer engineering (constructing computers).

3. FACULTY ISSUES

As noted in the introduction, rapid growth of computer science and unmet demand in Ph.D. production have led to many problems in building adequate computer science faculties and keeping them up to date. These problems differ in character for graduate institutions versus undergraduate institutions, and some of the problems are primarily of a short range nature while others will be problems for many years. The primary problems that we wish to discuss are depicted in the following figure, which illustrates how we have partitioned the problems into long range and short range categories, and have addressed the problems for both research-oriented and teaching-oriented institutions.

	LONG RANGE	SHORT RANGE
Research Oriented Institutions	• Recognition for good teaching →	• Enough faculty • Faculty retention • Teaching faculty • Lack of senior leadership
Teaching Oriented Institutions	• Enough faculty → • Retraining →	• Lack of senior leadership

This section of the report is structured with all of the problems listed first, followed by all of the proposed solutions. This was done because solutions typically address several problems.

Problem 3.1 - Enough Faculty

There are serious and continuing problems in obtaining a sufficient number of well-qualified computer science faculty. Although the very low production of Computer Science Ph.D.'s (less than 300 per year) that existed until recently is starting to ease, only 41 of the 1986-87 Ph.D.s [GRI88] went into the nearly 1000 non-Ph.D. granting computer science departments.

Thus, annual Ph.D. production continues to be far below that necessary to fill academic needs, and demand in the private and government sectors is also unmet. Yet in the long term, most computer science faculty should hold the Ph.D. in computer science. Ph.D. granting departments are beginning to see a flow of well-qualified faculty applicants, so hiring appropriate faculty may be just a short range (i.e., 5 year) problem. For the other institutions, the process could spread over twenty years. It requires a substantial growth in Ph.D. production, attractive computing environments in these institutions, and that teaching at these institutions be considered a viable option to teaching in the Ph.D. granting institutions.

Problem 3.2 - Recognition for Good Teaching

The reward system for promotion and tenure in graduate universities is strongly skewed toward research productivity and success in obtaining outside research support. Thus in computer science, where many of the faculty are young and few have had post-doctoral experiences to get their research underway, the pressures to produce research results to compete with colleagues in other disciplines at tenure time is intense. Coupled with the extra duties often given to junior faculty because of a shortage of senior faculty in the department, this creates added disincentives to emphasize good teaching or curricula development. Senior faculty also see the emphasis on research, see the need to produce more Ph.D.s and find research support for them, and find little university or peer recognition for efforts to improve educational quality. Approaches that would give added emphasis to educational development and teaching will be suggested later.

Problem 3.3 - Faculty Retention

New computer science Ph.D.s are employed as assistant professors with no post-doctoral experience. This is in part because of the extreme shortage of faculty, and in part because post-doctoral positions are unattractive to freshly graduated Ph.D.s in comparison with other employment opportunities. Post-doctoral positions pay less than tenure track positions, have fewer benefits, and certainly fall far below the attractiveness of industrial research opportunities. Thus, as noted above, the young assistant professor of computer science finds it difficult to compete in totality of accomplishments for tenure with his colleagues in other more established disciplines. This is even further aggravated for faculty in the systems or experimental areas of computer science. They must often establish an experimental environment before being able fully to undertake their research, they often lack a mentor, and research results are not of the traditional refereed journal form needed to compete for tenure with candidates from other disciplines. It is much more difficult to argue that an important and novel software system is a viable research contribution than it is to say that a series of papers is a measure of research. Although time may solve these problems of attracting and keeping young professors in academia, solutions for the shorter term are needed now.

Problem 3.4 - Teaching Staff

In many of the research-oriented institutions, a large percentage of the undergraduate education (sometimes 60 to 80%) is provided by teaching staff rather than by tenure track faculty. This staff may consist of full-time lecturers, part-time or adjunct faculty, and graduate or advanced undergraduate students. This prevalent use of teaching faculty can lead to a two-class system within the faculty, wherein the teaching faculty may not receive leaves or sabbaticals, may not be paid at the same rates or between terms or in the summer, may not receive support for attending conferences or workshops, and may have little if any say in departmental affairs. As there appears to be a need for these faculty, at least for the short term, it is important to seek methods to improve their effectiveness and to ensure that they are able to keep up with new developments in the field.

Problem 3.5 - Faculty Retraining

The body of computer science knowledge has expanded, requiring continuing modifications to the undergraduate curricula. Faculty have difficulty keeping up with these changes. This is particularly true in teaching-oriented departments which currently have faculty whose formal training is almost always not computer science and who are not doing scholarly work in computer science. Thus, retraining and revitalization for faculty members would greatly enhance the quality of the undergraduate experience in computer science. As the desire of students, including non-majors, to take some computer science courses increases, it is especially important that the computer science faculty be kept current in the field.

3.2 Solutions

In this section we list, in priority order, programs that will help solve the problems that we have just enumerated.

Solution 3.1 - Course and Curriculum Grants

The CCG program would be modeled after the standard NSF research grant programs. Computer science scholars would submit proposals to NSF for educational activities such as the development of a new course or curriculum. These proposals would be judged for their educational innovative value, their significance, originality, impact on the discipline, and the ability of the investigator to carry out the project.

The CCG program should start at the level of 20 grants per year. The average grant would support faculty and a teaching assistant for two years, at a typical level of $60,000 per year. This implies an ongoing yearly cost of $2,400,000 (40 grants active per year). This might have to be increased later depending on popularity and value derived to computer science education.

Solution 3.2 - Presidential Young Teacher Awards

The brightest and the best new Ph.D.s in academia currently compete for NSF Presidential Young Investigator awards. These awards have become very prestigious, and they help the young professor establish a research program. Awards tend to go to faculty in the very top computer science departments, and provide significant levels of support both from NSF and industry for a period of 5 years. We propose a similarly prestigious award for teaching excellence. This would dramatically demonstrate the importance of teaching quality and the importance it holds for NSF and the nation. Properly designed, it could help attract articulate, bright new Ph.D.s in computer science to teaching-oriented computer science departments. It should raise the importance of good teaching for tenure and promotion considerations. We believe that the nomination process should be patterned after the PYI process. The nominee's statement would describe the course development, educational software, teaching innovation, or similar activity planned. The grant would be at a level to supply summer support for approximately three to five years and we feel that industry participation could most likely be obtained. Program success can be determined by the number and quality of nominations received, and the reaction of institutions whose faculty members receive the award.

Solution 3.3 - Presidential Senior Educator Awards

This solution is directed at increasing the importance of education in Ph.D. granting universities without undermining the research capabilities of the nation in science. Science faculty are generally most research-productive in their early years. As they mature, they are better prepared to provide leadership and guidance. At this stage they can have a significant impact on the educational process.

In the more established disciplines it is not uncommon for the senior faculty to become heavily involved in the undergraduate program, but the shortage of senior faculty in computer science discourages such involvement.

Because of the importance of both improved education and continued research excellence to international competitiveness, we strongly recommend the establishment of the PSE awards. This may encourage senior professors to view teaching lower division courses as a privilege, and encourage universities to reward excellence of teaching at this level.

This program would be modeled after the research programs of NSF. Grants would support faculty and TA's to develop courses and educational tools, and would also require efforts to disseminate the material, typically via a center or clearinghouse (as described in other recommendations). Grants should be for periods of from three to five years, so that the methods can be tested and measured by actual teaching experience. It would be appropriate to allow principal investigators to suspend current NSF-funded projects so the research support would still be available to the PSE awardee at the end of the PSE award period.

The program scope should be ten awards per year, with an average duration of four years. The yearly funding should be about $75,000, implying an ongoing yearly cost of $3,000,000.

Additional problems and solutions

Additional solutions to the above problems are found in Appendix D. They deal with:

- —Revitalization and retraining programs.
- —Chautauqua lectures/workshops.
- —NSF research grants to young researchers whose research requires greater than usual elapsed time to mature (systems and experimental work), with the researchers' "tenure clock" stopped by their institution.
- —An NSF medal of excellence in teaching.
- —A task force to further study teaching faculty issues.

4. LABORATORY INFRASTRUCTURE

The nation's continued success in computer science depends partly upon our ability to move new hardware and software technology quickly into the mainstream of educational use. It is critical to have a laboratory infrastructure which facilitates this movement.

Laboratories have three roles in undergraduate computer science education. They support the curricula in the traditional scientific role of illustrating theory, bringing concepts to life, and teaching the practice of experimental methods in science. Labs also prepare practitioners for professional life. Graduates of computer science programs now form the backbone of the software specialist workforce. The professional skills of these students will be key to the nation's productivity and competitiveness in the future. Labs also provide a vision of the future in a fast moving field. Students need to work with modern equipment so their technical skills will not be obsolete on graduation, so their expectations will be high and so they are prepared to create the new systems that will be needed in the future.

Computer science is a laboratory science and requires an institutional commitment to equipment and laboratory infrastructure. However, departments and academic administrators have been slow to comprehend the implications of this, because many programs are located in or were founded in colleges or departments (especially mathematics) where there is little tradition of laboratory support, and because specialized needs of computer science have caused departments to take over computer center responsibilities in a piecemeal fashion without commensurate budget and staff. The result is a chaotic process in which everything from equipment acquisition to paper supplies is handled on an ad hoc basis and faculty end up doing staff work.

Although centralized computing organizations can deal with the hardware aspects of computer acquisition and operation, the increasing integration of computing into all fields and the need for computing specialists with application field expertise make it difficult for centralized organizations to deal with individual departmental needs. In addition, a dangerous situation is arising in which the decentralization of planning and acquisition undermines the ability of the institution to coordinate planning for financing, maintenance, and use of computers. This leads to non-productive use of both equipment and people; it also threatens the long range development of institutional computing resources Experienced computer science faculty called on to act as free consultants in these situations have further demands placed on their already-scarce time.

Problem 4.1 - Inadequate Laboratory Infrastructure

The laboratory infrastructure is not in place to support undergraduate computer science as a laboratory science. There are difficulties in four basic infrastructure areas: equipment, software, staff and operations. In the case of equipment, regular replacement must be budgeted for and performed on a three to five year cycle. However, equipment acquisition is largely treated as a unique event with funding and planning occurring in a crisis atmosphere. Software is often acquired haphazardly, is made available with little assistance for users, and requires maintenance beyond the capacity of available staff. A shortage of staff leads to the diversion of faculty, a department's most valuable resource, from education into operations and maintenance. Finally, in this atmosphere, actual operations costs are hidden and there is no acknowledgment that capital costs may be as little as twenty-five percent of life cycle costs. This results in chaotic planning and funding decisions as well as later diversion of monetary, human, and physical resources.

Solution 4.1 - Direct NSF Infrastructure Support Grants

The National Science Foundation should fund direct infrastructure support to create organizational models and to directly improve the infrastructure of a substantial number of existing programs. This program would be open to all, but it is anticipated that it will have the greatest effect at non-doctoral institutions. These institutions have the greatest needs in this area and are actually training the majority of computing practitioners.

Grants should last about four years, to support existing undergraduate computer science programs. Funding should be in the $200,000 to $400,000 range. There would be cost sharing and a commitment by the institution to continue funding after the expiration of the grant. Support would be for instructional hardware and software, staff, maintenance, supplies and operations. Proposals could be joint with the central computing facility but would have to show clearly the direct support of the undergraduate computer science program and responsiveness to its needs. We envisage grants to 100 institutions over a five year period at the rate of 20 per year. If the average grant is for $300,000, the total program cost would be $30,000,000 over eight to nine years. There should be an attempt to get active industry participation, perhaps by allowing donations as a part of the university contributions.

Many hundreds of institutions could benefit from this program. By funding 100 grants, NSF will ensure a competition which will lead to comprehensive self-examination by many institutions. The result will be the development of an infrastructure to support computer science instruction and a dramatic improvement in the quality of laboratory experiences at the undergraduate level. Of course, with the rapid changes in technology, provisions must be made to ensure institutional commitment to continuing equipment replacement, and needed revisions of lab materials.

Problem 4.2 - Availability of Information

There are very few resources to allow faculty to investigate hardware and software for laboratories. Some possibilities are vendors, trade shows, reviews and word of mouth. It is quite difficult, however, to explore the instructional capabilities of systems in this way. This is a serious problem for computer science because the rate of change means that faculty need a way quickly to identify useful hardware and software. In addition, there are few outlets to share laboratory materials. Course content appears in text books and is then available to all, but there is no similar distribution channel for laboratory materials.

This is a particularly severe problem in the non-doctoral institutions for two reasons. First, faculty tend to be drawn from disciplines other than computer science and consequently have had fewer opportunities to explore rich computing environments. Second, these institutions tend to be less well positioned to learn about and acquire new environments as they become available.

Solution 4.2 - Support for Creation and Dissemination of Lab Materials

The National Science Foundation should support generation of lab materials and a series of workshops and conferences to share current experiences with labs. The goal would be to find and disseminate successful organizational models and to change the cultural perspectives of academic institutions with respect to computer science laboratories.

This program could take the traditional forms of workshops or publication of model plans or could be less traditional, e.g., a traveling seminar for faculty, administrators and computer center directors who would visit schools regarded as having successful infrastructure organizations.

Solution 4.3 - NSF Sponsored Workshops

The National Science Foundation should sponsor workshops in which faculty use well-developed university laboratory computing environments, and explore the laboratory experiences based on them.

The goal is for faculty to broaden their hardware and software horizons in a university setting. The home institution of participants should be required to make a strong commitment that the faculty member will be able to use the new knowledge gained through the workshop. This could take the form of release time to develop labs. It is conceivable that this program could draw strong industry support, but if this happens the pedagogical goals need to be kept clearly in mind.

We envisage two-week summer workshops with ten to twenty participants. The workshops must be small so that faculty will actually be able to use the systems. Expenses of attendees should be paid as well as cost of the host institution. The goal is a continuing series of workshops which reach faculty members at forty to sixty institutions per year. A model for this is the current Undergraduate Faculty Enhancement Program.

Solution 4.4 - Establish A Clearinghouse

The National Science Foundation should fund a clearinghouse for laboratory materials and academic software in the computer science area. Such a clearinghouse could be modeled on similar projects such as the Minnesota Educational Computing Consortium (MECC), but the emphasis would be on depth in computer science rather than broad coverage of applications of computing. As such, it would require a much higher level of computer science expertise.

Problem 4.3 - Funding Agency Policies Do Not Encourage Infrastructure Development and Support

Funding policies of government agencies tend to neglect infrastructure, because the agencies' focus is on the immediate research issue, not on effects upon the institution.

Solution 4.5 - Provide Policy Leadership in the Federal Research Funding Community

The National Science Foundation should change certain policies, and encourage other funding organizations to make similar changes. Several possible improvements would be to:

—Make it clear that all grant awards are dependent upon adequate infrastructure support.
—Allow infrastructure support as a part of matching funds in grant proposals.
—Actively follow up on institutional performance in the area of infrastructure support, to ensure that commitments of institutional support are indeed kept.

5. INSTRUCTIONAL DELIVERY

We discussed three sets of problems. The first deals with the absence of suitable tools to assist in the delivery process, principally, the lack of high-quality, effective instructional materials. The second concerns inadequate distribution and assessment of instructional materials. The third was inadequacies of the faculty and others who are supposed to accomplish effective delivery. Our discussion and accompanying recommendations focus only briefly on deficiencies in pedagogical skills, as faculty retraining and teaching incentive problems have already been addressed in the Faculty Issues section of this report.

The content defined by a curriculum is only the starting point for education. The content must be delivered to students in a way that they can learn effectively. This involves various combinations of faculty; mechanical aids such as text, video, or software; and practice by the student.

The various choices of strategies and media define delivery systems which require instructional materials to deliver the content of a curriculum. When high-quality instructional materials are lacking, effective delivery is impeded. This is especially true for the laboratory component of a CS lecture/lab course involving experimentation and measurement of computer system or algorithm behavior, because preparing suitable lab exercises involves considerable programming. In short, a serious problem arises affecting the whole field of computer science when suitable instructional materials are either absent or out of date.

Problem 5.1 - Lack of Effective Materials

Regardless of the choice of medium or delivery strategy, we perceive that in computer science there is a lack of high quality instructional materials that help significantly to accomplish effective delivery.

The rapid evolution of computer science leads to rapid obsolescence of its curricula and instructional materials. In almost all institutions that do undergraduate teaching, there are few rewards for developing instructional materials (with the exception of textbooks). Particularly in research institutions, there are negative incentives for professors to devote time and energy to undergraduate education.

The rapid obsolescence of instructional computing equipment impedes development of imaginative, new approaches to teaching computer science that use computers in an integral fashion. But there are additional impediments. In particular, where computer software is involved, there are poor economic conditions in the educational marketplace because of the small installed equipment base, low unit prices for educational software, and rampant software piracy by faculty and students. It is very difficult for commercial vendors to recover software development costs under these conditions. While new courseware authoring tools of substantial power and utility have appeared recently, it is nonetheless difficult for faculty to muster development resources in sufficient quantity, quality and focus to develop educational software. Academic institutions are seldom set up to market, advertise and distribute educational software effectively. They are also poor at making the effort required to evolve a prototype system into a reliable, documented product or to provide continuing software support to users.

In our judgment, there is considerable unrealized potential for the application of computer technology to the teaching of computer science. In addressing this unrealized potential, we have found it useful to distinguish three categories of possible solutions which are distinguished by having differing degrees of risk.

Category I - Low Risk

At the lowest level of risk, we perceive opportunities to apply proven combinations of media and strategies to cases where content needs to be updated and/or instructional materials don't exist, in order to realize potential. The evolution of solutions in this category could be aided by the introduction of standards for development of interchangeable instructional modules and by better development tools for development using non-standard media. In this area, even though we understand how to accomplish development, there is a need for development to be better coordinated and organized and for dissemination to be made more effective. Solution 5.4 in Appendix E addresses this risk category by recommending that NSF provide individual grants to support instructional materials development.

Category II - Medium Risk

At a medium level of risk, we perceive opportunities to apply more broadly approaches that appear to work in prototype form. Often pilot studies indicate that existing prototypes have worked successfully under some circumstances, and there are promising indications that the basic approach might work in a broader context. However, wider adoption needs to be tested, and assessment needs to be done to determine true effectiveness in a scientifically valid manner.

Solution 5.5 in Appendix E addresses this risk category by recommending that NSF identify ways to support entrepreneurial projects that involve strategic alliances between higher education and commercial developers of instructional materials.

Category III - High Risk

At the highest level of risk, there are imaginative new approaches that combine new media and strategies which might be of potentially high impact if they could be made to work and if widespread adoption were feasible. But development and pilot testing has not proceeded to the point where it is known if they will work, and there is risk that they can't be made to work at all. Note here that new instructional applications may become possible because the underlying computer medium has gotten 300 times more powerful than it was fifteen years ago, and what ran fifteen years ago on the giant mainframe can now be done on a desktop computer that costs under a thousand dollars.

Solution 5.1, presented immediately below, is the highest-priority solution that we recommend NSF pursue in order best to solve Problem 5.1.

Solution 5.1 - Pursue High-Payoff Opportunities in Instructional Technology

The National Science Foundation should establish a program for identifying high-payoff targets of opportunity and supporting high-risk, high-impact pilot projects in the area of development of new instructional technologies and new instructional materials.

We believe there should be an energetic search for solutions that might make a big difference. We're not the experts in the programmatic means for accomplishing this within NSF, but we are convinced that a vigorous exploratory process needs to be undertaken. Why such special urgency here? Briefly, as the many well-publicized recent reports on the status of education in the nation have indicated, the catalogue of ills facing education at all levels is extensive and very frightening. The challenge is to find means sufficient for addressing the problems successfully.

It was our sense that bold, imaginative solutions are needed to meet the needs adequately and that "business as usual" is unlikely to suffice. Some of us are convinced that research into new instructional technologies coupled with innovative alliances between academia and industry hold the best promise for developing new approaches.

One element of the charge to our workshop was to identify "opportunities that computer science has to lead the academic community in a general enhancement of instruction through computer technology." Solution 5.1 is one of our principal recommendations, and it is aimed directly at this charge.

The benefits of a breakthrough in instructional technology extend beyond the bounds of undergraduate CS education to other sciences at the undergraduate instructional level and to other segments of education, such as K 12 and science education for the literate citizen via continuing education. This implies that high-risk research into bold, innovative approaches is potentially of broad applicability and high significance.

On the negative side, after much vigorous exploration, realizing the goal of improving education through use of new media, such as computers, has continued to be elusive. In fact, after the initial enthusiasm and novelty of trying a new method have worn off, scientifically valid assessment techniques have often revealed no lasting improvements or gain. Yet, even though the results to date have been discouraging, we believe we must continue to make a concerted effort to identify new solutions that work, particularly because the seriousness of the problems being addressed demands it.

Finally, we believe NSF support can make a critical difference for the two reasons: (1) Adequate resources will not be focused on the search for solutions by the commercial sector because of perceived lack of return on investment, and, (2) NSF's direct support can focus resources on an active search for solutions (which would otherwise not take place).

Additional problems and solutions

Other solutions discussed are included in Appendix E. They concern:

- —Institutional commitment to quality teaching.
- —Grants to develop instructional materials which use current instructional technologies.
- —Supporting alliances between the education and private sectors, to make available more and better instructional materials.
- —Support for the assessment and distribution of instructional materials.

6. CONCLUSIONS

Undergraduate computer science education in the United States has problems - serious ones - which must be fixed. NSF can help by establishing new programs of the type suggested in this report. Supporting these new programs by reallocating resources currently used to support computer science research is not as helpful a solution as restoring undergraduate educational support to previous levels: computer science research is already underfunded, both in absolute terms and in comparison to other scientific disciplines.

We believe that most of the programs and recommendations suggested in this report are applicable to all institutions engaged in teaching computer science at the undergraduate level. Indeed, we believe that there are opportunities here for community colleges, liberal arts colleges, comprehensive universities and more specialized institutions. Implicit in the recommendations are provisions to ensure that all these constituencies are adequately represented in the proposed NSF programs.

As examples, innovative curriculum design and implementation are significant problems for individuals in more isolated institutions. The existence of national centers for computer science education would provide such individuals with a clearly available resource for obtaining new ideas and materials. Workshop programs, such as those proposed for the centers, have long been a source of individual and institutional revitalization for individuals at these institutions. It is also likely that such institutions can readily implement such innovations and thus provide test sites for the materials that are developed in the centers.

Interdisciplinary programs appear to be more easily implemented in the context of a liberal arts program. It is therefore expected that the endorsement and encouragement of programs in computational mathematics, computational physics, and so forth, will provide liberal arts institutions with some alternatives to more narrowly directed technical programs in computer science.

The fundamental purpose of many of our nation's smaller institutions is teaching. Thus the encouragement, endorsement and recognition of teaching excellence, found in these recommendations, should be enthusiastically received. The Presidential Young Teacher awards and the course and curricula grants should bring more awareness to the need for excellence in teaching and directly improve undergraduate computer science education.

Computational resources have long been a problem at virtually all institutions. In this area, there has also been a feeling that outside support is only available to the major research universities and perhaps a few other targeted institutions. The implementation of a laboratory infrastructure program directed to issues of computer science education, modeled on the successful CER programs at NSF for research universities would be a most welcome addition.

Effective implementation of the recommendations will require significant expenditures for faculty and staff support, especially where course and curricular development work is concerned. If the programs are to have impact, funds must be available to support these individuals during the periods they are working on the projects. These funds must be the shared responsibility of NSF and the institutions. The institutional contribution must be such as to ensure a long term commitment to the activities.

Opportunities for merging together some of the individual solutions into broader programs were noted by workshop participants. For example, Solution 2.1, National Centers for Computer Science Curriculum Development and Solution 4.2, Support for Creation and Dissemination of Lab Materials, might be consolidated. However, the workshop as a whole did not make recommendations for or against such combinations.

Beyond NSF, professional societies have a continuing responsibility to coordinate the efforts of the many volunteers who make important contributions to curricular developments. But by their nature, volunteer activities can lack continuity, robustness and the level of effort necessary for practical implementation by all but a handful of the well-endowed institutions. In this workshop we have attempted to identify mechanisms to ensure the orderly and continuing development of computer science education and its timely and effective implementation.

The larger picture for computer science education, seen from the perspective of overall science education, is grim. Science achievement in the United States is dismal [IEA88]. Massive efforts will be needed on many fronts -

NSF, professional societies, the educational establishment - to recover the enthusiasm and funding for science education not seen in the United States since the Sputnik era. We would hope that a similar event is not needed to shock the nation into awareness and action.

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REFERENCES

AST87 Astin, A, K. Green, W. Korn, and M. Schalit, The American Freshman - National Norms for Fall 1987, American Council on Education and UCLA Higher Education Research Institute, Los Angeles, 1987.

ACM68 ACM Curriculum Committee on Computer Science Curriculum 68, "Recommendations for Academic Programs in Computer Science," Communications of the ACM, March 1968 (11:3) 151-197.

ARD80 Arden, B. W. (ed), What Can Be Automated? The Computer Science and Engineering Research Study. The MIT Press, Cambridge, MA 1980.

AUS78 "Curriculum 78: Recommendations for the Undergraduate Program in Computer Science," Communications of the ACM, March 1979 (22:3) 147-166.

BER87 Berztiss, A. T. "A Mathematically Focused Curricula for Computer Science," Communications of the ACM, May 1987 (30:5) 356-365.

BOO87 Booth, T. and Miller, R. E., "The First-year Activities of the Computing Sciences Accreditation Board," Computer, May 1987 (20:5) 94-102.

CSA87 CSAB, Criteria for Accrediting Programs in Computer Science in the United States, 1987, Computing Sciences Accreditation Board, 345 East 47th St., NY, NY 10017.

CSE77 Model Curricula in Computer Science and Engineering, Education Committee of the IEEE Computer Society, Report EH0119-8, IEEE Computer Society, IEEE-CS Press, Los Alamitos, CA, January 1977.

CSE83 Model Program in Computer Science and Engineering, Report EH0212-1, IEEE Computer Society, IEEE-CS Press, Los Alamitos,CA, December 1983.

DEN81 Denning, P. J., et al "A Discipline in Crisis: 1980 Snowbird Report," Communications of the ACM, June 1981 (24:6) 370-374.

DEN88 Denning, P. et al, Draft Report of the ACM Task Force on the Core of Computer Science", February 1988.

GIB86 Gibbs, N. E. and Tucker, A. B., "A Model Curriculum for a Liberal Arts Degree in Computer Science," Communications of the ACM, March 1986 (29.3) 202-210.

GRI86a Gries, D. et al, "Two Trends Colliding: Imbalance Between Growth and Funding in Academic Computer Science," Computer, September 1986 (19:9) 70-76, and Communications of the ACM, September 1986, (29:9) 870-878.

GRI86b Gries, D., "The 1984-85 Taulbee Survey," Computer, November 1986 (19:11) 69-71.

GRI87 Gries, D., "The 1985-86 Taulbee Survey," Communications of the ACM, August 1987 (30:8) 688-694.

GRI88 Gries, D. and Marsh, D, The 1986-87 Taulbee Survey Report, TR 88-897, Dept. of Computer Science, Cornell University, Ithaca, New York, 1988.

HOP87 Hopcroft, J. and D. Krafft, "Toward Better Computer Science," IEEE Spectrum, December 1987, 58-60.

IEA88 International Association for the Evaluation of Educational Achievement, Science Achievement in Seventeen Countries, Pergamon Press, New York, 1988.

McB88 McBride, B., "Decline in Computer Science Enrollment," Baylor University, Waco, TX, 1988.

MUL84 Mulder, M. C., and Dalphin, J. F., "Computer Science Program Requirements and Accreditation," Computer, April 1984 (17:4) 30-35.

NSB86 National Science Board, Undergraduate Science, Mathematics and Engineering Education, Report of NSB Task Committee on Undergraduate Science and Engineering Education, March 1986.

NSF80 National Science Foundation and Department of Education. Science and Engineering: Education for the 1980's and Beyond, U.S. Government Printing Office, 1980.

NSF86a National Science Foundation, Report of the NSF Workshop on Undergraduate Engineering Education, NSF, Washington, DC 20550.

NSF86b National Science Foundation, Report of the NSF Workshop on Undergraduate Science Education, NSF, June 1986, Washington, DC 20550.

NSF86c National Science Foundation, Report of the NSF Mathematics Workshop, NSF, June 1986, Washington, DC 20550.

NSF87a National Science Foundation, Employment Status of 1986-1987 New Doctorates in the Mathematical Sciences, NSF Notices, November 1987, page 1082.

NSF87b National Science Foundation, Enhancing the Quality of Science, Mathematics, and Engineering Education in the United States - Strategic Plan for FY1988 - FY1992, NSF, Washington, DC 20550.

SHA84 Shaw, M., (ed), The Carnegie-Mellon Curriculum for Undergraduate Computer Science, Springer Verlag, New York, 1984.

TAR85 Tartar J. (ed) "The 1984 Snowbird Report: Future Issues in Computer Science," Communications of the ACM, May 1985 (28:5), 490-493

TAS85 Task Force on Curriculum for Secondary School Computer Science, "Computer Science for Secondary Schools: Course Content," Communications of the ACM, March 1985 (28:3) 270-274.

Appendix A - Workshop Participants

Name	Institution	Working Group
J. Mack Adams†	National Science Foundation	Curriculum
Paul Amer	University of Delaware	Faculty
Bruce Barnes	Software Productivity Consortium	Faculty
Henry Bauer	University of Wyoming	Curriculum
Kim Bruce	Williams College	Curriculum
Nell Dale†*	University of Texas	Delivery
Cathy Druffel	Tartan Labs	Infrastructure
Michael Eisenberg	Mass. Inst. of Technology	Delivery
Clarence Ellis	MCC	Curriculum
Gerald Engel†	University of Connecticut	Curriculum
Dick Fairley	George Mason University	Curriculum
Jim Foley†	The George Washington University	
Peter Freeman†	National Science Foundation	
Daniel Friedman	Indiana University	Faculty
Charles Gear	University of Illinois	Faculty
Norm Gibbs†*	Carnegie Mellon University	Curriculum
Mary Haught (observer)	Consultant	Curriculum
Anita LaSalle†	National Science Foundation	Delivery
Glen Langdon	University of California	Infrastructure
Doris Lidtke†	Software Productivity Consortium	Delivery
Tim Long	Ohio State University	Infrastructure
Ray Miller†*	Georgia Institute of Technology	Faculty
Charles Mosmann	California State Univ., Fullerton	Infrastructure
Terry Pratt	University of Virginia	Delivery
Tony Ralston	State Univer. of NY at Buffalo	Curriculum
Jean Rogers	Stanford University	Faculty
Bob Sedgewick	Princeton University	Delivery
Mary Shaw†*	Carnegie Mellon University	Curriculum
Elliot Soloway	Yale University	Infrastructure
Tim Standish†	University of California, Irvine	Delivery
Fred Tonge	Tektronix Corporation	Faculty
John Werth†*	University of Texas	Infrastructure
Marv Zelkowitz	University of Maryland	Infrastructure

† : steering committee member
* : working group leader or co-leader

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Appendix B - Further Background on Double Majors

The need for computing specialists is clearly demonstrated, for example, by the widespread use of computers in laboratory instrumentation and experimental data collection and the widespread use of computational techniques in chemistry, engineering, physics, and other sciences. The 1988 Gordon Research Conferences this year include week-long sessions on topics such as "Computational Chemistry", "Fractals", and "Modeling of Flow in Permeable Media", all or which are heavily computational in nature. NSF's own programs in scientific visualization and supercomputer centers reinforce these clear trends.

At the University of California at Irvine, 27% of the physical science BS graduates take employment in the computing field. At NASA's Jet Propulsion Laboratory, 46% of the technical population is now involved in software development. By the turn of the century JPL expects this proportion to be 90%. However, only 7% of the current population has a computer science background.

The computer specialist programs of several universities represented at the workshop are described below. Other universities represented at the workshop likely have similar programs: we did not undertake a survey. In addition, we know of substantial programs at the University of Colorado and University of Toronto which focus on the same objectives.

—Carnegie-Mellon now offers tracks in chemistry, physics, and biological sciences that require the basic computer science sequence plus advanced computational electives and advanced electives in computational chemistry, physics, and biological sciences. A computer engineering degree in the department of computer and electrical engineering is similar. A cognitive science program in psychology requires at least the basic computer science electives. An information systems program in the humanities college relies critically on a sophomore computer science course created by the CS department especially for that program. A joint mathematics/computer science program is under discussion; this program will depend on the relaxation of certain of the usual departmental requirements in recognition of additional requirements in the partner department.

—The George Washington University offers an undergraduate operations research program in systems analysis and engineering with 11 computer science courses, and a statistics program with 8 computer science courses.

—The University of Illinois at Urbana-Champaign currently has in place joint BS programs in statistics and computer science and in mathematics and computer science. They have a 5-year computer science and accountancy curriculum that leads to a BS in one and a professional masters degree in the other; some modification of formal requirements supports this. A double professional masters degree between computer science and architecture also depends on some relaxation of departmental requirements. A joint program with aero/astronautical engineering is under discussion; with care, a student can now construct a 5-year BS/MS program, but there is interest in a 4-year joint double major. They are also discussing a joint program with microbiology in conjunction with their new Center for Prokaryotic Genome Analysis; this will involve major database issues.

Appendix C - Additional Curricula Recommendations

Problem 2.4 - Computer Science for an Enlightened Citizenry

In the period of little more than 40 years, computer users have grown from a few hundred specialists to a very large segment of our society. In a very few years, virtually every citizen will use computers in some form and thus must be aware of what computers can and cannot do, and of the societal effects of widespread computer use. Those citizens who do not have this basic level of understanding will be seriously disadvantaged, and the resulting societal problems will be directly proportional to the number of such disadvantaged citizens. Hence the general population needs better education about computers and computer science.

Solution 2.4 - Develop Educational Material and Innovative Delivery Methods

The National Science Foundation should support the development of a new course and new delivery methods for presenting the central ideas of computer science and the basic ideas of computer programming, as the foundation for discussing the sensible use of computers.

One major need is for a fundamentally new introductory course. This course should introduce the nature of computing, show the social implications of widespread computing, make students comfortable accessing an information utility, and develop fluency in the use of packaged software. It should survey classes of computers and applications, with emphasis on the diversity of the applications and the common elements of the successful ones. It should not be a programming course as such, though it should provide some elementary programming experience. It should also provide an opportunity to introduce nontechnical students to problem solving, deductive reasoning, and analytic thinking in a setting where they could get direct experience and immediate feedback. The discipline has an unhappy history with courses for nonmajors; they tend to be too shallow. There is a real need for a course with genuine substance, unlike too many of the computer appreciation, computer skills, and computer literacy courses that have come and gone in the past.

Useful activities that are important to expand include: developing material about computing for children, perhaps via PBS in the style of Sesame Street and Square 1 TV; and developing material for wide dissemination to adults, again perhaps via PBS.

Problem 2.5 - Diversity of Curricula

The great diversity of programs labelled computer science creates confusion. Students in computer science have trouble transferring from one institution to another, especially from two-year to four-year colleges. Employers don't know what it's reasonable to expect a computer science graduate to know; some respond by trying not to hire computer science graduates.

Nevertheless, the strength of the U.S. higher education system lies in its diversity—its ability to support, e.g., liberal and narrowly professional education, intensely competitive and more open programs, preparation for graduate school and for practice, etc. It is not our place to dictate that some of these are desirable, and others are not. It is appropriate for us to recommend thrusts that will lead to curricula that, via selection and adaption, support all the choices of colleges and universities.

Moreover, computer science is still maturing, and most of us felt that it is much too early to standardize on a single definition of the content of an undergraduate program or its organization into courses. We find that consensus may be emerging on the content, but not the order of presentation, of the core of the discipline.

Solution 2.5 - Policy for Supporting Curricular Diversity

The National Science Foundation should continue to formulate its educational support programs to address the lasting needs of an educated professional, with the recognition that a diversity of curricula is a necessary part of the maturation of the discipline. Do not attempt to standardize on a single curriculum at this time.

This is not a mandate for chaos, which would fragment the field. It is neither necessary nor appropriate for each curriculum design to start from scratch. There should be support for curriculum designs from many sources and widespread dissemination of these designs.

Problem 2.6 - Articulation of the Common Basis of Computer Science

There is an often-heard view that an undergraduate education in preparation for industry is different than an undergraduate education for graduate school. Employment representatives often complain that our graduates are not well-prepared for their needs.

There was considerable discussion of the perceived vocationalism of many two-year computer science programs, with concern that training in programming skills sometimes displaced genuine education. We decided that this was not a problem that required a direct solution, but that curricula development efforts should be established with the goal of designing an education that would be of lasting value to a professional. This is, of course, true for all disciplines. But it is particularly true of computer science, in which not only the technology but our understanding of the conceptual basis of the discipline change at an unprecedented rate.

An education of lasting value will allow the student to acquire:

—A thorough and integrated understanding of the fundamental conceptual material of computer science and the ability to apply this knowledge to the formulation and solution of real problems in computer science.

—A genuine competence in the orderly ways of thinking which scientists and engineers have always used in reaching sound, creative conclusions; with this competence, the student will be able to make decisions in higher professional work and as a citizen.

—An ability to learn independently with scholarly orderliness, so that after graduation the student will be able to grow in wisdom and keep abreast of the changing knowledge and problems of his or her profession and the society in which he or she lives.

—A philosophical outlook, breadth of knowledge, and sense of values which will increase the student's understanding and enjoyment of life and enable each student to recognize and deal effectively with the human, economic, and social aspects of his or her professional problems.

—An ability to communicate ideas to others.

Solution 2.6 - Education

The National Science Foundation and professional societies should find ways to explain to curriculum designers, administrators, and the computer science community that the perception is erroneous, and that the two populations need so much of the same material that a single program with tracks or guidance about electives is sufficient (and better).

Problem 2.7 - The Relationship Between Computer Science and Other Disciplines

Computer science has close ties with several other disciplines, including mathematics, electrical engineering and psychology. The interfaces between the curricula of these disciplines and the computer science curriculum is very important and should be the subject of considerable study. Unfortunately, the curricula subgroup did not have sufficient time to consider the problems in these diverse areas, but was able to address one of the important problems, the relationship between computer science and mathematics.

It is generally agreed by academic computer scientists that computer science is a highly mathematical discipline which depends upon mathematical support in many if not most of its undergraduate courses, and that discrete mathematics as broadly understood encompasses most of the mathematics which is needed in undergraduate computer science courses.

However, there is considerable disagreement about various questions related to mathematics support of undergraduate computer science courses. Two of the most important questions concern the appropriateness of discrete mathematics as a prerequisite or corequisite, and the role of calculus in computer science programs.

Does the very first course (one semester or one year) in college computer science require a discrete mathematics prerequisite or corequisite analogously to the need for a calculus prerequisite or corequisite for college physics? This question is closely related to the question of what the character of the first course in computer science should be: strictly a programming course or a course in which learning to program in some language is a vehicle for teaching about broader issues in computer science.

What should the role of calculus be in undergraduate computer science programs? This question is not about the desirability of a knowledge of calculus in any liberal education with a focus on science but rather with whether calculus provides direct support for undergraduate computer science. Therefore, we need to ask: What courses in undergraduate computer science do lean or should lean on calculus? What level of knowledge of calculus is necessary in these courses? Should students intending to go on to graduate work in computer science learn calculus even if they don't have much use for it as undergraduates? A related question in this context is how much statistics should be studied by an undergraduate computer science major and does it have to be calculus-based.

Solution 2.7 - Curricula Development

The National Science Foundation should fund work aimed at studying the mathematics requirements of the undergraduate computer science curricula and how these requirements should be used to support undergraduate computer science courses. Of particular importance in such a study should be the relation of mathematics to the first course in computer science.

Appendix D - Additional Faculty Recommendations

Solution 3.4 - Revitalization/Retraining Workshops

The existing NSF Undergraduate Faculty Enhancement Program must be expanded to provide more summer revitalization opportunities. In funding the program NSF should recognize that many of the faculty for whom the program is designed are dependent on summer income, and that their institutions typically cannot provide such income. Thus the workshop needs to provide more support to participants than just travel and per diem. One example worthy of further support in this general area follows as solution 3.5.

Solution 3.5 - Chautauqua Style Lectures/ Workshops

The purpose of this proposal is to leverage the expertise of the truly outstanding computer science educators with the energy and experience of faculty in regionally located colleges and universities.

An outstanding educator would go to a region and hold a relatively short workshop in some area of computer science. Faculty from the region would attend. At the workshop they would outline projects in education that they could carry out at their home institutions. Approximately six months later they would all reconvene to discuss the progress and outcomes of these projects. Especially noteworthy projects would be published or distributed in other ways so that they could be applied in education over a broad spectrum of CS programs.

Solution 3.6 - NSF Young Researcher Awards

The problem of faculty retention for untenured, tenure-track faculty is particularly severe when the individual chooses a "systems" path. What we are discovering is that such research requires enormous blocks of time which are generally unavailable. After two to three years of frustration these faculty often leave for industry where they continue to work on the same or related problems. The result of losing young systems faculty is that the departments become populated primarily by non-systems faculty who cannot adequately bring the teaching of systems into the classroom. These system researchers need more time to develop a reputation, otherwise their lack of publication depth leads to a negative tenure decision.

This is a problem for two reasons. The loss of a faculty member affects the structure of a department with respect to coverage, etc., but more importantly the loss because of an expected or real negative tenure decision wrecks havoc on the morale of the entire department.

The solution to the problem is an award, not unlike the conventional post-doctorate. The major differences are that the grant can be applied for any time during the first three years at the institution, and unlike a post-doctorate, the awardee maintains his/her current salary. Like a post-doctorate, the awardee receives total release time from teaching, and the application for such a grant may come prior to accepting a position, but the award only goes to Ph.D.s. NSF might also explore ways in which the tenure decision for the awardees might be delayed for as many years as the young researcher award is in effect.

Solution 3.7 - A Task Force to Study Teaching Faculty Issues

NSF should fund a task force that would bring together members of teaching faculties to discuss the current problems in regards to such two-tier arrangements and come up with some solutions to make such systems successful including identifying which teaching methods are most successful.

Solution 3.8 - NSF Medal of Excellence in Teaching

There exists a lack of recognition within universities of the importance of quality teaching and educational commitment. This problem is perpetuated by a lack of recognition for teaching excellence by recognized nation leading organizations such as NSF. University lack of recognition is demonstrated explicitly at decision times of tenure and promotion. This attitude exists at both research oriented and four-year institutions and in fact tends to be growing at the latter. We find this trend to be impacting negatively the quality of undergraduate CS education.

We propose that NSF establish the "NSF Medal of Excellence in Teaching" to be distributed among faculty who demonstrate true teaching excellence. We argue that such an award even carrying a minimal stipend (5-10K) will change significantly the current attitude of declining importance of teaching. We propose inviting hardware vendors to give a machine (pc, workstation) and five years maintenance to each award winner. We predict vendors will compete to have their machines in the hands of NSF selected best teachers.

We recognize that a major difficulty in implementing this proposal is in defining the evaluation process of who are the best teachers. There exist many approaches (student quantitative and qualitative, peer evaluation, supervisor evaluation) none of which are accepted by a majority and all of which are controversial. Difficult as the evaluation process may be, however, the NSF Medals should not be dismissed summarily.

We propose 200 awards of $5,000-10,000 per year distributed proportionately among Ph.D. granting and non-Ph.D. granting institutions. No university would be permitted to win more than one award per year, to permit the widest distribution and widest impact. After three years, approximately half of the CS programs would have an award winner.

Appendix E - Additional Delivery Recommendations

Problem 5.2 - Inadequate Faculty Teaching Performance

Poor teaching performance may result from deficiencies in pedagogical skills, unsatisfactory knowledge of the subject, or lack of interest in teaching. Since the latter two deficiencies were addressed in the Faculty Issues section of this Report, we address here only the first deficiency.

While the award of a Ph.D. is treated as a "license to teach," and although service as a teaching assistant (TA) is often a requirement in Ph.D. programs, there is rarely any required training in pedagogical skills. While pedagogical excellence comes naturally to some faculty without any training, in other cases, pedagogical skills are conspicuously lacking and the faculty involved might benefit from exposure to opportunities to learn how to teach more effectively.

Solution 5.2 - Institutional Commitment to Quality Teaching

This set of recommendations is aimed not so much at the National Science Foundation as it is at individual computer science faculty, administrators in institutions responsible for instructional delivery, and accreditation boards and commissions. NSF should convene workshops to focus attention on these specific issues.

- —Local voluntary self-assessment mechanisms for teaching effectiveness should be available and departments should encourage their faculty to use them.
- —Accreditation agencies (such as CSAB and ABET) should continue to require teaching evaluation mechanisms and to review teaching performance. They should note the availability of helpful mechanisms for identifying and correcting problems of inadequate pedagogical skills in their reviews of undergraduate teaching quality.
- —Universities and individual computer science departments should be encouraged to provide training and support for classroom presentation and course management skills.
- —Methods courses for teaching computer science should be developed.
- —Faculty retraining workshops should include helpful information about pedagogical aspects of the use of new instructional materials that have been shown to be effective.

Problem 5.3 - Inadequate Distribution and Assessment

The more successfully and rapidly that new instructional technologies evolve and new instructional materials appear, the more difficult it is for computer science instructors to keep up to date. There must be improved ways to help instructors learn about new developments, determine whether the claims of improved value are credible, and ascertain whether adoption is feasible or desirable. Furthermore, the field as a whole needs improved, scientifically valid means for assessing whether the new approaches have improved the state of practice.

Solution 5.3 - Improved Assessment Methods

The National Science Foundation should support research into better assessment mechanisms for new instructional technologies.

Research into better assessment mechanisms is an important solution to Problem 5.3. A history of past failures and exaggerated claims makes it essential to validate scientifically the actual improvements, if any, that result from the introduction and use of new instructional technologies.

Many research and development efforts in new instructional technologies have used procedures for so-called "formative evaluation" and "summative evaluation," but studies that claim to assess effectiveness of new instructional technologies still encounter credibility problems. A major problem has been the non-repeatability of pilot experiments that show advantages of new technologies when tried under field conditions. Learning improvements have tended to vanish in actual field use when the novelty of the new techniques has dissipated, when the enthusiasm of the originators has been absent, or when biases in the subject samples have been eliminated (say, through use of broad ranging samples of student/teacher populations, as opposed to samples involving teachers who are direct trainees of the originators or students who are in special experimental schools operating under the Hawthorne effect).

One successful method of obtaining scientifically valid results is the large-scale macro experiment with careful statistical analysis. For example, it is estimated that IBM paid ETS (the Educational Testing Service) over $8 million to evaluate the effectiveness of its "Writing to Read" program to teach young children how to read. ETS determined that the improvements were very real, and the experimental design was large enough to remove any doubts about bias in subject sample. Without careful assessment such as this, we won't know whether proposed new improvements in fact work as well as the proponents claim they do, and thus we won't have confidence that scientifically valid advances have been achieved. But the macro-experiment is forbiddingly expensive.

Consequently, we are convinced there is a need for research to identify improved means for assessment, and particularly to allow us to achieve an acceptable confidence level at substantially reduced expense. The goal is to be able to get trustworthy results without enormous expense. If at all possible (and it may not be), we need to learn how to identify ways scientifically valid assessments can be done on smaller control group sizes than the macro-experiment with thousands of subjects. Another research goal is to evolve techniques for identifying the characteristics of subpopulations for which a given approach works (if any). For example, it may be that a proposed new approach works well with individuals with a particular cogniti e style or particular disabilities, but is ineffective for others.

Solution 5.4 - Curricula Development Grants

The National Science Foundation should provide individual grants to support instructional materials development. This solution addresses the low risk solution category (Category I, in Section 5).

Solution 5.5 - Support Innovative Alliances Between Education and Commercial Developers

The National Science Foundation should identify ways to support potentially entrepreneurial projects that involve strategic alliances between education and commercial developers of instructional materials. This solution addresses the medium risk solution category (Category II, in Section 5).

Commercial developers and vendors can do a better job of developing, productizing, marketing, advertising, distributing, and manufacturing than academic institutions. Yet academic institutions have subject matter expertise essential for development of good instructional materials. Consequently, strategic alliances and cooperative ventures between academic institutions and commercial enterprises provide the best hope for attainment of results under certain favorable conditions.

Solution 5.6 - Support improvements in the mechanisms for review of instructional materials.

Solution 5.7 - Identify ways to support more effective distribution of instructional materials.

Approaches such as those discussed in Solution 4.4 with respect to laboratory instructional materials are appropriate.

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2. Report of the Engineering Workshop

REPORT OF THE 1988 NSF WORKSHOP ON UNDERGRADUATE ENGINEERING EDUCATION

April 25 - 26, 1988

Engineering education is of great importance to the well being of the United States. It is a key to avoiding a possible crisis caused by the erosion of U.S. technological preeminence. National action must be taken *now* to reverse this erosion and to reflect current and new realities.

A commitment to new national priorities and incentives to reinvigorate the engineering education enterprise requires fresh vision and renewed attention to undergraduate engineering education and the nature of its interfaces with both secondary and post-baccalaureate education.

The goal is to ensure that the nation's system of engineering education yields engineers capable of surpassing our economic and technological competitors in the 21st century, recognizing that this system functions in an age characterized by:

- rapid shifts in the nature of critical technologies and their scientific bases, as exemplified currently, for example, by information, light-wave and biotechnologies,
- expansion from an economy based largely on production of energy, food and goods to one critically dependent on high-speed computer-based creation, organization, flow and control of information,
- transition to a world economy that emphasizes specialized products with shortened concept-to-marketplace cycles,
- major changes in the racial and ethnic composition of the U.S. population.

Emerging technologies carry civilization forward inexorably, presenting opportunities and problems of increasing scale and complexity. These technologies provide, for the first time perhaps, the opportunity to shape to a remarkable degree the world in which we will live in the next century. Realizing this capability places great emphasis on reshaping and enhancing engineering education, in parallel with education generally. The economic implications are immediate. Today's current and emerging technologies soon become commonplace and diffused worldwide. Furthermore, they have become subject to offshore product development and manufacturing. As new ones emerge and outstrip the old at a heightening pace, the nation confronts a new version of the adage: "The race is to the *technologically swift and commercially astute.*"

Thus, as never before, quality of life requires technologically enlightened business and civic leadership — *the* key to improved productivity, economic growth, social stability, and enhancement of the global environment. Organizational strength depends on individuals who have a broad understanding of both current and emerging technologies *and* the socioeconomic factors that affect and are affected by them. Future leaders of the nation will need to include those men and women who, by educating themselves to plan and direct the development and application of new technologies, will ensure the ability of our economy to support the social programs and the economic well being of the United States. Moreover, demographic realities require the strengthened participation of present minority groups (which are becoming the majority) and the fuller participation of women in education and industry.

While this societal scene has been developing throughout the eighties, and was already a strong influence on the recommendations of both the 1986 NSB Report on Undergraduate Education and the Report of the 1986 NSF workshop on Undergraduate Engineering Education, it has intensified recently. Indeed, during the ensuing two years since the 1986 Reports:

- The number of high school graduates choosing engineering studies has decreased.
- The number of minorities and women in undergraduate engineering programs has begun to drop.
- The retention of underrepresented groups in academic programs and in professional practice continues at an unsatisfactory level.
- The global position of the U.S. economy has worsened.
- The necessity for engineers to change specialties as technologies wax and wane has become more imperative.

The members of the present Workshop affirm the recommendations of the 1986 group and express grave concern that government response to supporting implementation of that Workshop's recommendations has been insufficient to even "stem the tide" let alone begin to resolve the issue. While the organizational response of the NSF to those recommendations was the creation of an Office of Undergraduate Science, Engineering and Mathematics Education and an exciting new slate of educational programs, funding support is inadequate to the task and its urgency. In particular, the budgets for the several NSF undergraduate programs offered in FY 1988 (Undergraduate Curriculum Development in Engineering; Undergraduate Curriculum Development in Mathematics: Calculus; Instrumentation and Laboratory Improvement; Undergraduate Faculty Enhancement; Research Experiences for Undergraduates; Career Access Opportunities in Science and Technology for Women, Minorities and the Disabled) do not even begin to address the need: the requests of the proposals for each of these programs were many times the funds available; this response showed that there are a great variety of significant ideas offered by the community, a large number of capable citizens ready to contribute their considerable talents to the cause, but, for lack of adequate funding, execution is stymied. The present Workshop participants thus concluded that there is no way out of the worsening dilemma other than to move ahead deliberately and recapture the spirit of forward progress and leadership the nation once held. There is no equivocation about the conclusion. To emphasize the urgency, this Workshop offers a suggested context in which to proceed and a complementary set of recommendations.

The principal admonishment of the 1986 Workshop Report was: "NSF's role will be to encourage and support the intellectual effort necessary to restructure the curriculum and teaching methods in the light of present day and near future technical realities." From this, a vision of undergraduate engineering education through the start of the 21st century can be based on the notion that the engineer's essential role in organized society is an integrative process, i.e., an emphasis on "construction of the whole", if you will. The primary goals of this educational process are therefore to develop, in as individualized a way as possible, each student's:

- *Integrative capability:* the recognition of engineering as an integrative process in which analysis and synthesis are supported with sensitivity to societal need and environmental fragility,
- *Analysis capability:* the critical thinking which underlies problem definition (modeling, simulation, optimization) and derives from in-depth understanding of the physical, life and mathematical sciences, the humanities and social sciences,
- *Innovation and synthesis capability:* the creation and elegant implementation of useful systems and products including their design and manufacture,
- *Contextual understanding capability:* the appreciation of the economic, industrial and international environment in which engineering is practiced, and the ability to provide societal leadership effectively.

Each of these goals contributes to the fundamental purpose of education: the enhancement of enthusiasm and ability to learn on a career-long basis. Present and future demands of engineering practice and societal participation require engineers to have well developed learning skills and to be adaptable to rapid technological change as well as change in the global marketplace.

Further consideration suggests that the process for realizing these goals is centered on:

- Development of human intellectual resources,
- Development of instructional materials and educational delivery systems,
- Creation of innovative and effective laboratories that use resources efficiently.

Baccalaureate engineering education must be considered as part of a continuum of education from K—12 through the baccalaureate to graduation and beyond. In this sense, all undergraduate engineering education programs supported by NSF should take cognizance of the pre-college interface at the front end and the master's/doctoral/industrial interface at the output end. In the long term, the improvement of K—12 education will do much to enrich the four-year baccalaureate experience but, in the short term, educational experiments to radically alter the first year or two of a collegiate program may have great impact and are in order. In a corollary fashion, short term restructuring of engineering education at the undergraduate/master's interface should be considered both to improve the undergraduate experience and to allow a clearer distinction to be made between a practice-oriented master's degree and a research-oriented doctorate.

Additionally, there should be a rational and considered response from the engineering profession to the need, by all citizens, for a basic understanding of the technological principles that govern the global marketplace and the ability to analyze critically the many variables involved. This need has become increasingly important as the nation encounters increased world competition.

RECOMMENDATIONS

The Workshop recommendations are intended to drive sweeping changes in engineering curricula—interpreted in the broad sense—and in the way engineering education is done, and to nurture young people within an educational environment that is alive with exciting change to pursue both challenging industrial and dynamic academic careers. While the number of faculty evolving from the latter career-path pales in comparison to the larger cadre of their industrial peers, nonetheless they represent the engine for continual renewal of the U.S. human technological resource base and must be developed with special care.

The actions recommended below focus on human resources, creation of materials for educational use and the transportability of those resources throughout the nation's engineering education system. In addition to nurturing young people in engineering, these recommendations also stress the need to spread an understanding of technology throughout society as a whole by including engineering concepts in the liberal arts and business educational experiences.

The actions recommended are to:

- increase substantially the funds available for developing new educational techniques, instructional materials and delivery systems as well as innovative and effective laboratories,
- support the development of programs that lead to a better understanding of foreign cultures and languages and the practice of engineering on a global scale,
- fund the development of a variety of freshman/sophomore courses taught by engineering faculty and focusing on the integrative nature of engineering to serve the dual purpose of starting an engineering student's education with the core methodology of the engineering process and offering a substantive experience for non-engineering majors,
- create a doctoral loan program for U.S. nationals that is faculty-mentored and requires teaching by the doctoral candidate to facilitate entry to a faculty career in engineering by forgiveness of the loans over the first several years of academic service,
- support professional development programs for faculty so they can include new technological developments and educational methods in their teaching,
- focus attention on recruiting and retaining women and underrepresented minorities throughout engineering including graduate and undergraduate fellowships and the doctoral loan program,
- encourage engineering education institutions to rethink the undergraduate/master's level interface by funding curricular and course development programs which lead to articulation and integration of these programs, as well as enhanced practice-oriented content,
- alter NSF programs for awards to faculty and students to include an emphasis on the commitment to combined teaching and research for producing the scholarly leaders in academe; e.g., the criteria used in PYI awards should stress that teaching as well as research is essential.

In addition to the preceding specific thrusts, the workshop offers two recommendations that are somewhat broader: namely;

- Funded projects should have built-in mechanisms to assure the transfer of successful new academic programs, instructional materials and laboratory innovation throughout the nation (consortia of educational institutions are suggested as an effective mechanism to accomplish this task).
- The NSF should provide for on-going and long-term independent evaluation of the programs offered for aiding undergraduate engineering education in order to understand changes they have caused in the sociology and culture of the collegiate system. These evaluations will be useful for determining how well the programs have contributed to the improvement of undergraduate engineering education and will help in developing plans for the future.

BIBLIOGRAPHY

Engineering Education and Practice in the United States: Foundations of our Techno-Economic Future. Report of the National Research Council Committee on the Education and Utilization of the Engineer. J. A. Haddad, chairman. National Academy Press, Washington, D.C., 1985.

Undergraduate Science, Mathematics and Engineering Education. Report of the National Science Board Task Committee on Undergraduate Science and Engineering Education, H. A. Neal, chairman. National Science Foundation, Washington, D.C., 1986.

Quality of Engineering Education. Final report of the Quality of Engineering Education Project, W. E. Lear, project director. American Society for Engineering Education, Washington, D.C., 1986.

Proceedings, November, 1986 National Congress on Engineering Education, E. M. Nordby, chairman. Accreditation Board for Engineering and Technology, New York, N.Y., January, 1987.

A Nation at Risk: the Imperative for Educational Reform. Report of the National Commission on Excellence in Education. D. P. Gardner, chairman. U.S. Department of Education, April, 1983.

Cranch, E. T. "Continuing Engineering Education in the United States: An Overview and Assessment." *Proceedings, World Conference on Continuing Education,* ASEE/IEEE. Lake Buena Vista, Florida, May, 1986.

Report of the NSF Workshop on Undergraduate Engineering Education, J. C. Hancock, chairman. May, 1986.

A National Action Agenda for Engineering Education. Prepared by a Task Force of the American Society for Engineering Education, E. E. David, chairman. American Society for Engineering Education, Washington, D.C., 1988.

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2. Report of the Geosciences Workshop

FINAL REPORT OF THE WORKSHOP ON UNDERGRADUATE EDUCATION IN THE GEOSCIENCES

March 28-29, 1988

Contents

A. PREAMBLE

1. The Committee strongly agrees with the National Science Board report, "Undergraduate Science, Mathematics, and Engineering Education," (March 1986) which identifies basic deficiencies in undergraduate education in the United States, and recommends NSF action to advance the quality of undergraduate education in engineering, mathematics, and the sciences. The Committee notes that such deficiencies, for example inadequate pre-college instruction, declining enrollments, deteriorating instructional facilities, and lack of funding for research efforts involving students, are particularly evident in the geosciences.

2. The budget enhancements for the NSF Science and Engineering Education Directorate in FY 87 and FY 88, the stated interest of the research directorates in promoting education, and NSF budget proposals all underscore the new opportunity for NSF to initiate and expand programs that address undergraduate education problems exacerbated by NSF curtailment of such programs in the late 1970's and early 1980's. Clearly an NSF commitment to long-term and uninterrupted support is required.

3. A necessary, but not sufficient, condition for enhancing undergraduate education is the improvement of the quality and motivating aspects of pre-college education in science and engineering.

B. SPECIAL CONSIDERATIONS FOR THE GEOSCIENCES

1. The geosciences are the sciences that most directly address and integrate environmental and earth-system processes and problems. The Geosciences are defined by its component disciplines, including geology, oceanography, and atmospheric sciences.

2. The geosciences depend upon interdisciplinary perspectives involving other disciplines, such as chemistry, math, physics and biology.

3. The geosciences also depend upon close interactions among its own several diverse fields that range from solar physics, to meteorology, to the internal structure of the earth.

4. The geosciences offer exemplary courses and curricula illustrating process-oriented science that can capture the minds of students and motivate them to enjoy, appreciate, and study science.

C. GENERAL RECOMMENDATIONS

1. This Committee takes the position that NSF should be actively involved in the planning and direction of undergraduate science, mathematics and engineering education. In support of this mission, NSF should structure a program that focuses on science education with continuity and relative budgetary stability. Incremental increases must be made yearly.

2. NSF must function in a leadership capacity to ensure that its mission and objectives are realized. The Committee agrees in principle that the "people directly responsible for the health of colleges and universities" (USEME, NSB86-100, 1986, p.7) must put forth the greatest effort in ensuring a significant presence in undergraduate science, mathematics and engineering education; nevertheless, the greatest impetus (relative to national policy and base-level funding) must come from the Federal Government.

3. NSF funding for educational programs should primarily come from the Science and Engineering Education Directorate. This directorate should oversee and evaluate programs that focus primarily on the educa-

tional aspects of the Foundation's activities while the Divisions within the Earth Science's Division should emphasize the research programs in the discipline. Those programs proposed here (that are best administered through the Geosciences Directorate) should be implemented only if additional funds are available.

4. At least one Geoscience representative should be appointed to the Advisory Committee to the NSF Directorate for Science and Engineering Education (SEE).

5. Plans should acknowledge and build upon achievements of the effective NSF programs conducted in the 1960's and 1970's. Some in depth evaluation of the previous programs should be undertaken or made available to aid in planning future programs. Those programs that worked well should be considered for renewed funding and implementation.

6. Programs that are developed should recognize and address the needs of geoscience educators to teach not only undergraduate students majoring in one of the geoscience disciplines but also students majoring in other fields of science as well as non-science majors.

7. The geoscience disciplines should be considered sciences of significance and importance equal to that of the traditional core sciences of physics, chemistry, and biology for general education i.e., viable alternatives for fulfilling general science requirements, for representing application of the scientific method, and for demonstrating the benefits of science for meeting human needs. Because of the human relevance of many geoscience disciplines, it is likely that geoscience courses may soon serve better than traditional core sciences to excite and stimulate student interest in science.

8. Tax relief to help restore the net stipends for Teaching Assistants (and Research Assistants) to attractive levels is essential for enhancing undergraduate programs. In the absence of such relief, undergraduate teaching will suffer as more universities eliminate laboratory sections from science classes because of budgetary limitations for support of graduate students who often instruct those laboratory sections.

D. RECOMMENDATIONS FOR NSF UNDERGRADUATE EDUCATION PROGRAMS

1. Direct Support for Individual Students

The highest priority items under this category involve programs that motivate undergraduate students to follow careers in the geosciences by bringing them into direct contact with active researchers. NSF should emphasize this commitment to undergraduate education by encouraging the inclusion in each geoscience research grant proposal of the proposer's ideas for enhancement of undergraduate education and the amount of additional funds, if any, that would be required. Additional specific recommendations follow:

(1) Endorse and adequately fund existing programs for undergraduate research. These include the Research Experiences for Undergraduates Program (REU) components: REU Sites and REU Add-ons. These funds should be added to the regular research budgets of the Divisions of the Directorate. Reallocating funds from the research programs will reduce rather than enhance opportunities for undergraduate research.

(2) Initiate additional programs for undergraduate research experiences. Funding for research projects that primarily involve undergraduate students should be available to all types of institutions without the restrictions of the REU programs. These research projects would encourage independent work in the geosciences; they could include proposals generated by students. In addition, the research experience could serve as a bridge leading to graduate work by, for example, pairing an undergraduate with a graduate student for research, under the supervision of a collaborating professor.

2. Laboratory Activity

The geosciences, perhaps more than other science disciplines, rely heavily on the analysis of field observations and measurements. Undergraduate geosciences courses for both majors and non-majors must reflect this emphasis. Accordingly, NSF funding for equipment used in geoscience education must recognize the need for logistical support for field trips and field classes (e.g., vehicles, camp facilities) as well as field instrumentation. Particularly expensive field equipment such as side-scan SONAR, expendable bathythermographs (XBT's), and current meters could be made available to undergraduate courses by sharing regionally among institutions through consortial arrangements. Some could be located at summer field stations having programs for undergraduates.

Laboratory sections are essential for analyzing field data and examining materials and processes not easily observed or controlled in the field. Laboratory equipment (e.g., microscopes, flumes, video imaging equipment), computers for data analysis and modelling, and demonstration materials (e.g., videotapes and slides) should be supported by NSF undergraduate geosciences programs. This support should have priority in light of recent trends to eliminate laboratory sections from geosciences courses.

The NSF programs in place that address needs for laboratory equipment and instrumentation must recognize the extra expenses associated with geosciences field trips and data analysis.

3. Faculty Enhancement

The enhancement of current faculty competence and knowledge should be an important component of funding for education in the geosciences. This primarily pertains to, but is not limited to, the undergraduate colleges and universities which do not have a large graduate and/or research commitment. Faculty at these institutions, can easily fall behind in their fields when they do not themselves actively pursue research. It is recommended that NSF:

(1) reintroduce summer science institutes at which college science teachers can learn from the research authorities in the field.

(2) support research grants for faculty from primarily undergraduate institutions to conduct research with promising undergraduate students.

(3) develop a new program to fund postdoctoral fellowships that focus on combining teaching with research. Little attention is paid to encouraging the most able students in considering teaching careers and in giving them the necessary experience to develop teaching skills. This program could be established to fund postdoctoral training that combines teaching part-time at an institution that emphasizes undergraduate teaching with part-time research. The research could be undertaken at the institution of the fellow's teaching appointment or, if appropriate, at a neighboring laboratory or university. Students at the host teaching institution would benefit from expanded and upgraded curricular offerings. The postdoctoral teaching fellow would be encouraged to teach subjects that would not otherwise be offered and to incorporate recent advances in his/her field into existing courses.

(4) use marine labs and field camps more effectively during the summers for undergraduates, secondary school teachers and college teachers. Because of economic constraints and declining undergraduate interest and participation in science, summer courses are now grossly undersubscribed. Such courses can provide a low-cost vehicle for high-quality training by some of the nation's best researchers in geosciences. This is a highly leveraged activity because the infrastructure is already in place (faculty, laboratory facilities, equipment and even course offerings).

Additional Recommendation

(5) provide funds for faculty to attend professional meetings whether or not they are presenting papers.

(6) establish a visiting scholars program for faculty to go to research laboratories during the summers to learn the latest methods/procedures in their interest discipline.

(7) support sabbaticals for undergraduate faculties.

(8) offer funding for undergraduate faculties to participate in short courses and/or mobile short courses.

(9) support research faculty to get "caught up" in evolving subdisciplines which are related to their own.

4. Curriculum and Courses

It is recommended that NSF:

(1) fund selected curriculum development projects focussed on introductory geoscience courses. The emphasis for such projects should include a recognition of the interdisciplinary nature and the relevance to human activities of the geoscience disciplines, the advances in the systems approach to the study of the earth, and the need to integrate the earth science disciplines. Proposals could include redesigning current courses, developing new courses, and developing courses focussed on particular groups of students, including but not limited to non-majors, underrepresented groups, and students enrolled in professional programs including teacher education. Any curriculum development support must include plans to disseminate the results so that they will be made available to the geoscience educator community at large.

(2) encourage consortial arrangements that increase opportunities for geoscience study. These could include proposals to pair a university with an historically black college or university (HBCU), with a junior or community college, or with a small undergraduate college. Alternatively a grouping could be arranged among several smaller institutions. The goal would be to provide expanded curricular offerings in the geosciences to a wider range of students and to provide for joint research efforts and sharing of major items of equipment. The role of the NSF would be to provide seed money to initiate such consortial arrangements.

(3) Work with professional societies to enhance undergraduate education through

(a) visiting scientist programs

(b) course material development

(c) encouragement of undergraduate participation in professional meetings

5. Underrepresented Groups

Several population groups of significant size in the U.S. are underrepresented in science. Their contributions and support are needed if the potential of the country is to be realized. In particular, the underrepresentation of minority groups (Blacks, Hispanics, Native Americans, American Samoans) is a major concern. Solving this problem requires not only awareness and conscious action on many fronts, but programs specifically designed to meet the needs in geoscience. Two such programs are recommended:

(1) Undergraduate geoscience students of high potential from minority groups need to be identified during their early college years and then assigned mentors for tracking and encouragement. As a part of this undergraduate mentor program (UMP), the students should have role models and the possibility of participating full time in summer geoscience research programs lasting at least two months.

(2) The teaching of undergraduate geosciences in institutions with a high percentage of minority groups needs to be significantly enhanced. In addition to having visiting scholars give lectures and workshops, cooperating arrangements among such small institutions and nearby institutions having geoscience faculty, instrumentation, and research programs should be encouraged and supported. Dual degree programs and consortia between and among HBCU's and neighboring non-HBCU's (also discussed in Section D.4(2)) are strongly recommended.

E. RELATED CONCERNS OF THE WORKSHOP

1. Pre-college Education

The education which undergraduates receive prior to their college enrollment was a major concern of the Committee. There was strong endorsement of NSF programs for pre-college education. The Committee made the following recommendations:

(1) The curriculum for primary and secondary school teacher students should be geared to provide a breadth of knowledge in the geosciences. This could be achieved by restructuring the traditional educational major curriculum to provide more breadth in courses or by encouraging students planning a precollege teaching career to major in a geoscience discipline, rather than in a typical education college major.

(2) NSF should fund programs where talented high school students and teachers could conduct and participate in research in NSF-funded research labs during the summer.

(3) In-service educational institutes or summer science teacher institutes should be supported by the Foundation, in order to update primary and secondary school teachers in the geosciences.

Additional recommendations:

(4) Funding should be made available for scholars to go to secondary schools to discuss the importance of the geoscience disciplines.

(5) Professional societies in the geosciences should be encouraged to sponsor sc[illegible]e fairs.

(6) Smaller colleges should form consortia to improve the education of science teachers.

2. Scientific Literacy

The mandate of this Committee has been to address concerns of undergraduate education. Nevertheless, we take very seriously the questions concerning scientific literacy, particularly as they relate to the geosciences. Scientific literacy may be defined as the formation of a reasonable scientific background and of an appreciation of science as a process and a way of learning. This includes both an understanding of the earth and an understanding of how science fits into people's lives. Scientific literacy is critical for the general population, including decision and law makers.

Courses and other programs in geosciences have the potential to excite the interest of students, and the population as a whole, broadening their knowledge of earth processes, providing the information necessary to make informed decisions on questions of the environment, geosciences, and technology. NSF should continue support of NOVA and other mass-circulation educational materials.

F. PRIORITIES

The priority listing was developed by correspondence after the Workshop meeting. Each participant was asked to identify his/her top three choices in ranked order. The Chairperson than combined the responses received from seven of the participants using a 3-2-1 weighting for each individual's three choices to arrive at the priority listing presented here. The first two priorities stood well above the rest. Priorities #3, #4, and #5 were very close in the ratings.

Priority	Section in Report	Item
1.	D.1	Direct support for individual students
2.	D.3(1)	Summer institutes for college college teachers
3.	D.5(2)	Undergraduate geosciences instruction at institutions with a high percentage of minority groups
4.	D.5(1)	Identification, tracking and encouragement of high potential undergraduate geoscience students from minority groups
5.	D.3(4)	More effective use of marine labs and field camps for undergraduates, secondary school teachers and college teachers
6.	D.3(3)	Postdoctoral fellowships that focus on combining teaching with research
7.	B.4	Exemplary courses and curricula that illustrate the process-oriented geosciences

F. Workshop on Mathematics

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2. Report of the Mathematics Workshop

Report of the Workshop on Undergraduate Mathematics Education

February 25 - 26, 1988

The Mathematics Workshop was convened on February 25 and 26, 1988. The purpose was to assist NSF with establishing priorities for undergraduate education in the mathematical sciences. The Workshop strategy was to review and build on the undergraduate portions of the November 1987 NSF document "Enhancing the Quality of Science, Mathematics and Engineering Education in the United States: Strategic Plan for FY1988 - FY1992, National Science Foundation". Workshop attendees are listed on the attached sheet.

Similar Workshops held in Mathematics, Science and Engineering in 1986 led to the establishment of a series of undergraduate programs that NSF launched in FY1987 and FY1988. The conclusions of the earlier Mathematics Workshop were based principally upon the National Science Board report entitled "Undergraduate Science, Mathematics and Engineering Education" (known as the Neal Report) and the National Research Council Report "Renewing U.S. Mathematics" (known as the David Report). The reports of the 1986 Workshops were also instrumental in the founding of NSF's Office of Undergraduate Science, Engineering and Mathematics Education (USEME) in the Science and Engineering Education Directorate. Workshop participants were sent review copies of the program announcements for the new programs, and were impressed with the programs that have resulted from the planning process described above.

Workshop participants recommend an expansion of NSF efforts in undergraduate mathematics education to fund a broad spectrum of projects in curriculum and materials, in faculty and student development, and in research about how students learn mathematics. The goal should be to assist creative faculty in pursuing innovative approaches to long-standing problems that impede the flow of students through the introductory college mathematics needed for careers in science, engineering and mathematics as well as for a technically literate general populace. There must be an associated strategy to help lay the groundwork for budget growth that will be required to fund such initiatives.

Workshop participants endorsed the renewed NSF emphasis on undergraduate education. They were impressed with the high level of cooperation evidenced by the Division of Undergraduate Science, Engineering and Mathematics Education (USEME) and the Division of Mathematical Sciences (DMS) in the organization of the workshop and in the design and operation of the programs in undergraduate education. Participation in NSF programs in mathematics education by individuals from all parts of the mathematics community is critical to success of the efforts, and the cooperation of the two organizations can only enhance efforts to stimulate participation. It will also facilitate necessary interactions with other science and engineering disciplines. We encourage the Foundation to ensure that such cooperation is built into its plans and structures and is independent of the individuals within the organization at any given time.

This spirit of cooperation is all the more important because the mathematics community has a long history of participating in education programs at a much lower rate than might be expected given the prominence of mathematics in the precollege and undergraduate curricula. We commend the recent outreach efforts of both USEME and DMS as well as inclusion of "mathematics" in the USEME title and its use in all USEME program announcements as good first steps at increasing the participation rate. In a similar vein, we recommend that the name of the Science and Engineering Education Directorate be changed to Science, Engineering and Mathematics Education.

Returning to the budgetary issue, it is recognized that priorities need to be set within NSF as well as seeking additional support. In that connection, the pipeline issue and the scientific literacy issue should be seen as critically important issues for the United States and the centrality of undergraduate mathematics to those issues must be emphasized. Simply put, this nation is not educating a sufficient number of well qualified students to keep a competitive edge in technological developments. Moreover, our adult population is largely illiterate in issues related to science and technology. Knowledge of mathematics at an appropriate level is a prerequisite to progress in both areas.

The referenced materials were discussed and there was agreement to work according to the diagram.

WORKSHOP STRATEGY PROGRAM

That is, successive Workshops should lead to modifications of strategy and thus to modifications of NSF programs.

In what follows, the general headings are taken from those of the S' ategic Plan.

LEADERSHIP ACTIVITIES

PERCEPTION OF NSF EDUCATION PROGRAMS IN THE MATHEMATICAL SCIENCES COMMUNITY:

Previous paragraphs have noted some concerns on this topic. More attention is needed to find ways for the broad mathematics community to be aware of and to participate in NSF programs for undergraduate education.

There is a perception in the mathematics community that participation in SEE programs and involvement in educational issues are not held in high regard and are not productive. This must be dispelled.

CAREER ACCESS:

The relationship of changing demographics in the United States to the potential shortage of human resources in science and engineering is widely recognized and well understood. Clearly, mathematics K-14 is the major barrier to participation in science and engineering. NSF already has in place excellent programs to improve minority access to careers in science and engineering. These efforts should continue. However, there should be an increased recognition of the special role that mathematics plays in science and engineering career access, and the NSF should establish a program or solicitation targeted on improving the retention and success of minorities in the study of mathematics.

SCHOLARSHIPS/FELLOWSHIPS:

One of the major problems in mathematics education facing this nation is the problem of the supply of well prepared mathematics teachers. The respect and rewards are at a low level. Additional incentives must be found to encourage bright young people to enter teaching at the secondary level. NSF should create a scholarship/fellowship program to support the *best* college students preparing for a career in mathematics teaching through their senior and graduate (MA, part-time or full-time) years of study, and perhaps provide additional support for one or two summers of continued development. The expectation would be that this program would not only increase the number of highly qualified mathematics teachers, but would also raise the prestige of the profession by providing a clear signal that NSF believes that mathematics teaching is important, just as mathematics research is important. (Similar Programs might make sense for encouraging secondary science teachers.)

MATHEMATICAL LITERACY:

In addition to the need for reform and improvement of undergraduate education in mathematics for future mathematicians, scientists, and engineers, there is also a need to improve the mathematical and quantitative "literacy" of the general public. The recognition of this need has been manifested at many colleges and universities by an interest in general education mathematics courses and requirements. The mathematical sciences community should support this interest and assume a leadership role in order to ensure that the programs and courses that are developed are of high quality and reflect the true nature of mathematics as a living, evolving discipline. We recommend that NSF be prepared to support curriculum development in this area.

INSTRUCTIONAL STRATEGIES:

There is considerable experimentation in the field with alternate instructional strategies designed to increase success in mathematics learning. Many of these strategies are being developed in an attempt to improve retention of minorities and other at-risk students in the science and engineering pipeline. Although such experiments are sometimes supported by NSF as curriculum development projects, the fit is not perfect. Furthermore, there is a need to encourage additional experiments of this type. We recommend, therefore, that NSF encourage proposals for the development and evaluation of such strategies. (See also our recommendations under Materials, Curriculum, and Technology; Faculty, and Research in Postsecondary Education below.)

TARGETING:

The current targeted approach to NSF funding of education projects in mathematics is valuable and is appropriate for the initial period of reentry into undergraduate education funding. Targeted solicitations are particularly valuable in NSF's effort to address high priority problems and to stimulate local support. However, it is important that NSF also support the best ideas that emerge from the field. The availability of such flexible funding should be well publicized.

INFORMATION GATHERING AND NETWORKING:

There is a serious lack of available information on current undergraduate education activities in mathematics. NSF should play a leadership role in ensuring such information is collected and made available to the mathematics community. In particular, information on funded NSF projects should be well disseminated.

NSF is uniquely positioned, because of its activities in both research and education, to encourage networking within and between all segments of the mathematics community. We urge the Foundation to explore possible approaches to establishing such networks (newsletters, electronic mail, etc.) and to take a leadership role in encouraging or establishing such a network.

COMMUNITY SUPPORT FOR EFFORTS IN EDUCATION:

There is an unfortunate (pernicious) tendency both inside and outside of NSF to regard activity in research as more valuable than activity in education. NSF should make a determined effort to reverse this tendency. In particular, should barriers exist within NSF that prevent cooperation between the mathematics research personnel and mathematics education personnel, they should be removed. The NSF should publicly take the stand that efforts to improve instruction in mathematics and science are as important to the nation as research efforts and should be appropriately recognized and rewarded.

FEDERAL AGENCIES:

The National Science Foundation is not the only federal agency supporting research in mathematics and consequently is not the only federal agency with legitimate concerns for the future of undergraduate education in mathematics. We urge other federal agencies to support improvements in undergraduate education in mathematics and recommend that appropriate coordinating mechanisms be developed to ensure the most effective use of federal funds. The Workshop was not aware of appropriate mechanisms for carrying out such coordination at present.

LEVERAGED PROGRAM ACTIVITIES

INSTRUMENTATION:

Computing has become an important part of mathematics and of education in mathematics. One aspect of this new element is that mathematics research and education now have certain elements of a laboratory science.

- The mathematics community needs assistance in exploring the capabilities of current and future computer technologies as they pertain to mathematics instruction.
- It also needs assistance in investigating how computer technology can affect the curriculum.
- The faculty needs support in the upgrading of their skills in the use of this equipment, in their knowledge of how the equipment can be used, and in the integration of this equipment into the curriculum. In particular, they need to learn how to develop effective teaching materials and skills for this new classroom environment.
- Assessment techniques need to be developed to evaluate the effectiveness of the use of computer technology in instruction.
- Faculty need to find out how to decide when to use paper and pencil techniques and when to use computer technology in solving mathematical problems and instructional problems; what new problems are now accessible with computer technology that will allow the students to more readily learn the concepts and ideas that are currently included in the curriculum; and what concepts are now more important or newly accessible that we need to present to our students because of the new computer technology?

It is recommended that there be a separate initiative, adjunct to the present instrumentation program, to address the issues described here.

MATERIALS, CURRICULUM AND TECHNOLOGY:

Curriculum development broadly interpreted should form the centerpiece for new initiatives in undergraduate mathematics education. This is because work on curricula cuts across all of the major areas of concern. Faculty are enhanced by their involvement with new course design; new technologies are incorporated in an essential way; and the new content is related to experiences with different learning strategies for improved student/faculty interaction.

- Materials Development: it is clear that a major effort is required across the math curriculum with special emphasis on introductory courses which serve the general liberal arts student as well as potential math, science and engineering majors. We feel strongly that significant funding should be available for innovative projects at both the national and local levels open to all areas. However, it may be strategically advantageous (in leveraging funding and stimulating interest) to target specific courses (such as introductory statistics) or content strands (such as geometry) for special attention.
- Encourage the development of goals and objectives, including conceptual understanding, for beginning mathematics courses, together with means of assessing success in achieving them.
- Encourage the development of learning strategies and understand their relationship to curriculum content.
- To stimulate further interest in mathematics and science education, we urge the establishment of regional undergraduate mathematics centers which would bring together, under one umbrella, researchers, educators, and developers.

FACULTY:

We recommend that the Faculty Enhancement Program be expanded in two ways. First, encourage the broadest participation on the part of faculty involved in undergraduate mathematics teaching, including two-year college faculty, selected high school faculty and research mathematicians. Second, broaden the focus to include instructional strategies and pedagogical techniques.

We also recommend the development of exchange programs between faculty at colleges (two- and four-year) and universities, with an aim toward the sharing of instructional and technical ideas.

Finally, we encourage the development of exemplary programs in the involvement of graduate students in effective teaching and curriculum development activities.

RESEARCH FOR UNDERGRADUATES:

The Research Experiences for Undergraduates program should be expanded. Cross-disciplinary projects should be encouraged.

Additionally, a new program should have as its purpose the attraction of undergraduates to mathematical careers through the following kinds of activities:

- A "young scholars" program to bring together exceptional students in grades 12 - college juniors to participate in active mathematical investigation on subjects not in the traditional curriculum;
- Cooperative projects which involve business, industry, or other academic disciplines to provide non-traditional problem-solving experiences for undergraduates.

CAREER ACCESS:

Erich Bloch, Director of NSF has stated that "There is no problem that is more important, because without more participation from these [underrepresented] groups we cannot possibly meet our needs for trained technical and scientific personnel in the decades ahead."

NSF programs and recommendations will determine the climate in which the mathematical community will respond to the educational challenges of increasing the participation of minorities in mathematics at all levels. We are aware of the various NSF programs for research initiation by minority scientists, minority graduate fellowships and the (newly created) Career Access Program in Science and Engineering Education. However, we stress the urgent need for the mathematical community and NSF to combine forces and offer targeted support and encouragement for the following.

- Replicate those programs that make significant contributions to mathematics education for minorities. Ensure such programs are run by mathematics departments and involve mathematicians in significant ways.
- Establish programs that recruit, support and train minority students to become pre-college mathematics teachers. A network of mathematicians and school district administrators of large minority enrollments, who are involved in Pre-college teacher mathematics education should be formed. Nationwide in-service and pre-service programs should be developed for achieving a representative proportion of minority teachers.
- Establish minority graduate fellowships for pre-college teachers.

RESEARCH IN POST-SECONDARY EDUCATION:

NSF should establish a full program to support research on learning and teaching undergraduate mathematics.

A part of the lack of success that undergraduates have in mathematics may be the result of the fact that we know too little about [illegible] young adults can learn mathematics and what teachers can do to help.

Basic research into the learning process at the undergraduate level is sorely needed. Such research is just beginning in this country and NSF support should be aimed at stimulating its development. In addition to how young adults learn, there should be investigations into the effects of alternative modes of instruction and how they relate to learning; determinations of what are the real prerequisites for learning mathematics at the undergraduate level; and experimentation with, as well as evaluation of, alternative curricula that represent qualitative differences in the nature of the mathematics that students are expected to know.

ADDITIONAL COMMENTS

Priorities Among Major Activities: Although all areas of undergraduate mathematics need revitalization, it is important to recognize for both financial and programmatic reasons a natural priority: *stimulation of faculty must occur in order to revise curricula which in turn will imply requirements for computers and mathematics laboratories which make possible student projects in investigative mathematics.* Different institutions will be at different points of this natural evolution, so NSF programs must be flexible enough to accommodate different needs. Moreover, the loop feeds back, since design of projects to change courses or involve students will lead to renewal of faculty.

Categories of Undergraduate Mathematics: The part of undergraduate mathematics that is in greatest disarray, indeed in shambles, is the component for general education of students not in quantitatively based disciplines. Virtually no one knows how to educate college students to be mathematically literate. Since scientific and mathematical literacy is a major goal of the NSF, it is crucial that a major leadership effort be undertaken to help define national goals for what educated citizens should know about mathematical sciences and how these goals can be achieved in general education.

Resources: By targeting priority areas and inviting proposals, NSF not only is able to fund select programs, but stimulate local planning which in many cases can lead to local resources for the same activity. To maximize the likelihood of this natural leveraging, NSF may want to recognize locally supported projects that complement its own efforts.

G. Workshop on Physics

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2. Report of the Physics Workshop

Report of the NSF Workshop on Undergraduate Physics Education

April 14-15, 1988

I. Introduction and Overview

Despite the success of modern science, the 1980's may be characterized as the decade of crisis in science education. Starting with *The Nation at Risk*, studies of increasing depth have documented a failure of the system to cope with the recent explosion in technology and science. Problems abound in all phases of the educational loop, beginning with childhood and the family and continuing to elementary school, secondary school, and university. Scientists, engineers, citizen-voters, political candidates, teachers, and parents are all part of the loop.

In recognition of this alarming problem, in 1986 the National Science Board commissioned a study of undergraduate science, mathematics and engineering, the Neal Report, which focussed on undergraduate education. Responding to the Neal Report, the National Science Foundation established an Office of Undergraduate Science, Engineering, and Mathematics Education and began new undergraduate programs in faculty enhancement, instrumentation and laboratory improvement, curriculum development in engineering and calculus, career access, and research experience for undergraduates. The NSF also called for a series of workshops to make specific recommendations for improving undergraduate education in each of the sciences.

Here we report on the results of a two-day workshop devoted to improving undergraduate education in physics and astronomy. (Henceforth, we will use "physics" to refer to both physics and astronomy.) We first reviewed and confirmed the crisis in science education. This confirmation is found in part in the statistics of the performance of young Americans, in the projected shortfall of trained physicists and, perhaps most urgently, in the abysmal state of scientific literacy of most college graduates. Our approach has been to use the Neal Report as a basic document and to make specific recommendations for how NSF might address the problems. Many of the problems in physics education are clearly shared with other disciplines, and we expect that NSF will combine the results of the various workshops. However, physics has some particular concerns that differ from the general picture portrayed in the Neal Report.

We cannot comment on the relative state of science education in different countries. This complex problem may hinge in part on broad cultural differences and is beyond the scope of our committee. In the United States, we see at least three basic problems underlying the present poor condition of science education and scientific literacy: (1) Teaching is considered a second-class intellectual activity compared to research, (2) Science is isolated from the broad body of knowledge expected of the well educated person, and (3) There is not enough interchange between research and teaching communities. These problems are serious. We are convinced that they cannot be overcome without a radical revision of undergraduate curricula. In such a revision, we see a broad presence of science - as a relevant theme in the social sciences, for its influence on history and contemporary social and economic thought, and as a theme in the humanities, for its cultural and aesthetic value.

The most important thing the NSF can do for science education is to increase the prestige and respectability of teaching. To accomplish this, we recommend that the NSF establish grants for teaching and curriculum development, analogous to the influential grants now given for research, and that the NSF award prizes and fellowships to outstanding teachers. To address the problem of scientific illiteracy in the general college population, we recommend that the NSF award prizes and fellowships to outstanding teachers. To address the problem of scientific illiteracy in the general college population, we recommend that the NSF establish summer institutes for humanities and social science teachers, introducing them to scientific ideas that might be integrated into their courses. Conveying science to the nonscientist may produce the broadest and deepest base of support for science in the long run, and we place high priority in this activity. We also recommend that the NSF administer brief science examinations (exit interviews) to graduating college seniors and then publicize the results.

Section II. concerns curriculum and faculty development, section III student recruitment and retention, and section IV. science for nonscience majors. Appendix A is a suggested questionnaire to be attached to NSF research grants, with the aim of sensitizing the researcher to science education. Many of our specific recommendations are given price tags; these amounts refer only to physics and astronomy education, with the exception of the recommendations in section IV.

II. Curriculum and Faculty Development

Most college physics curricula do not adequately reflect recent scientific developments. The standard course attempts to "cover" a large range of topics rather than teach general scientific reasoning and problem-solving skills, fails to incorporate new ideas in the understanding of human cognition and educational strategies, and does not exploit new educational tools such as computers and video-disks.

A crucial problem is that teaching and teachers are not truly valued at research institutions. The strong emphasis on research at these institutions, as reflected by the criteria used for promotion, salary increases, and collegial respect, deters faculty from investing time in education. Such an emphasis on research is even creeping into four-year colleges that have traditionally concentrated on teaching. On the other hand, the heavy teaching responsibilities at non-research institutions makes it difficult for faculty members here to keep current on advances in science. The dual isolation of university researchers from educational activities and small-college teachers from current research offers an opportunity for interchange between faculty at different types of institutions. Moreover, good curriculum development may require the complementary talents of faculty members at both research and non-research institutions and will often transcend the scope of any one individual.

Recommendations:

1. *SUPPORT FOR CURRICULUM DEVELOPMENT.* We recommend curriculum development both by individuals and by groups. The NSF should award unsolicited grants for curriculum-development proposed by well-qualified faculty members in the same way that it now provides grants for research projects. Such proposals, like research proposals, would be funded on the basis of merit and through a process of peer review. For example, the NSF could award 50 grants of $60 K per year each.

Since substantial curriculum-development efforts often require resources and talents beyond the capabilities of any single indiviual, the NSF should encourage the group approach. Such a curriculum-development team should probably include complementary expertise in physics, education, and cognitive science. It should be provided with adequate physical resources such as computers and video facilities. Preference should be given to teams composed of researchers and educators. The product of such a group should include exportable educational materials. Its activities should include interactions with teachers and students at various levels. Proposals for curriculum-development projects should be welcomed at any time and should be subject to appropriate peer review. It is also essential to support some long-term projects, perhaps up to five years in length. We suggest that the NSF might fund a few groups, at a cost of $500 K per group per year.

A primary goal of both the small-scale and larger-scale curriculum-development programs would be the development of teaching materials worthy of widespread national dissemination. For this reason, each grant would contain a provision for dissemination of the materials through publications, conferences, workshops, or visits. The grants would support all phases of the materials-development effort, including summer salary, funds for materials and equipment, and money to cover the costs of travel, publication, and communication.

2. *WORKSHOPS, SUMMER SCHOOLS, AND FELLOWSHIPS.* The NSF should support conferences, workshops, and summer schools dealing with instructional improvement and curriculum development, and it should fund individuals to attend these activities. We suggest about 4 workshops per year, at a cost of $250 K each. The NSF could also fund individuals to visit educational-development groups, for periods of one to ten weeks, in order to transfer expertise and to help evaluate the programs.

Programs that offer summer research opportunities to college physics teachers now exist at several of the National Laboratories. It is our sense that these programs can be made more visible and more effective. Information about the programs at the various Laboratories should be available through a single publication. It would also be desirable if the conditions and selection procedure from the various programs could be common. Faculty Members accepted for such a program should have the opportunity to apply to NSF for small grants to bring their experiences back to the classroom. For example, some funds might be necessary to introduce a newly mastered measurement technique into an undergraduate laboratory, or to provide support for production of new and engaging class or laboratory notes. A small expansion of the existing program for Faculty Enhancement seems the natural vehicle to handle this program, at a level of perhaps $1000 per person for about 50 people. If the number of faculty visitors at any given National Laboratory is 10 or more, a weekly meeting to share ideas and to develop educational strategies might be productive.

The NSF should provide fellowships for faculty to acquire new knowledge and skills, with the expectation that they would subsequently use such knowledge in their teaching and curriculum development. We suggest 30 fellowships per year, at $40 K each.

3. *CONSULTING TEAMS.* We recommend formation and support of consulting teams to promote two-way communication between teaching and research faculties. For example, a research university may wish to draw on the experience of outstanding people in a teaching college, where the smaller number of students often permits more flexible experimentation with new modes of instruction. The NSF and the research university could jointly fund a team of consultants from the teaching college. Or a research university might wish to draw on

the extensive work done at a teaching institution to develop computer-based laboratories. Or a team of faculty from a research institution might present a two-day program of "Highlights in Current Research" to a faculty seminary group from several teaching colleges near each other.

4. *VISIBILITY OF WOMEN AND MINORITY GROUP SCIENTISTS.* We recommend increasing the visibility of women and minorities active in scientific research. Colloquia and seminars at colleges and universities offer good opportunities. We recommend that investigators holding NSF research grants be encouraged to apply for supplementary funds to pay the honoraria and travel costs of colloquium speakers who are women or minority group members. Such speakers could be identified as NSF-sponsored and would serve as role models. We assume a typical cost of $1000 and suggest that NSF support 25 of these awards each year. Such incremental funds would be requested by principal investigators at the time of grant applications.

5. *PRESIDENTIAL SCIENCE TEACHER-SCHOLAR AWARDS.* To promote the recognition and prestige of outstanding teachers and teaching, the NSF should establish a well-publicized program of Presidential Science Teacher-Scholar Awards. We recommend two types of awards: (a) a career-development award for distinguished undergraduate science teaching or curriculum development and (b) awards to eminent scientists and teachers to spend a year teaching physics to nonscience majors. A recipient of the first type of award might be allotted a grant of $10 K per year for five years to carry out the research or development program of choice, as in the Presidential Young Investigators Awards. Additional support from other sources might be matched by NSF up to some maximum limit. Unlike the PYI awards, we recommend that no limit be placed on the age or professional seniority of applicants. We suggest an initial operation of 10 new awards per year, until the success of the program can be evaluated. The second type of award, for teaching or popularizing to nonscientific audiences, is discussed more fully in section IV.

III. Student Recruitment and Retention

At colleges and universities throughout the nation, fewer bright students are enrolling in physics programs. In addition, capable students are dropping out of existing courses in physics. Consequently, the supply of trained physicists for research and development in the national economy is limited, threatening our competitiveness Few women and minority students take physics courses. High school students are given bad advice by high school counselors regarding opportunities in physics. Physics is perceived as being too difficult for most students.

Our workshop considered these problems to be important, but did not have time to develop detailed recommendations. Below are preliminary recommendations.

Recommendations:

1. *A TRAVELLING "CIRCUS" OF SCIENCE.* With help from industry, create a nationwide travelling science "circus" to help identify science as a rewarding and important career. Science centers have shown the importance of this type of enterprise but have difficult reaching students outside of the immediate urban area.

2. *WORKSHOPS ON PHYSICS CAREERS FOR HIGH SCHOOL COUNSELLORS.* Help make high school counselors more aware of the opportunities in physics by giving workshops and lectures on physics careers at national meetings of high school counsellors. The NSF could commission a high-quality video tape on physics for high school physics teachers and counsellors.

3. *TUTORING CENTERS AT COLLEGES AND UNIVERSITIES.* The NSF should raise the profile of tutoring centers staffed with students from minority groups, including women. These centers should provide a high degree of staff training and demonstrate the success of tutoring.

IV. Science for Nonscience Majors

Science and technology are major catalysts for change in the modern world, yet few nonscientists feel comfortable with these subjects. Since it is this same group of nonscientists that produces our voters, teachers, legislators, and journalists, it is clearly important to give them some appreciation for science. On a broader level, science is as much a part of our cultural heritage as are philosophy and art; in an ideal world, college graduates would know as much about Michael Faraday as they do about Henry VIII. The recognition that science must be a major element of the vocabulary of the educated person will take a revolution in the way we educate.

Recommendations:

1. *SUMMER SCIENCE INSTITUTE FOR HUMANISTS AND SOCIAL SCIENTISTS.* Nonscience majors come to the classroom with a body of knowledge about literature, history, philosophy, and social science - these are the subjects that will shape their approach to thinking and their world view. Consequently, this body of knowledge must be tapped and incorporated in any meaningful encounter with science.

Placing science in a human and cultural context can be approached from two directions: science courses can include the historical and philosophical context of science, and humanities and social science courses can include appropriate scientific ideas. The second approach aims at a much larger fraction of the undergraduate population and may produce a broader base of support for science in the long run. To encourage this approach, we propose NSF Summer Science Institutes for humanities and social science teachers. These teachers might then be able to incorporate science into their courses in a natural and compelling way. For example, a philosophy teacher might be able to include discussion of the experiments of Joseph Henry. NSF would have to be very careful in selecting the people to teach such Institutes. We would favor selecting participants who were not already involved with the history of science or with science policy.

We suggest that about 4 Institutes be established initially. Each Institute would run about 1 month in the summer and pay the expenses and salaries of about 40 participants. Individual universities or other institutions would submit proposals to NSF to run one of the Summer Institutes. Joint sponsorship of this program by the National Endowment for the Humanities might add cachet for the humanists. We recommend that the activities of the Summer Institutes be documented and widely disseminated. Estimated costs would be about $250 K per Institute, including partial support for participants.

2. *EXIT EXAMINATION PROGRAM*. Inspired by Irwin Shapiro's video tape on naive scientific beliefs of graduating Harvard students, and trading on NSF's clout with the college community, we suggest that NSF begin a systematic program of interviewing graduating college seniors on their knowledge of basic science. These interviews could be done in perhaps 100 colleges across the nation, selected at random each year. The questions would be extremely basic, such as "What causes the seasons?" or "What causes a spinning ice skater to increase her rate of spin when she pulls in her arms?" The results would be published and would probably embarrass the colleges that do not do well. NSF could call in a group of consultants to design a new questionnaire each year. We suggest that this program be allocated about $100 K per year and continue for five years before evaluation. The objective would be to raise the awareness of college administrators about the low state of scientific literacy in their graduates.

3. *PRESIDENTIAL SCIENCE TEACHER-SCHOLAR AWARDS*. This type of award, designed to recognize and encourage outstanding people teaching science to the nonscience major or the general public, was mentioned briefly in section II. Recipients would spend a year teaching physics to nonscience majors. We see this as a symmetric arrangement, in which leading research physicists might travel to four-year colleges while prominent college teachers might similarly travel to research universities. The resulting courses should be documented and published where appropriate. As incentive, NSF would pay the salary, travel expenses, and supplementary budget (secretarial help, research assistance), as well as overhead to the participating institution. Costs could be reduced if the teaching year coincided with a sabbatical year, in which case perhaps only half of the professor's salary would have to be paid by NSF. We estimate the cost to be about $100 K per person and suggest a start of 10 teacher-scholars. To make these positions even more prestigious, they should be well publicized, including a ceremony at the White House.

4. *GRANTS FOR POPULARIZATION OF RESEARCH RESULTS*. New research results might be continually translated into an accessible form in order to engage the nonscientist. We suggest the addition of small supplements to existing research grants to assist such a translation, either by the principal investigator or by some other person associated with the research program. Such a program, in addition to bringing new results quickly to a wide audience, could strengthen the coupling between members of the research community and the broader public.

Appendix A: A No-Threat Questionnaire

NSF is the major funding agency for research in universities. Including a questionnaire in all research grants might encourage scientists to reevaluate the importance of education and also provide data on how many scientists were investing time in education. We suggest a thorough discussion of the implications of such a questionnaire before it is put into operation. An example follows:

The NSF is committed to fostering undergraduate participation in scientific research. To assist the Foundation in assessing the extent of involvement of undergraduate students in grant-supported research in physics, please answer the following questions:

1. How many undergraduates will participate in your research project

   during the academic year only?

   during the summer months only?

   all year around?

2. Will any undergraduates use the research experience gained in this project for an honors thesis or similar special academic recognition?

3. Do you regard research participation in your project as a desirable educational for an undergraduate?

4. What has been your past experience with undergraduate participation in your research activity?

5. Have you taken any steps to convert research results to a form suitable for use in an undergraduate class or laboratory? Please furnish details.

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