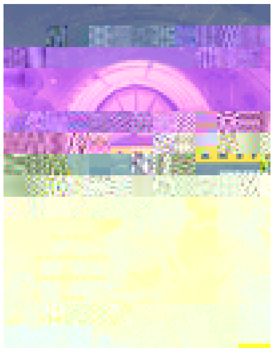

Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology

Committee on Undergraduate Science Education, National Research Council

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# Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology

Committee on Undergraduate Science Education
Center for Science, Mathematics, and Engineering Education
National Research Council

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# Foreword: A Call To Action

What does it mean to be scientifically, mathematically, and technologically literate in our society? When and how do young people begin to develop the requisite skills and knowledge, and what is the responsibility of the scientific community in helping them do so? Early childhood studies about how and at what developmental stages children learn various kinds of information and concepts are helping us to understand the kinds of intervention and education that are important well before

". . . diverse opportunities for all undergraduates to study science, mathematics, engineering, and technology as practiced by scientists and engineers, and as early in their academic careers as possible." In addition, the authoring committee has taken great care to address both the separate and complementary roles that various members of the campus community could play in realizing this goal. Chief academic officers, so often unacknowledged as key stakeholders in changes of this magnitude, are encouraged to assume a primary leadership role. Important, as well, are the specific strategies provided in the report to help chief academic officers, individual faculty, and academic departments improve all aspects of undergraduate SME&T education. These strategies include raising expectations for pre-college preparation in SME&T, providing inquiry-based and

# Preface

In 1993, the National Research Council (NRC) established the Committee on Undergraduate Science Education (CUSE) as a joint initiative of the Commission on Physical Sciences, Mathematics, and Applications and the Commission on Life Sciences. This standing committee is now an integral component of the NRC's Center for Science, Mathematics, and Engineering Education.

Charged by the NRC with seeking ways to improve scientific literacy for all undergraduates, the committee has worked to identify, develop, and promote implementation of undergraduate programs that enrich the understanding and appreciation of scientific knowledge and improve the skills necessary for continued learning, productive lives, and informed decision making.

To date, the committee has published two reports, entitled *Science Teaching Reconsidered: A Handbook* (National Research Council, 1997a) and *Science Teacher Preparation in an Era of Standards-Based Reform* (National Research Council, 1997b). The committee also provided comments on the *National Science Education Standards* (National Research Council, 1996b). These reports are available free of charge on the World Wide Web at <http://www.nap.edu> In addition, a short introduction to the *National Science Education Standards* has been provided as an appendix to this report (see Appendix D).

In late 1995, the committee embarked on the work that would directly lead to the publication of *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology*. Through the generous support of the Exxon Education Foundation, the committee hosted a series of regional symposia and topical forums—a "Year of Dialogue"—to explore many of the issues raised by the NRC and National Science Foundation reports on undergraduate education respectively entitled *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Research Council, 1996a) and *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Science Foundation, 1996b). These reports are also available free of charge on the World Wide Web at <http://www.nap.edu>

This report's primary goal, six vision statements, and multiple strategies for implementing the visions are designed to assist top-level academic officers, individual faculty, and departments in the critical process of institutionalizing the improvement of undergraduate science, mathematics, engineering, and technology (SME&T) education. The content of the report was informed by and reflects the "Year of Dialogue," which is detailed in Appendix A. It also reflects research findings on undergraduate SME&T education and many discussions held before and since the "Year of Dialogue" with national organizations for science, mathematics, engineering, and technology education and with faculty and chief academic officers from a variety of institutions of higher education across the country.

*Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* is written to encourage members of the postsecondary SME&T community to reflect on the following kinds of questions related to undergraduate education (modified from Fox, 1998):

Science education for all undergraduates: Are we exposing all of our students to the kinds of effective teaching techniques and meaningful educational experiences that truly excite them about SME&T? Do we actively engage students in SME&T in ways similar to how we work as scientists, mathematicians, or engineers, given that the vast majority of students in our introductory courses will never again have formal exposure to our disciplines? Are we providing students with the intellectual skills and background they will need to appreciate and continue learning about SME&T throughout their lives? Are we helping our students understand "real world" applications of SME&T? Do we make explicit connections between our disciplines and others in the natural sciences, social sciences, and the humanities in our courses and when advising students?

Preparation of future K-12 and undergraduate teachers of science, mathematics, and technology: Are we preparing future teachers to engage the next generation of students in science, mathematics, and technology? Do we, as undergraduate faculty, model the kind of teaching and promote the kind of learning we would like to see in grades K-12? Do we encourage our graduate students and postdoctoral fellows to think seriously about quality teaching of undergraduates both in their current roles as teaching assistants and in their future roles as faculty members?

Retention of SME&T majors: Seymour and Hewitt (1997) have carefully documented the distressingly high numbers of students who enter college with intentions of pursuing majors in SME&T and then change paths shortly thereafter. Are we doing enough to encourage these students to continue their study of SME&T by engaging their interests while they are enrolled in our introductory courses? In addition to the rigorous disciplinary content contained within introductory courses for prospective majors, do these courses also provide students with connections to broad SME&T concepts, including applications to the natural and engineered worlds? Do we work with colleagues in other SME&T departments to integrate information and concepts from other required courses into our own courses? Do upper-division courses build upon rather than repeat concepts that students learned in their introductory SME&T courses? Are our curricula structured to offer "gateways" in their later undergraduate years to students who did not pursue SME&T majors in their first year? Do we, as faculty, know enough about the myriad career opportunities that are available to SME&T majors to advise them properly?

Making teaching community property (Shulman, 1993): Do we speak with departmental colleagues often enough (or

# Executive Summary

Through science, mathematics, and engineering, our nation continues to lead the world in the development and utilization of new technologies. Whether related to our health, to the environment, or to our production and use of material goods, science, mathematics, engineering, and technology (SME&T) are integral and essential parts of daily life for virtually everyone in the United States and around the globe. However, the understanding of SME&T by most Americans, which reflects the level of SME&T education most Americans have had, is inadequate for full participation in this increasingly technological world. Our nation is becoming divided into a technologically knowledgeable elite and a disadvantaged majority. Given the large and increasing numbers of students in the higher education system and the fact that all teachers of grades K-12 are products of that system, improving SME&T education, particularly at the undergraduate level, could be a critical means for closing the gap.

Changes are needed in current approaches to teaching SME&T at the undergraduate level as well as in graduate training and continuing education for teachers. To effect these changes is an enormous challenge. However, on campuses across the United States, many individuals are making substantive improvements to SME&T courses, programs, and curricula. The time has now come for the institutionalization and sharing of these improvements. Nothing less than the fundamental reform of American postsecondary SME&T education is at stake.

To guide the institutionalization and sharing of postsecondary SME&T education reform, primarily at the undergraduate level, the authoring committee of this report—the Committee on Undergraduate Science Education (CUSE)—has adopted a primary goal. It is based on five years of research and discussions with members of many sectors of the higher education SME&T community, including two years of intensive research into and consultations about major issues in SME&T

standards-based approaches to science and mathematics (and eventually technology) education should enable more students to reach these desired levels of achievement.

Strategies for Promoting and Implementing Vision 1

| Executive and academic officers of postsecondary institutions can implement Vision 1 by | Individual faculty and academic departments can implement Vision 1 by |
|---|---|
| 1. Asking academic SME&T departments and the Office of Admissions to establish appropriate institutional admissions standards for science and mathematics preparation. | 1. Responding to both the current educational experiences and accomplishments of today's students and to the changing expectations about what pre-college students should know and should be able to do in SME&T as a result of the increased use of national and statewide standards-based curricula and assessment tools. |
| | 2. Working with their institution's Office of Admissions to make clear to prospective students the departments' expectations for entry into SME&T programs and the institution's goal of providing SME&T education to all of its enrolled students. |

However, the committee recognizes that standards-based K-12 education in science, mathematics, and technology is not yet available to most students across the country. Colleges and universities must now rely on standardized examinations in these disciplines that do not necessarily assess the kinds of learning emphasized in national standards. Many postsecondary institutions also employ open admission policies. Such policies provide critical educational opportunities for students who may not have had the academic experiences called for by national and state standards.

Moving K-12 education to a system that is more consonant with standards will likely require at least a decade. Nevertheless, change is occurring—albeit at different rates—in many parts of the country, and increasing numbers of students are likely to arrive at postsecondary institutions with greater exposure to science and mathematics standards. Thus, postsecondary institutions, their admissions offices, and faculty will need to monitor these trends in K-12 education with respect to admissions policies and the content and teaching of undergraduate courses. Admissions policies should be revisited regularly to account for changes taking place in the K-12 sector.

The committee also recognizes that, although this vision and the accompanying implementation strategies are appropriate for a majority of students in the nation's high schools, many other students will need creative alternative pathways to higher education. These students include those who have not performed well academically in high school but who have potential to succeed at college-level studies and those who did not receive the kind of education articulated in this report and who, as adults, are now seeking additional education.

## VISION 2

SME&T would become an integral part of the curriculum for all undergraduate students through required introductory courses that engage all students in SME&T and their connections to society and the human condition.

Science is an integral part of our daily lives. It also is an historical and procedural foundation for human thinking about

Strategies for Promoting and Implementing Vision 2

| Executive and academic officers of postsecondary institutions can implement Vision 2 by | Individual faculty and academic departments can implement Vision 2 by |
|---|---|
| 1. At institutions with active research programs, convening | |

encouraged whenever possible. Other students, especially those who aspire to careers in teaching, would be encouraged to participate in original research, either through inquiry-based laboratory experiences associated with SME&T courses or through the kinds of supervised research opportunities available to SME&T majors. For research experiences lasting one semester or less, students might become involved with faculty- or student-originated projects in progress or with smaller projects designed by a faculty member and a group of students in a research-based course.

## VISION 3

All colleges and universities would continually and systematically evaluate the efficacy of courses in SME&T.

Faculty would continually evaluate their courses for efficacy in promoting student learning. Such evaluations would reflect in part the emphases outlined for Vision 2. Thus, in addition to mastery of the specific subject matter taught in a course, success would be defined and measured by the degree of understanding and appreciation gained by students of both general scientific concepts and of the scientific approach to understanding natural processes. Evaluations would include measurements of learning at several levels: in the courses themselves, in subsequent SME&T courses, and, ultimately, in career and life. The results of such evaluations would be used continually to produce improvements in courses for students both inside and outside of the major, to assist in the professional development of individual faculty, and to allow departments continually to assess and improve their curricular offerings.

Strategies for Promoting and Implementing Vision 3

| Executive and academic officers of postsecondary institutions can implement Vision 3 by | Individual faculty and academic departments can implement Vision 3 by |
|---|---|
| 1. Benchmarking undergraduate programs within their | |

## VISION 4

SME&T faculties would assume greater responsibility for the pre-service and inservice education of K-12 teachers.

Improving the SME&T education of both pre-service and in-service K-12 teachers is one of the most important challenges facing college and university faculties.[2] Scientists, mathematicians, engineers, and teacher educators all need to share responsibility for teacher preparation (e.g., Riley, 1998). If *Vision 4* were to be realized, these faculty would provide integrated pre-service and inservice experiences that blend scientific knowledge with pedagogical methods and effective teaching practices. Teacher education programs would be informed by the *National Science Education Standards* (National Research Council, 1996b), the *Curriculum and Evaluation Standards for School Mathematics* and the *Professi*

piloting new programs and practicing effective teaching and assessment activities.

The authoring committee recognizes that implementing the visions of this report could require new funds or shifts in the allocation of resources. The costs involved may vary considerably from institution to institution. With the evidence and information provided in this report, the committee hopes to stimulate serious discussions at all higher education institutions that will take into account the need for new or reallocated resources to implement change.

Strategies for Promotion and Implementing Vision 5

| Executive and academic officers of postsecondary institutions can implement Vision 5 by | Individual faculty and academic departments can implement Vision 5 by |
|---|---|
| 1. Creating both general and discipline-based Teaching and Learning Centers that<br>• provide advice and technical support so that innovations can be implemented successfully;<br>• provide students with internships, assistantships, or fellowships to encourage input into the development of courses; and<br>• offer small grants to provide faculty with released time or other resources for particularly innovative SME&T course development that exceeds substantially the normal course preparation commitment. | 1. Including a scholarly assessment of faculty participation in improving teaching and curriculum as one of the criteria for promotion, tenure, and other personnel decisions. |
| 2. Providing incentives, including recognition, to individual faculty to upgrade their teaching skills and knowledge of educational issues by and/or facilities utilization. participating in programs at their institution's Teaching and Learning Center and in departmental or cross-disciplinary seminars and workshops. | 2. Using a departmental vision and plan for curricular innovation to guide requests for space |
| 3. Providing incentives, including institutional recognition and additional financial support, to departments and other program units that collectively work to improve teaching, student learning, and curricular offerings to meet the needs of all of their students. | 3. Allocating space for students to work1(ats)-7eaddita3(colleeearning,)-12( and )13.<br>o f t h e c |

## VISION 6

Postsecondary institutions would provide quality experiences that encourage graduate and postdoctoral students, and especially those who aspire to careers as postsecondary faculty in SME&T disciplines, to become skilled teachers and current postsecondary faculty to acquire additional knowledge about how teaching methods affect student learning.

Graduate degree programs should provide graduate and postdoctoral students with training in the pedagogical skills they need to teach undergraduates effectively in classroom, laboratory, and field settings. In adopting Vision 6, universities also would provide all faculty with resources and opportunities for continuing professional development, informal education, and professional interaction with their higher education colleagues to help faculty enhance their professional skills and expertise as teacher-scholars throughout their academic careers.

The committee recognizes that not all of the recommendations and strategies for implementation provided above and in the main body of the report will be equally useful or applicable to all postsecondary institutions. Different institutional histories, patterns of governance, campus cultures, and efforts to date to improve undergraduate education may make some implementation strategies more useful than others for a given institution. For example, many of the strategies for implementing Vision 6 (changes in graduate and postdoctoral programs) will not apply to community colleges and four-year undergraduate institutions. However, the committee believes that most SME&T departments and institutions should be able to utilize or adopt many of the implementation strategies offered in the report. The committee also recommends that all SME&T programs at two- and four-year colleges and universities work with other professional schools on campus that have direct or indirect interests in SME&T education (e.g., education, medical, business, and law schools), with programs in the humanities and social sciences, and with SME&T departments at other institutions in their regions.

Strategies for Promoting and Implementing Vision 6

| Executive and academic officers of postsecondary institutions can implement Vision 6 by | Individual faculty and academic departments can by |
| --- | --- |

# Introduction

As a nation, the United States is creating opportunities and challenges for the future that may be unparalleled in recorded human history. However, as was heralded in a publication some 15 years ago (National Commission on Excellence in Education. 1983) and as indicated by the results of the Third International Mathematics and Science Study (TIMSS), educationally we are still very much a nation at risk (Pister and Rowe, 1993; National Research Council, 1997e; National Assessment of Educational Progress, 1997; U.S. Department of Education, 1998a).

During the years immediately following the launch of Sputnik, the United States overhauled its educational system to encourage the training of science and engineering specialists needed to meet the technological and military challenges presented by the Soviet Union. In succeeding years, our nation has defined the leading edge for most scientific and technical fields, and advancements in these fields have played an ever-increasing role in the life of our nation and its citizens.

As has been well documented, the scientific literacy of most Americans has not kept pace with the central role that science and technology play in their personal lives or in their communities. Indeed, to be effective in tomorrow's society, people will need to be able to think more analytically about events, objects, and processes and to analyze them in the context of natural phenomena (e.g., Rutherford and Ahlgren, 1990; National Education Goals Panel, 1997).

> "If the United States is to ensure a competitive workforce which possesses the necessary scientific and technological skills to fill the jobs of the future and compete in a global economy, we must develop the mathematics and science skills of all of our students, not simply the very best."
> National Education Goals Panel, 1997, pg. 9

National and state standards-based reforms in grades K-12 across the country have the potential to change fundamentally the ways in which all primary and secondary students learn science and mathematics. While this potential has not yet been realized uniformly, increasing numbers of pre-college students are learning through reform-based teaching and methods. Increasingly, college and university faculty find that they are being challenged to guide the postsecondary SME&T education of students with heterogeneous experiences and interests. For several important reasons, change in lower-division undergraduate education is key:

- Lower-division undergraduate science and mathematics education prepares a large proportion of the nation's leaders. Most of our nation's leaders—policy- and decision-makers—matriculate at institutions of higher education. Because most of them do not pursue formal career tracks in science, mathematics, or engineering, the undergraduate years are the last time that they—and most other undergraduate students—are asked to think broadly about SME&T in any formal way. Nonetheless, these graduates will go on to have an impact on scientific research, technological advances, and the resolution of technologically related issues through their work (e.g., in public policy and law) or as voters and consumers.

"Not long ago, a college chemistry professor grew angry with the way her daughter's high school chemistry class was being taught. She made an appointment to meet with the teacher and marched with righteous indignation into the classroom-only to discover that the teacher was one of her own former students."

Yates, 1995, pg. 8B

- Because of existing and new requirements for teacher certification in many states, lower-division undergraduate science and mathematics education will need to prepare the next generation of teachers more rigorously. The same faculty who teach these courses for pre-service students also will need to become more engaged with professional development for many practicing teachers. If current projections hold, up to two million college graduates will be needed in the next decade to serve as grade K-12 teachers (Darling-Hammond, 1997). The quality of science and mathematics education that these graduates received as undergraduates could have a direct impact on the amount of mathematics or science their K-12 students study and may contribute to the level of student achievement in these subjects (e.g., mathematics: Hawkins et al., 1998; science: O'Sullivan et al., 1998; see also Education Trust, 1998). Many of these students will eventually enroll in the nation's colleges and universities. As called for in National Research Council and other reports, if inquiry-based and standards-based teaching and learning are increasingly accepted as the prevailing educational paradigms for K-12 education, postsecondary institutions will need to respond, especially by including these techniques in the preparation of prospective teachers and the continuing education of current teachers.

  The National Council of Teachers of Mathematics (1989, 1991), the American Association for the Advancement of Science (1993), and the National Research Council (1996b) all have contributed to high-quality national standards in K-12 science and mathematics. The International Technology Education Association has developed *Standards for Technology Education* (the publication of which is expected in early spring of 1999) in a complementary style to the previous standards efforts. To date, statewide curriculum frameworks have been enacted by more than 25 states (Council of Chief State School Officers, 1997). Like the national efforts, these state frameworks also define what students should know and be able to do in science, mathematics, and technology throughout the K-12 years.[4] These K-12 standards can assist undergraduate institutions in defining minimum entrance requirements in SME&T. These standards also could be used to restructure current standardized testing programs in mathematics and to construct standardized tests in science and technology that could be administered to *all* students who seek to pursue higher education. Thus, agencies such as the Educational Testing Service and the American College Testing Program could be important partners in and contributors to the improvement of undergraduate SME&T education.
- Lower-division undergraduate science and mathematics education sets the stage for career scientists, mathematicians, and

[4] Although no similar standards are being proposed for undergraduate education on a national scale, in the fall of 1997, the Education Trust in Washington, DC initiated a two-year project with public universities and community colleges from seven states to explore the possibility of establishing curricular standards in history and one of the natural sciences on each campus. The results of that initiative were not available at the time of publication of this report.

engineers who will become the next generation of postsecondary faculty. Of the students who pursue careers in science, mathematics, or engineering, a significant fraction become faculty members at the nation's two- and four-year colleges and universities. If current trends continue, many of these students will not have received even minimal training in the practice of teaching during their graduate or postdoctoral years. Instead, they will assume faculty positions with only vague knowledge about effective teaching practice, about the ways students learn, or about the literature that can inform them and help them improve their teaching. Many of these new faculty members will use teaching practices that they themselves encountered as undergraduates. Future teachers who, in turn, take courses from these faculty also may adopt similar techniques to teach their own students, so a kind of cycle continues. Lack of background and skills in teaching, meager or nonexistent institutional programs for ongoing faculty development, and an academic culture that sometimes emphasizes performance in research more than in teaching are all factors that work against innovation in and new approaches to undergraduate SME&T instruction. Thus, the structure of graduate and postdoctoral programs directly influences the quality of undergraduate instruction in science and mathematics and, in turn, the future of K12 SME&T education.

Breaking this cycle—or improving its outcome—is particularly important given recent studies that suggest that many students who enter colleges intent on becoming SME&T majors change their plans after taking introductory SME&T courses. Many of these students report that a major consideration in their decision to switch to other majors is the quality of teaching they encountered in those introductory courses (Seymour and Hewitt, 1997).

Thus, all SME&T faculty, departments, programs, and SME&T colleges should consider the following kinds of and 2) individual faculty members and their departments. It is critical that academic administrators and faculty work

# A Goal and an Agenda For Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology

Based on research and extensive dialogue with representatives of many sectors of the SME&T higher education community, the members of the Committee on Undergraduate Science Education (CUSE) call for the following to become a primary goal apparent that undergraduate education also must be considered as an integral part of the continuum of education in the United States that extends from pre-kindergarten through the graduate and postdoctoral years. The order in which the vision statements and strategies for implementation are presented in this report reflects that continuum.

Innovative, effective undergraduate SME&T education depends, in part, on having students matriculate at postsecondary institutions who have had sufficient pre-college educational experiences to enable them to undertake college-level work. Therefore, Vision 1 addresses pre-college preparation and the changes that are occurring in K-12 science and mathematics education.

Vision 2 then focuses on the roles and responsibilities of postsecondary faculty and SME&T curricula. Postsecondary faculty add value to students' pre-college educational experiences by making explicit to students the connections among the natural science disciplines and by providing opportunities for students to understand the processes and limits of science through inquiry-based and interdisciplinary approaches to teaching and learning. For science majors, this exposure might often involve participation in undergraduate research.

Next,are

comprehensive universities, and research universities. When the roles of graduate and postdoctoral programs are addressed, as in Vision 6, it is as they pertain to undergraduate education.

The committee recognizes that not all of the recommendations and strategies for implementation will be equally useful or applicable to all postsecondary institutions. Different institutional histories, patterns of governance, campus cultures, and efforts to date to improve undergraduate education may make some implementation strategies more useful than others for a given institution. For example, many of the strategies for implementing Vision 6 (changes in graduate and postdoctoral programs) will not apply to community colleges and four-year undergraduate institutions. However, the committee believes that most SME&T departments and institutions should be able to utilize or adopt many of the implementation strategies offered in the report. The committee also recommends that all SME&T programs at two-and four-year colleges and universities work with other professional schools on campus that have direct or indirect interests in SME&T education (e.g., education, medical, business, and law schools), with programs in the humanities and social sciences, and with SME&T departments at other institutions in their regions.

Since large numbers of undergraduates now begin their higher education careers at community colleges and then matriculate at four-year institutions or move directly to the workplace (National Science Foundation, 1997a), two- and four-year institutions, educational associations, and local businesses and industries must work closely together at the local, state, and national levels to develop comprehensive plans for improving undergraduate SME&T education.

# Visions For Undergraduate Education in Science, Mathematics, Engineering, and Technology

## VISION 1

All postsecondary institutions would require all entering students to undertake college-level studies in SME&T. Entry into higher education would include assessment of students' understanding of these subjects that is based on the recommendations of national K12 standards.

If undergraduates are to view SME&T as an integral component of their education, the stage should be set long before they enter college. Ideally, their pre-college experience should have included both quality instruction in standards-based classrooms and a clear awareness that achievement in science, mathematics, and technology will be expected for admission to college. Once implemented, standards-based approaches to science and mathematics (and eventually technology) education should enable more students to reach these desired levels of achievement.

However, the committee recognizes that standards-based K-12 education in science, mathematics, and technology is not yet available to most students across the country. Many colleges and universities must now rely on the results of standardized examinations in these disciplines that do not necessarily emphasize the kinds of learning called for in national standards. Many postsecondary institutions also employ open admission policies. Such policies provide critical educational opportunities to many students who may not have had the academic experiences called for by national and state standards.

Moving K-12 SME&T education to a system that is more consonant with standards will likely require at least a decade. Nevertheless, change is occurring—albeit at different rates—in many parts of the country, and increasing numbers of students are likely to arrive at postsecondary institutions with greater exposure to science and mathematics standards. Thus, postsecondary institutions, their admissions offices, and faculty will need to monitor these trends in K-12 education with respect to admissions policies and the content and teaching of undergraduate courses. Admissions policies should be revisited regularly to account for changes taking place in the K-12 sector.

The committee also recognizes that while this vision and the accompanying implementation strategies are appropriate for the great majority of students in the nation's high schools, many other students will need creative alternative pathways to mandated by many states based on these national standards and benchmarks (Council of Chief State School Officers, 1997). These standards call for students increasingly to engage in inquiry-based, collaborative learning experiences that emphasize observation, collection, and analysis of data from student-oriented experiments. They also stress the importance of helping students learn about the relationships among the sciences and the relevance of science, mathematics, and technology to other realms of inquiry and practice.

At present, not all K-12 students receive an acceptable preparation in science and mathematics at the pre-college level. For example, in the most recent National Assessment of Educational Progress examinations in mathematics, about one in three students in grades 4 and 8 and slightly less than one in three (31%) in grade 12 could not demonstrate even the most basic competency, and only 5% or less performed at the advanced level (e.g., Reese et al., 1997). In the most recent relevant international study, students from the United States demonstrated a steady decline from the 4th through the 12th grade in their

- opportunities for faculty in the SME&T disciplines to work more closely with their admissions officers, college administrators, pre-college standardized testing agencies, and accrediting bodies to better define specific competencies.[7]

## Strategies for Promoting and Implementing Vision 1

Executive and academic officers of postsecondary institutions can implement Vision 1 by

1. Asking academic SME&T departments and the Office of Admissions to establish appropriate institutional admissions standards for science and mathematics preparation.

The NCTM *Curriculum and Evaluation Standards for School Mathematics*, AAAS *Benchmarks for Science Literacy*, the NRC *National Science Education Standards*, and individual state curriculum frameworks and learning results have established a "floor" for the level of knowledge and competency that should be mastered by students in science and mathematics before and during the high school years. Concomitantly, institutions of higher education should set higher standards for their entering students. These standards should be consistent with the program goals of the institution and institutional missions, as well as with state standards or benchmarks. A requirement or admissions preference for four years each of science and mathematics in may be appropriate for many postsecondary institutions and would send a powerful message to students, parents, and schools about the importance of these subjects. If colleges, universities, university systems, ,o987aryimpleme in53389 Tw 0.0034 Tw 0.2539ation S.258cers of postsecondary AdmTw 0.2534(and)-3986titutions can implement of providing SME&T education to all of its enrolled students.

well as with pre-college standardized testing agencies and accrediting bodies to better define specific competencies.

See Appendix A for additional information about strategies for implementation of Vision 1 as discussed during the Committee on Undergraduate Science Education's "Year of Dialogue" regional symposia and topical forums.

## VISION 2

SME&T would become an integral part of the curriculum for all undergraduate students through required introductory courses that engage all students in SME&T and their connections to society and the human condition.

Science is an integral part of our daily lives. It also is an historical and procedural foundation for human thinking about and understanding of the natural and engineered worlds. Therefore, colleges and universities should require all entering students, irrespective of their ultimate selection of a major, to undertake college-level studies in SME&T. Science majors would gain a focused, in-depth exposure to scientific principles, and those who wished to do so could build on their experiences to participate in faculty-supervised original research. They and all non-science students would also enroll in courses that focus on providing awareness, understanding, and appreciation of the natural and human-constructed worlds and that involve at least one laboratory experience. Introductory undergraduate curricula would incorporate physical, biological, and mathematical sciences, engineering, and technology in a manner that allowed all students to understand and appreciate the interrelationships among these disciplines in the context of human society. All of these courses would include topics that are both intellectually challenging and near the frontiers of inquiry. Wherever possible, these topics would engage students in discussing problems that students would find timely and important.

If this vision were to be realized, faculty would design and offer introductory science courses that met the needs of students with diverse educational backgrdents, be realiaspir-14.3(, proced)6.4(abornss,)styl1 Tf4(realiTtopi)-3s and that met0.8( )13.04379 Tw 1

In addition, all programs in SME&T would be structured to allow as many undergraduate students as possible to engage in original, supervised research under the tutelage of a faculty or senior graduate student mentor. Undergraduates would become involved with as many phases of a research project as time permitted. These might include experimental design, searching the literature, performing the research using modern scientific instruments and techniques, analyzing and interpreting data, and preparing a report for publication or presentation at an institutional, regional, or national scientific meeting. SME&T majors would undertake such research for a minimum of one academic term, although research experiences obtain a strong but broad grounding in SME&T first. Then, if they so choose, students can become better versed in more specific and narrow concepts as they advance through their undergraduate careers. Although there have been numerous attempts to restructure undergraduate science education within disciplines (e.g., in the chemical sciences: American Chemical Society, 1990; in the earth sciences: Ireton et al., 1996; in engineering: National Research Council, 1995a; in the life sciences: Coalition for Education in the Life Sciences, 1992, and Biological Sciences Curriculum Study, 1993; in the mathematical sciences: National Research Council, 1991; in the physical sciences: Arons, 1990, Wilson, 1996, and Redish and Rigden, 1997), there have been few systemic efforts to restructure introductory courses for science majors, pre-service teachers, and students who will go on to other academic pursuits.

There are many reasons to reconstitute the courses under discussion so that they emphasize applications and connections with other areas of knowledge (National Research Council, 1982, 1996a; Cheney, 1989; American Association for the Advancement of Science, 1990; Tobias, 1990; Hazen and Trefil, 1991; National Science Foundation, 1992, 1996b; Alberts, 1994; Jones, 1994; Project Kaleidoscope, 1991, 1997; Boyer Commission on Educating Undergraduates in the Research University, 1998). First, the proposed interdisciplinary courses provide integrated perspectives of SME&T and its relationship to the human condition in a way that invites student involvement and active participation. Second, such courses also serve as gateways to more discipline-based subjects by allowing students to understand the importance of studying what might otherwise seem to be disconnected and unrelated topics. When such interdisciplinary courses are reserved for upper-level science majors, non-science majors (including future teachers) cannot benefit from them. It is the latter group for which such approaches to teaching SME&T may be especially appropriate.

"My own experience leads me to conclude that It is pointless to define scientific literacy In terms of any particular body of scientific knowledge. I neither know nor understand most of present-day science. And yet, I am a dean of science at a private c3ericanand 3 for mathentlesn sciencean ),rhe82.er r.ience Jone596,booksu interest in SME&T is piqued by this approach, they may want to enroll in additional upper-level, discipline-based courses.

"Why are the head of the Environmental Protection Agency, the Ambassador to Kazakhastan (a

Interest in offering interdisciplinary courses at both the introductory and more advanced undergraduate levels has risen in recent years. Many workshops have been sponsored by Project Kaleidoscope to explore such diverse topics as "Blueprints for Reform in Undergraduate Neuroscience," "Connecting Within and Beyond the Sciences," and "Biochemistry: Bio or Chemistry?" (more information about these and other workshops is available at Project Kaleidoscope's website at <http://www.pkal.org>). In addition, "Interdisciplinary Learning Communities on Puget Sound" is organized to develop faculty skills in leading interdisciplinary programs. It will culminate in 1999 with a public symposium to present and discuss participants' work on curriculum and collaborative research. (More information is available at The Evergreen State College's Washington Center for Improving the Quality of Undergraduate Education website at <http://192.211.16.13/katlinks/washcntr/home.html>.)

The following are examples of interdisciplinary courses for students, although it should be noted that few course offerings of this type have been evaluated fully for efficacy: "Science and Society," offered at the University of California, Davis (<http://www.ucdavis.edu>); "Connecting the Sciences," offered at Nassau Community College (<http://www.sunynassau.edu/>); "The Explanatory Power of Science," offered at the University of Texas at El Paso (<http://www.utep.edu>); "Quantitative Perspectives on Energy and the Environment," offered at the University of Pennsylvania (<http://www.upenn.edu>); and "The Science and Technology of Everyday Life," offered at Hope College (<http://www.hope.edu>). One course-based 4.4( ysed)-15r4.4( yse[assau Co7( ExplanatoroF4855 96.)-101638 Tw[TechnologMat cos: Achievrdiscip51

## Strategies for Promoting and Implementing Vision 2

Executive and academic officers of postsecondary institutions can implement Vision 2 by

1. At institutions with active research programs, convening local blue-ribbon panels of faculty who are recognized for their contributions to both research and teaching to report on what is needed to offer a cutting-edge SME&T curriculum for undergraduates on their campuses consistent with their institutions' mission.

The panel's report should provide a series of concrete short-term and long-term goals for the institution to pursue. Such discussions might include learning outcomes expected from introductory SME&T courses regardless of the course in which a student enrolls; greater opportunities for students to undertake original or independent research in teaching laboratories or in conjunction with faculty research projects; ways to enhance teacher preparation in mathematics, science, and technology; and the influence of K-12 standards-based curricula on undergraduate education in SME&T. Broader campus discussion about implementation, led by members of the panel and one or more high-ranking academic administrative officers, should follow release of the report.

2. Supporting the inclusion of core SME&T requirements and core course offerings that include at least one or preferably more laboratory experiences at the undergraduate level for all students and an option for independent research for all science majors.

All colleges and universities should critically evaluate their core SME&T requirements for undergraduate degrees and their core course offerings in these subjects. Departments other than those offering these courses should participate. The subjects of the evaluation should be the course content of each course and the development, integration, and financing of the total curriculum. Faculty (and departments) should be given financial and other incentives to offer integrated, interdisciplinary courses at the introductory level and/or to coordinate the content and sequence of science courses with other introductory courses that beginning students are likely to take. For example, many first-year premedical students are likely to enroll simultaneously in introductory biology and chemistry. Instructors could present shared themes in these courses (e.g., properties and use of energy in chemical and biological systems) in a coordinated fashion and could refer to more specific material being covered in the other course. Beginning students would then have an early opportunity to see important connections usually not made until later in their undergraduate years. Graduate students, postdoctoral fellows, and selected undergraduates could participate in teaching (especially in laboratories) and in the development and assessment of such courses, thus helping faculty members make the most effective use of their resources. By seeking and using input from a diverse set of students (both undergraduates and graduates), faculty also would be able to modify more regularly the material presented and the methods of presentation. The adoption of new laboratory courses, which are critical for the teaching of science as an active way of learning, needs serious resource commitments from postsecondary institutions.

3. Encouraging individual faculty to learn to develop new and innovative courses and make existing courses more effective by promoting an institutional culture that rewards this participation and that provides technical support.

Most faculty members have been educated in traditional disciplines, and their teaching careers are usually traditional as well. To encourage these faculty to learn new and effective approaches to teaching and to develop new courses or curricula based on this knowledge, administrators should provide faculty with the resources required for consultation with colleagues and experts

science and technology forward? Do scientists always display objectivity when addressing scientific questions or issues?

- Science as a "way of knowing" and the limits to such knowledge: How are the approaches that scientists employ to view and understand the universe similar to, and different from, the approaches taken by scholars in other disciplines outside of the natural sciences? What kinds of questions can be answered by the scientific and engineering methods, and what kinds of questions lie outside of these realms of knowledge? How does one distinguish between science and pseudoscience? Why are scientists often unable to provide definitive answers to questions they investigate? What are risk and probability, and what roles do they play when one is trying to provide scientific answers to questions? What is the difference between correlation and causation?
- The relationships among basic science, applied science, and technology: What are the realms and limits of basic science, applied science, and technology? How are basic science, applied science, and technology related to and dependent upon one other (e.g., Hurd, 1994)? In what ways are the questions that engineers ask similar to and different from those asked by natural scientists? How is scientific research conducted and supported in the United States?
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National Science Foundation, personal communication). This is true even for some of the nation's research-intensive universities (Boyer Commission on Educating Undergraduates in the Research University, 1998).

In institutions where laboratory experiences are required for all undergraduates, these experiences may only involve following rote procedures to address predetermined questions and to arrive at conclusions that are widely known and available through textbooks or other sources. Problems and issues that scientists and engineers face everyday, such as designing adequate controls, accounting for interacting variables, replicating findings, and dealing with the uncertainty of statistical analysis of data, often are not presented to students in introductory or lower-division SME&T courses. Students who do not continue their SME&T studies stand a good chance never to appreciate fully how scientific investigations are conducted or how the concepts and facts that they have studied were generated. Every undergraduate should experience the logic, joy, and frustration of asking original questions and carrying out a plan to address them.

3. Emphasizing the development of introductory SME&T courses that include applications and hands-on learning experiences.

Currently, many SME&T curricula require students to learn much of the fundamentals before being allowed to apply

content, and pedagogy (see also additional discussion of this topic in Vision additional avenues for disseminating such work may become available through digital libraries that are established for this purpose (e.g., National Research Council, 1998a).

to teaching similarly should be viewed by both applicant faculty and awarding institutions as serious scholarly activities

learning. SME&T faculty and education faculty could co-advise graduate students who are undertaking research in SME&T undergraduate education. Faculty members in SME&T departments could pursue research in teaching and learning in their discipline as the primary focus of their scholarship, or as a component. Joint appointments could be made both to an academic department and the institution's school of education. Research opportunities also could be provided to current and future teachers. Such opportunities would provide pre-service teachers with invaluable experiences and would help dispel myths about the research capabilities of teachers in education and in SME&T disciplines.

See Appendix A for additional information about and strategies for implementation of Vision 3 as discussed during the Committee on Undergraduate Science Education's "Year of Dialogue" regional symposia and topical forums.

## VISION 4

SME&T faculties would assume greater responsibility for the pre-service and inservice education of K-12 teachers.

Improving the SME&T education of both pre-service and in-service K-12 teachers is one of the most important challenges facing college and university faculties.[17] Scientists, mathematicians, engineers, and teacher educators all need to share responsibility for teacher preparation (e.g., Riley, 1998). If Vision 4 were to be realized, these faculty would provide integrated pre-service and in-service experiences that blend scientific knowledge with pedagogical methods and effective teaching practices. Teacher education programs would be informed by the *National Science Education Standards* (National Research Council, 1996b), the *Curriculum and Evaluation Standards for School Mathematics* to engage students in exploration of the natural world, especially as encountered in their own communities. Middle-school teachers of science and mathematics (grades 5 to 8) will now need broader knowledge of these disciplines and the skills to help their students engage in meaningful scientific inquiry. And high school science teachers will need to have a deep knowledge of the scientific or mathematical disciplines they teach and detailed knowledge of the strengths and limitations of the scientific method. High school teachers also will need to be equipped to help students understand that science is a "way of knowing" that can be compared with other ways of knowing (Moore, 1993).

"It has become impossible to ignore the mounting evidence that our elementary and secondary public schools are not performing as they should. Some say we have a national crisis on our hands. Although we in higher education are very skillful at ignoring the obvious, it is gradually dawning on some of us that we bear a substantial part of the responsibility for this sad situation and, hence, and [sic] equally substantial responsibility for dealing with it. Moreover, it is increasingly clear that our role must extend far beyond helping out embattled K-12 colleagues with 'their' problems. We need to deal with our own, including the way we educate and train the teachers and administrators of the K-12 schools, as well as the processes by which high school graduates become college students and graduates. Simply put, pervasive K-12 reform with their high school counterparts to improve physics teaching at all levels. AAPT's Committee on Research in Physics Education examines and disseminates the results of research about how students learn physics and how that knowledge can be used to improve classroom instruction. [21]

sensitive instruments, donors may want to require the schools to assume this responsibility as part of their end of the partnership.

In addition, teachers need to know the purpose and operation of the donated equipment and its potential for improving learning. To address this need, graduate or undergraduate work-study students (as part of their financial aid packages) could be assigned to conduct workshops on the use of equipment, to be available to answer questions, to troubleshoot problems, or to work directly with teachers in their classrooms in using the donated equipment.

4. Establishing an institutional "hot line" telephone number or current events website to provide local teachers with information about departmental or campus-wide events involving SME&T speakers or other activities.

Often the most valuable resources that can be made available to teachers and their students by postsecondary institutions are those that cost little or nothing, such as invitations to hear outside speakers and other visitors to the campus who have valuable perspectives on advances in SME&T. Postsecondary partners could establish a prerecorded "hot line" or a special the content and pedagogy of teacher preparation programs in SME&T.

Such relationships might involve postsecondary institutions reimbursing local school districts for the salaries and benefits of these teachers, allowing them to spend a sabbatical leave on campus. Alternatively, SME&T departments and schools of education might jointly offer graduate-level credit to master teachers seeking advanced degrees.

Individual faculty and academic departments can implement Vision 4 by

1. Measuring the effectiveness of each component of the pre-service curriculum in fostering innovative pedagogy and in exploring SME&T concepts.

Universities should undertake long-term studies of their graduates who have embarked on careers in teaching to assess the effects of both the education and SME&T components of the institution's pre-service programs. The emphasis should be on how well the K-12 students of these teachers are learning science and mathematics and on how the teachers' performance was affected by their postsecondary curricular experiences. Results from these studies could then be shown to and discussed with newly hired teachers, their former education and SME&T professors, and relevant school system administrators.

2. Inviting regional K-12 science and mathematics teachers to participate in on-campus seminars where recent scientific or pedagogical research is discussed.

These seminars might consider such topics as the appropriate use in classrooms of information technology and the Internet or ways for postsecondary and K-12 schools to cooperate in implementing science and mathematics standards. The seminars and similar activities could be sponsored by both schools of education and SME&T departments to increase understanding and awareness among a wider spectrum of educators.

3. Inviting master teachers to serve as adjunct faculty and colleagues in both schools of education and SME&T departments.

If content and pedagogy are to be truly integrated components of teacher preparation programs, then master teachers with recognized teaching skills and a great deal of experience in the classroom should become more directly involved with both the practicum and course work activities of pre-service teachers. These mationlp( greaake )-1abbat6er te3(the)]TJ-0.0002 9740.0032 Tw 1 skills of their university colleagues. Finally, K12 master teachers could benefit by learning techniques used in college-level SME&T teaching laboratories that might be useful for their own students.

4. Employing discipline-based science teachers in the continuing education of fellow teachers.

Teachers who have extensive training and background in science could be engaged to work with postsecondary faculty to provide courses and other in-service experiences for their fellow teachers. Such an approach might be particularly appropriate for professional development for the teachers of the primary and middle grades who often lack content knowledge but want more. This approach would have the added benefit of allowing teachers from different grade levels to interact much more than is usually possible during the school year and to discuss issues of common concern, such as coordination of curricula across grades and school levels.

See Appendix A for additional information about and strategies for implementation of

that teaching performance often is perceived as having little more than a tie-breaking value in important personnel decisions, such as tenure, promotion, or merit salary increases (Boyer, 1990; Joint Policy Board for Mathematics, 1994; Kennedy, 1997; Boyer Commission on Educating Undergraduates in the Research University, 1998; however, see also Office of the President, University of California, 1991). Because some other postsecondary institutions are following the research university model, they are increasingly interested in the original research conducted by their faculty yet also continue to expect high levels of performance in teaching and service.

In two recent surveys, faculty and administrators at various institutions were asked about the direction their institutions should take with respect to emphasizing research, teaching, or some combination thereof. Results indicated that, between 1990 and 1992 and 1992 and 1994, faculty preference at institutions ranging in Carnegie categories from Research I to Baccalaureate II had shifted from a balanced emphasis to a stronger emphasis on teaching. Many of the respondents to the two surveys also indicated that while their institutions purported to emphasize a greater expectation for both teaching and research, the operative reward systems in their institutions did not support this emphasis (Gray et al., 1996).

(2) Faculty development of innovative courses for all students requires the interest and support of departments as well as the time and effort of the individual faculty members. However, pressures within the disciplines and departmental funding patterns strongly favor the recruitment and production of majors and future graduate students, not scientifically literate non-majors. Faculty need to see comparable incentives and rewards for teaching general education courses to students who will not go on to careers in SME&T. For such innovation to be sustained, departments must make it a priority to nurture the creativity of their individual faculty members and to disseminate the instructional and pedagogical fruits of their labors.

well as to classroom, laboratory, discussion, and study group spaces (e.g., Baker and Gifford, 1997; National Science Foundation, 1998b; Benson and Yuan, 1998). Such facilities should be available to students beyond regularly scheduled class times. The absence or limited availability of such space can be a major barrier on many campuses to implementing new approaches to teaching. New teaching and learning paradigms, such as collaborative learning teams, may also challenge existing college schedules and security arrangements or involve facilities that lie outside the physical boundaries of a department's classrooms and laboratory spaces. Institutions must find ways to make facilities more open while maintaining security and minimizing differences in departmental resources, physical space, and perceived "ownership" of resources by certain faculty or departments. Planning for supporting infrastructure does not need to precede planning for curriculum innovation. To the contrary, planning for new or reconstructed spaces and for new instrumentation and equipment is best undertaken following or in conjunction with the articulation of a plan about how those spaces and equipment would be used use such centers and other resources as part of career-long professional development of their teaching skills and efficacy. Specialized support for the SME&T disciplines could be enhanced by staffing these centers with professionals who have specific backgrounds in SME&T, such as science librarians.

every institution can or will standardize to this extent, in part due to the expense. At the very least, faculty should have easy access to new software that allows them to share data more easily and to experience fewer of the problems associated with converting formats. Non-faculty benefits would include less time spent by information technologies staff on learning how to fix new problems associated with exotic software applications and more time spent training other employees to use applications more effectively. Accordingly, it is important for the institution to provide sufficient access to both common information technology resources and web-based services for assigned work.

5. Devising a comprehensive plan to update or replace computer hardware, software, and associated resources on a regular basis.

As with most other disciplines, SME&T faculty, students, and departments increasingly depend on information from sources around the world to accomplish their work and to engage in the development of new courses and other projects. As the pace of innovation quickens in information technology, institutions of higher education must make conscious decisions to devote more of their resources to making sufficient numbers of appropriate and up-to-date tools available to teachers and learners. Regular replacement of the oldest hardware and software on campus and the transfer of previously purchased high-end equipment to users with less need for the latest innovation should become part of an overall institutional plan for providing everyone on campus with maximum needed access to information technology.

6. Working to assess and meet institution-wide needs for the space, equipment, and other resources needed to upgrade and improve the curriculum.

A comprehensive plan for curricular reform and innovation often points to the need to design new facilities or remodel old ones. However, such a plan should not simply serve as a catalyst but also as a driver of the changes to be made. Academic leaders can assist the process by making clear to all involved that curriculum should drive the design of physical space. They can then work with individual faculty, departments, and programs to develop a vision for curricular innovation. Once the vision exists, it should be translated first into specific courses and activities and then into an identification of the kinds of space, instrumentation, and equipment needed to support these courses and activities. When all those steps have been taken, a comprehensive plan of action can be constructed and proposed to the community. Once the community has embraced the plan, campus leaders can approach potential donors for the needed funds.

Individual faculty and academic departments can implement Vision 5 by

1. Including a scholarly assessment of faculty participation in improving teaching and curriculum as one of the criteria for promotion, tenure, and other personnel decisions.

Many panels, commissions, and individual authors have addressed these issues (e.g., Boyer, 1990; Glassick et al., 1997; Kennedy, 1997). Some organizations have engaged colleges and universities in studies to find ways to incorporate comprehensive and fair assessment of teaching into personnel decisions (e.g., Hutchings, 1996). A detailed discussion of these issues is beyond the purview of this report. However, the authors of this report agree that if departments and institutions truly want faculty to view quality teaching of undergraduates as being on par with other scholarly responsibilities and achievements, they must require that clear evidence of such accomplishments be collected and submitted as part of all

Graduate degree programs should provide graduate and postdoctoral students with training in the pedagogical skills they need to teach undergraduates effectively in classroom, laboratory, and field settings. In adopting Vision 6, universities also would provide all faculty with resources and opportunities for continuing professional development, informal education, and professional interaction with their higher education colleagues in order to help them enhance their professional skills and expertise as teacher-scholars throughout their academic careers.

". . . we have not, as a nation, paid adequate attention to the function of the graduate schools in meeting the country's varied needs for scientists and engineers. There is no clear human-resources policy for advanced scientists and engineers, so their education is largely a byproduct of policies that support research. The simplifying assumption has apparently been that the primary mission of graduate programs is to produce the next generation of academic researchers. In view of the broad range of ways in which

[illegible]

may explicitly or implicitly discourage their students from spending too much time and effort preparing for careers in teaching if it "distracts" them from their research projects or lengthens the time needed for them to obtain their degree (Boyer Commission on Educating Undergraduates in the Research University, 1998).

Lack of preparation for teaching extends to the postdoctoral level. In some fields, Ph.D.s undertake two or more and private research universities across the United States. These students were asked to indicate their major responsibilities as teaching assistants, the type and level of preparation they had received, and those aspects of teaching in which they wanted more preparation. When data from the 1997 survey were compared to data from a similar survey conducted at the same institutions 10 years earlier, Diamond and Gray found that greater numbers of graduate students were receiving more opportunities for training in teaching. The training identified included conducting classroom discussions, using audiovisual aids and instructional technology, and understanding university regulations about classroom and professional conduct.

> "Because so much of teaching assistants' development takes place informally within departments, it is essential that structures be developed and maintained that encourage and support departmental faculty and administrators. Each new cohort of graduate students has the same needs and only through constant attention can the quality of their experience stay consistent over time. Improving that experience takes even greater effort, but such efforts [sic] can pay dividends on individual campuses and in individual departments in the preparation of future generations of faculty members."
>
> Diamond and Gray, 1998, pgs. 18 and 19

However, the survey also identified remaining trouble spots. For example, 25 percent of the 1997 survey respondents stated that they were being offered no formal preparation for their teaching responsibilities. Further, the surveys showed that the major responsibilities of teaching assistants had changed little: grading (97% of the respondents in both surveys) and conducting office hours for undergraduates (94% of respondents in both surveys). When the 1997 survey respondents were asked what additional preparation they would like, they gave preference to self-evaluation, course evaluation, developments in technology, and classroom presentation. Three out of every four of the graduate student-respondents in the 1997 survey indicated that they planned to pursue academic careers.

Most likely, many of these students will find such positions in institutions other than research universities (Commission on Professionals in Science and Technology, 1997). Thus, graduate and postdoctoral programs should help prepare them for such employment by making available opportunities to study issues related to undergraduate teaching and to gain practical experiences as teaching assistants for undergraduate SME&T laboratories. These opportunities should be available as early in the graduate or postdoctoral careers of these students as possible.

Suggestions for developing effective programs for graduate students and examples of such programs in the biological sciences, chemistry, mathematics, and other disciplines can be found in Lambert and Tice (1993). Also, the Council of Graduate Schools, in collaboration with the American Association of Colleges and Universities, has established the "Preparing Future Faculty" program. This initiative encourages new approaches to graduate education for students in research institutions who are planning careers in academe by providing opportunities to practice teaching and to learn about the roles and responsibilities of faculty members at institutions that primarily serve undergraduates.[28]

2. Establishing arrangements with community colleges, other undergraduate institutions, and K12 schools that allow graduate and postdoctoral students to experience teaching at these types of schools.

Opportunities for faculty positions at top-tier research institutions are diminishing

[28] Additional information about this program is available at <http://www.cgsnet.org/programs/pff.htm>

fellows highly value the securing of positions in academe, departments could invite colleagues from other types of postsecondary institutions to department meetings to discuss the requirements for and expectations of faculty members at those institutions. Graduate students and postdoctoral fellows might also be invited to provide peer assessments of faculty teaching.

5. As part of the interview process, asking faculty candidates to present a general lecture to undergraduates on a topic selected by the department or program or to give a pedagogical seminar to faculty and graduate students that discusses some aspect of teaching.

Expecting faculty candidates to present either a lecture to undergraduates on some aspect of the discipline or a seminar to faculty and graduate students in which the candidates discuss some aspect of teaching can send a powerful message to graduate students and prospective faculty members about the importance the department places on teaching.

See Appendix A for additional information about and strategies for implementation of Vision 6 as discussed during the Committee on Undergraduate Science Education's "Year of Dialogue" regional symposia and topical forums.

importance of inquiry-based and interdisciplinary approaches to teaching and learning in the early undergraduate years and adequate preparation and experience in teaching for graduate students.

Other forces also are at work that postsecondary faculty, departments, and institutions increasingly must heed. National and statewide standards and curriculum frameworks are being implemented for K-12 science and mathematics education. Legislators in many states are demanding greater accountability and firm assurances from postsecondary faculty in public institutions that undergraduates are receiving a quality education (Boyer Commission on Educating Undergraduates in the Research University, 1998). Federal agencies, such as the National Science Foundation (1997b), increasingly are requiring proposals for research grants to indicate how the proposed research and its results will improve educational opportunities for students. Private foundations, such as the Howard Hughes Medical Institute, the Pew Charitable Trusts, and the Exxon Education Foundation, are now providing large-scale financial support to improve SME&T education at the K-12 and undergraduate levels.

The support for reform outside of postsecondary institutions is strong and compelling. Increasingly, the committee has witnessed support for changing SME&T education from inside these institutions, as well. This is heartening, for improvement in education can be truly successful only when those who must implement recommended reforms embrace them. In the five years of CUSE's existence, the members have seen evidence of increasing numbers of college and university SME&T faculty who recognize the need to restructure undergraduate SME&T education and who are willing to work individually and collaboratively toward that end. In addition, organizations that represent higher education and professional disciplinary societies are examining their roles in catalyzing educational change. Examples of programs sponsored by such organizations include

- Project Kaleidoscope's Faculty for the 21st Century (F21) program,[29] which is a five-year effort to locate and support up to 1,000 pre-tenured faculty in SME&T disciplines who have been recognized for their SME&T education potential. F21 members gather annually at national meetings to discuss and work through the many facets of changing undergraduate and K-12 education.
- New Experiences in Teaching (Project NEXT)[30] and Workshop for New Physics Faculty,[31] which seek out newly appointed postsecondary faculty in mathematics and physics, respectively. These faculty then get together for several weeks during the summer to focus on quality teaching.
- The American Association for Higher Education's "Teaching Initiative," including the "Peer Review of Teaching Project,"[32] in which major universities have examined ways to incorporate peer review of teaching, especially formative review, into the evaluation of faculty performance.
- The National Research Council's newly initiated study of how the evaluation of SME&T teaching can be improved, which will consider the special circumstances involved with teaching in SME&T disciplines (e.g., teaching laboratories, field studies, and mentoring of undergraduate studentSMn1 Tc0.5 inlines (e.g., [(l.efTc0.0303w4(teachw-0.00987.3(d)6. Tc

Faculty" initiative[33] to enable graduate students at large research universities to experience first hand the roles and responsibilities of faculty members at a variety of institutions that serve undergraduate students.

- The presidents of postsecondary institutions affiliated with the Association of American Universities, who recently commissioned a "Task Force on K-16 Education" to explore how to define entrance requirements in light of K-12 reform standards, how to articulate introductory undergraduate course objectives, and how to prepare future teachers and provide continuing professional development to practicing teachers. (Recommendations were expected in 1998.)

University's report (1998), which cites numerous examples of innovative undergraduate education programs at research universities.

- A recently released report, The Integral Role of the Two-Year College in the Science and Mathematics Preparation of Prospective Teachers (Virginia Collaborative for Excellence in the Preparation of Teachers, 1998), describes 11 exemplary science and math programs found in two-year colleges across the nation.

While these efforts are noteworthy and important, CUSE members believe that individual faculty, their departments, individual institutions of higher education, and umbrella organizations, such as professional disciplinary societies and higher education organizations, need to act together toward common goals. As suggested throughout this report, the undergraduate SME&T education enterprise involves too many players, objectives, and levels of engagement for change in any one component to have a significant, long-lasting impact by itself. As also indicated in this report, professional disciplinary societies and higher education organizations have particularly critical roles to play in bringing the component parts of the higher education system together. For example, these organizations can bring together innovators from different postsecondary institutions to share their successes and failures in improving SME&T education and to disseminate best practices beyond individual departments or institutions. In the end, dissemination of such information will have little effect unless individual faculty use that information to change their own teaching and to share their experiences with departmental and institutional colleagues.

Most faculty who would like to change their teaching in existing courses or, as recommended in this report (see Vision 2 beginning on page 25) and elsewhere (e.g., Boyer Commission on Educating Undergraduates in the Research University, 1998), to create new courses that are truly interdisciplinary in scope and presentation, may not yet have the time, resources, or support and encouragement from their departments or institutions. CUSE members would urge faculty at least to try small, easily accomplished changes that could be evaluated for their efficacy and serve as the basis for additional improvements. For example, faculty could change an existing course in one way in each semester it is taught and base subsequent changes on feedback received from both current and former students and from colleagues.

Given their increasing emphasis on incorporating more real world examples and hands-on projects into courses and curricula and their traditional ties to industry, colleges of engineering can provide valuable insights and guidance to other science and mathematics departments that are looking to revamp their own programs. For these reasons, faculty and administrators in colleges of arts and sciences should consider consulting with their engineering colleagues for advice and feedback in this process. Faculty and administrators in other professional schools (e.g., schools of law and medicine) and at two-year colleges also might be in a position to provide examples of how courses have been revised to include more case studies and approaches to problem solving. All of these colleges and schools within postsecondary institutions have a vital interest in quality undergraduate SME&T programs. By working together, they can make changes to undergraduate SME&T courses and programs more dynamic and fruitful within their own programs as well as across the nation. This type of recommendation also can be extended to SME&T departments. Change could begin by reserving one or two departmental meetings per semester to talk about the goals of the curriculum and what students emerging from courses in the department should know and be able to do after completing introductory and more advanced courses. Faculty who have revised their courses could discuss these changes with and solicit comments from departmental colleagues. SME&T departments also could invite colleagues from the school of education to one of those meetings (and vice versa!) to focus on issues of teacher preparation and professional development in science, mathematics, engineering, and technology. Graduate and postdoctoral students also could be invited. One or several presentations in the department's colloquium series during a semester or an academic year could be devoted to critical issues in SME&T teaching and learning.

What, ultimately, will change the predominant culture in institutions serving undergraduates? What will change the prevailing norms in undergraduate SME&T education and in the preparation of K-16 teachers of SME&T? We know much more now than we did even 10 years ago about how students learn (e.g., National Research Council, in press) and how to make good use of this knowledge in classrooms and laboratories (e.g., National Research Council, 1997a), if we choose to do so. Perhaps changes in practice will come from national and state efforts to provide standards for K12 science and mathematics education that stand to give us greater confidence in coming years that more students who enter college are more well prepared in the SME&T disciplines than ever before. Perhaps it will be our willingness to capitalize on this better preparation to provide undergraduate students with greater depth of understanding and appreciation of these subjects. Or to use information technology resources now available at previously unimaginable levels. Surely, change will occur when we take advantage of these resources—as individuals, departments, and institutions. Surely, it will occur when teaching and learning are viewed as worthwhile and important as other scholarly pursuits (Boyer, 1990).

The committee recognizes that implementing the visions of this report will require new funds or shifts in the allocation of existing resources from within postsecondary institutions. Depending on factors such as institutional governance and the progress that departments and institutions already have made in improving undergraduate SME&T education, costs may vary considerably from institution to institution. However, the evidence and information provided throughout the body of this report and the perspectives offered by participants at the regional symposia and topical forums (see Appendix A) suggest that change is both needed and, most likely, inevitable. The committee hopes that this report will stimulate serious discussions at all higher education institutions that also will take into account the need for new or reallocated resources to implement and support such change.

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Summarized below are the structure, demographics, main themes, and topics of the symposia, first, then of the topical forums. Both the regional symposiums and the topical forums were exceedingly important in helping the members of CUSE to identify and analyze the most important issues that must be confronted by those who wish to improve undergraduate SME&T education. The wealth of ideas that emerged from the hundreds of participants served as the basis for the vision statements and strategies for implementation that are included in this report. Participants' commitment to sustainable improvement of undergraduate SME&T education surely will be critical to the success of subsequent efforts.

## REGIONAL SYMPOSIUM SERIES: STRUCTURE AND DEMOGRAPHICS

The four symposia were held in different regions of the United States and hosted by a variety of institutions, organizations, and agencies from the academic, business, and government sectors. The dates, locations, and hosts of the symposia are listed in Table 1.

Invitations and announcements for the four symposia were disseminated to attract participation from a broader spectrum of stakeholders in the SME&T education community than could be present at the national convocation held in Washington in April of 1995.

Before each symposium, registrants received copies of the reports, *From Analysis to Action* and *Shaping the Future* to provide a common context for discussions at the symposia. Registrants also were polled about the recommendations in *From Analysis to Action*. The recommendations of most interest to registrants for any given symposium were then highlighted for discussion, and registrants were so notified. The committee also asked registrants to share information or visions for overcoming obstacles to implementing the recommendations in the report. The agendas for each symposium also included other issues identified by the registrants as critical for improving undergraduate science education.

Attendance at each symposium ranged from 101 to 145 participants. Registrants included SME&T faculty, focused around three themes: "Options for Action for Students," "Options for Action for Faculty," and "Options for Action for Institutions." Symposia discussions of these themes are synthesized and summarized below. Topics that received the most attention tended to be national in scope. Topics emphasized at a particular regional meeting are delineated as such. Discussion points are summarized to convey the breadth of issues covered at the meetings.

At all of the regional symposia, participants raised many common issues regarding the current state of science education in the United States. They included issues that have been noted in previous reports on education, beginning with A Nation at Risk (National Commission on Excellence in Education, 1983). These served as gambits for the general discussion that followed about how to improve undergraduate SME&T education. Once participants had raised several initial sub themes and issues, they proceeded to discuss solutions as well as obstacles likely to be encountered. Main topics that were raised repeatedly appear in boldfaced type.

## Theme I: Options for Action for Students

Registrants often began discussions under this theme by commenting that the mediocre science and mathematics preparation of many incoming college students may be impeding their readiness to pursue SME&T courses as undergraduates. Participants also felt that students seem reluctant to tackle challenging SME&T subjects in college. Attendees remarked on the general lack of motivation and diligence among students, including students in upper-division courses who are SME&T majors.

At each symposium, some participants speculated on whether appropriate pre-college preparation for SME&T education could be prescribed (see text related to Vision 1). There was discussion about faculty establishing informal guidelines in collaboration with college admissions offices that would indicate the level of mathematical and scientific knowledge and skills that entering students would need to go on successfully to complete lower-division undergraduate SME&T courses. The mention of guidelines led to discussions of the impact of national and state K-12 mathematics and science education standards and curriculum frameworks now—and in the future—on the background and interest levels of incoming SME&T students. Participants at the symposium in Houston were particularly concerned about how the pre-college preparation of students might affect the postsecondary community (see also "Theme II: Options for Action for Faculty" below for further discussion of K-12 standards).

Participants in all of the regional symposia seemed to agree that the level of preparation in SME&T for most incoming college students is inadequate, and they raised the issue of what the postsecondary system could or should do to assuage the problem. Participants asked how enterprising universities should be in attracting to the natural sciences students whose incoming skill levels are weak.

In discussing the level of preparation of today's students to undertake college-level work in SME&T, participants seemed particularly concerned with recurring evidence of the lack of access and exposure to high-quality pre-college SME&T education for some students, particularly those from groups historically underrepresented in these disciplines. Discussions of how to address this issue tended to differ by region. Participants' concepts of and ideas about equity, access, and exposure also emerged. Some of the participants pointed to the need for each postsecondary institution to develop a coherent, focused plan to improve SME&T education that includes informal linkages with K-12 education. Such partnerships would forge a more cohesive and synchronous SME&T educational continuum for grades K-16. At the symposium in Claremont, participants whose institutions have been affected by judicially or

Some participants questioned whether it was in anyone's best interest to isolate or segregate majors from non-majors in lower-division courses. This discussion complemented comments about the preparation of students for interdisciplinary or science teaching careers at the pre-college level and how this preparation would benefit from dismantling the separation of courses for SME&T majors and non-majors. Many participants in the symposium at Waltham thought that interdisciplinary undergraduate courses offered great promise either to invigorate (in the case of incoming students) or to reinvigorate (in the case of students already enrolled) interest in SME&T. However, some participants at this regional symposium were especia1096 -1.05d -1.055 Tate[owevertion of stre-colleion ) incoertm( inobstaclE&T at )--13cithe for many faculty and one that presaged more creativity in the structuring and delivery of SME&T courses. Beyond their general enthusiasm for increased use of information technology in postsecondary SME&T curriculum, participants

- championing the effective incorporation of information technology into the K-12 SME&T curriculum;
- strengthening the access of all pre-college students, including minorities and women, to K-12 SME&T courses;
- seeking out and initiating partnerships, summer internships, or activities beyond the school environment to update the skills and knowledge of pre-college teachers in the SME&T disciplines.

Attendees speculated about industry's opinion of the content of undergraduate SME&T courses and the knowledge and skills that industry expects or would like graduates to possess. A small number of business and industry representatives attended the symposia, so these questions were not answered definitively. However, some representatives suggested that, where feasible, postsecondary institutions involve industry in education discussions.

Finally, many participants acknowledged that funding issues in relation to education reform (see discussion of Vision 5 in the report) are a perpetual challenge for institutional administrators. Nonetheless, many participants felt it was extremely important for executives within postsecondary institutions to examine and implement many of the suggestions raised during the symposium series for improving undergraduate SME&T education. Participants urged administrators to accept assistance and guidance from faculty in what they projected to be a long and time-consuming process.

## REGIONAL SYMPOSIUM SERIES: CONCLUSION

As revealed in the summaries given above, the symposium series was very useful in catalyzing broad conversations among a diverse set of education representatives interested in improving K-12 and undergraduate SME&T education. Attendees at all four symposia touched on many of the daunting challenges postsecondary institutions face in the current era of reform. These include educating all students to become more scientifically literate, incorporating valuable and realistic scientific experiences into undergraduate SME&T courses, and balancing rewards and recognition for faculty among their primary responsibilities of research, teaching, and community service. Participants in all four of the symposia showed keen interest in having postsecondary institutions clearly and forcefully articulate renewed commitment to teaching and a judicious appreciation for innovation and research by faculty who are trying to become better teachers.

Finally, participants stated their strong appreciation for networking opportunities offered by meetings such as the regional symposium series. Participants noted that such meetings encourage interactions between constituents from diverse educational communities and perspectives, permitting discovery of common concerns, solutions, achievements, and the sharing of information, experiences, and findings. Institutions such as the NRC and sponsors such as the NSF and Exxon Education Foundation were urged to continue hosting meetings such as these symposia to continue regional dialogues about improving SME&T education.

## TOPICAL FORUMS: OVERVIEW

The 10 one-day topical forums were held after the four regional symposia. CUSE designed the forums to explore more specific issues in undergraduate SME&T education with a variety of scientific and educational audiences. The symposium series was an opportunity for a broader constituency to initiate discussions on issues associated with making scientific literacy a priority for all undergraduates. Host organizations for the forums assisted CUSE in identifying topics for discussion and in formulating agendas. CUSE members helped focus the topical forums to give participants opportunities to devise practical solutions to overcome those barriers identified or discussed in the regional symposia. Where possible, CUSE revisited the issues raised in the symposia series to gain as broad a perspective as possible for articulating the visions and strategies for implementation found in this report.

## TOPICAL FORUMS: STRUCTURE AND DEMOGRAPHICS

The 10 topical forums were conducted between October 10, 1996 and May 1, 1997. Forum dates, topics, hosting organizations, locations, and number of participants are given in Table 2. For nine of the forums, participants were asked to pre-register, although some people attended who had not. The forum held at the annual meeting of the American Society of Limnology and Oceanography was announced in the meeting program, and participants were not asked to pre-register. Attendance at the topical forums was more variable than at the regional symposia (see Table 2 for attendance figures).

Many of the forums were held in conjunction with annual or regional meetings of professional associations and societies, as professional development activities on university campuses, or, in one instance, via a multi-site video conference link as a cooperative activity with the Florida State Department of Education. Because of the diverse agendas for the different forums, attendance ranged from 15 to 125 participants, and the length of time for these sessions ranged from one hour to a full day. Wherever possible and appropriate, invitations were extended to people outside the hosting organization, such as local K-12 teachers, business leaders, federal and state education representatives, and foundation executives. The partnerships formed between CUSE and the organizations that hosted each of topical forums gave committee members additional opportunities to engage postsecondary educators and administrators in discussions about changes needed in postsecondary education and factors that may be impeding such changes. Indeed, by scheduling some of these forums in conjunction with other types of activities, such as annual meetings, CUSE was able to engage people from the SME&T community who were unable—or otherwise might not have elected—to participate in the regional symposia.

## TOPICAL FORUMS: SYNOPSES

A synopsis of each forum is presented below, grouped into one of three categories: forums hosted by 1) Professional Organizations and Associations, 2) Universities, and 3) a State Educational Organization. Each synopsis contains cross-references to the specific visions contained in the body of this report.

### Forums Hosted by Professional Organizations and Associations

National Council of Teachers of Mathematics (NCTM). This half-day forum was held in conjunction with a regional meeting of the NCTM. It focused on communication between SME&T faculty and faculty in schools of education in creating and fostering effective interdisciplinary courses that complement educational goals articulated in K-12 mathematics and science standards (see additional discussion in the section on Vision 2 in the report). As a result of similar discussions at the regional symposium hosted by GTE, this topical forum highlighted effective interdisciplinary programs and collaborations among faculty in different kinds of postsecondary institutions.[36] The forum also gave participants the time and opportunity to consider the characteristics of a successful interdisciplinary program. The intention was to encourage forum participants to replicate similar courses at their own institutions.

Forum participants—both SME&T and education faculty—acknowledged that interdisciplinary courses can be very challenging

[36] Courses highlighted at this forum have been taught at the University of Missouri, Columbia, Kansas State University, and the University of Missouri, St. Louis.

TABLE 2 DATES, TOPICS, HOSTING ORGANIZATIONS, LOCATIONS, AND NUMBER OF PARTICIPANTS OF THE TEN TOPICAL FORUMS

| Date | Forum Topic | Host | Location and Number of Participants |
|---|---|---|---|
| October 10, 1996 | Productive Partnerships: Collaborations between Science, Mathematics, and Education Faculty for the Improvement of Teacher Education | National Council of Teachers of Mathematics Regional Meeting | Kansas City, MO 13 participants |
| October 15, 1996 | Involving Research Faculty in the Reform of Undergraduate Science Education | | |

to organize, implement, and maintain. After examining the characteristics of successful interdisciplinary programs, forum participants engaged in an active investigation of the steps required to produce similar programs to meet the needs of a wider range of students, including science majors and K-12 teaching majors.

Featured at this forum were comprehensive, introductory courses designed to bridge the natural sciences and humanities. They reflected, in part, national standards in mathematics and science. Participants in the forum were urged to view such courses as an effective way to impress upon students— especially prospective K-12 teachers—the importance and significance of SME&T in their lives (a perspective that would later be reflected in Vision 2 of this report).

Society for Environmental Toxicology and Chemistry: This forum was held in conjunction with the annual meeting of this society, and several CUSE members attended to conduct a half-day break-out session. Entitled "Developing Scientific Literacy through Environmental Science Courses and Programs," the session provided an opportunity for members of CUSE to interact with environmental scientists on ways to enhance the general scientific literacy of environmental science students (see this discussion of Vision 2 in this report). Participants reviewed environmental science programs from different postsecondary institutions, including several being taught at the University of Oklahoma, as follows: "Interdisciplinary Perspectives on the Environment" (Department of Philosophy), "Environmental Policy and Administration" (Energy Center), "Environmental Evaluation and Management" (School of Civil Engineering and Environmental Science), "The Ecology of the Greco-Roman Mediterranean" (Department of Classics), and "Principles of Plant Ecology" (Department of Botany). Another course, "Environmental Science," offered at Trinity College in Washington, DC, also was examined. Participants then discussed the creation of additional programs for non-science majors that would link environmental concepts in interesting, informative, and creative ways.

American Geophysical Union: This half-day forum was conducted as a workshop that used earth science and geological exploration as the basis for discussion. Participants identified various skills that their students are expected to master in undergraduate courses and that might be needed in the modern work environment. Conversation centered mainly on skills for science majors, although participants noted that students with other interests and career aspirations also need many of these skills. The skills identified included

- Ability to undertake scientific inquiry

—Define a scientific question
—Plan a way to answer the question scientifically
—Use scientific equipment
—Analyze data
—Interpret results

- Ability to create products of scientific inquiry—data

—Maintain an organized and detailed laboratory notebook
—Develop data sets
—Produce diagrams that allow students to relate variables to one another

- Ability to communicate the product of the scientific inquiry-oral reports

—Organize presentations for coherence and conciseness
—Effectively present data and conclusions
—Prepare visual aids
—Syntax and grammar

- Ability to communicate the product of the scientific inquiry—written reports

—Organize presentations for coherence and conciseness
—Effectively present data and conclusions

goal of all SME&T courses should be to teach students about the scientific method. Forum participants agreed that understanding this fundamental way of thinking about science would enhance students' general scientific literacy and their ability to understand specific scientific issues more clearly. Attendees also agreed that hands-on experiences generated via challenging careers and commit to improving them for all of their lower-division undergraduate students.

Acknowledging that such changes will require shifts in the culture of research universities, participants in this forum offered several straightforward suggestions, including the following:

- Researchers should highlight their teaching during guest lectures or when speaking at their own or other institutions.
- Researchers should ask guest speakers and lecturers at professional conferences and other academic events to convey information about their teaching.
- At least one departmental research seminar in a colloquium series could be devoted to a discussion of educational issues and pedagogy. Such a meeting also could be constructed to inform faculty of the most current research on science teaching, as well as K-12 education reform efforts.
- SME&T faculty could engage in greater collaboration with colleagues in their institution's school of education. A good beginning would be inviting education faculty to meetings of SME&T departments to inform SME&T faculty about best teaching practices.
- Because research SME&T faculty have the best perspectives of the "cutting edge of knowledge" in their disciplines, they could collaborate with education faculty who are knowledgeable about pedagogy and methodology. Together,

they do take should be rigorous, emphasize the interrelationships among disciplines, incorporate information technology

This forum's final theme was the state of pre-college science and mathematics education. Many participants urged the postsecondary community to lend active support to K-12 education reform by adjusting college admission requirements and SME&T courses to reflect the current national standards for K-12 mathematics and science. In addition, participants said that courses for prospective teachers should not simply mimic courses for science majors but should be more specifically attuned to teachers' needs. Some participants wondered whether there should be special content courses for future teachers and, if so, how to decide what those courses should contain. However, most participants agreed that prospective teachers should learn their science as other science students do. Thus, their science methods courses should be taught in science buildings and should include laboratories. Courses should be taught in ways that students will be expected to teach in their own classrooms. Early field placement was also considered an essential component of effective preparation of K-12 teachers so that these students can apply as soon as possible the information, skills, and techniques they learn in their college classrooms and laboratories.

Discussions from this forum helped the committee prepare Visions 2, 4, and 5.

## Forum Hosted by a State Educational Organization

Florida Department of Education. This forum, although physically based in Tampa, was an interactive teleconference with participants at seven sites around the state. It examined the implications of standards-based education for introductory college science courses.

the starting point for more encompassing systemic changes in SME&T education. (It is important to note that most faculty remarked that the message to improve undergraduate teaching must come from university administration, while conversely, deans and provosts commented that, ultimately, faculty controlled the classroom environment. This strongly suggests that more effective communication is essential between faculty and administrators about expectations, strategies, and goals for teaching at the postsecondary level.)

This forum's discussions helped to inform the development of Visions 1, 2, 3, and 5 in this report.

## TOPICAL FORUMS: CONCLUSION

The topical forums offered important opportunities for the members of CUSE to build upon the momentum of the national convocation held in 1995 and the subsequent regional symposia. In collaboration with professional organizations and universities and, in one case, with a state department of education, CUSE members were able to explore with colleagues across the United States issues that were raised at the regional symposia. For example, strategies for developing and implementing interdisciplinary courses—prominent topics in the first symposium at the University of Michigan—were subsequently revisited at the two topical forums held in collaboration with the NCTM and the University of Washington System.

Center for American Archeology, Kampsville, IL
Center for Educational Equity in Mathematics, Science, and Technology, California State Polytechnic Institute, Pomona, CA
Central Connecticut State University, New Britain, CT
Central Florida Community College, Boca Raton, FL
Central Florida Community College, Ocala, FL
Central Michigan University, Mt. Pleasant, MI
Central Washington University, Ellensburg, WA
Centralia College, Centralia, WA
Chadwick School, Palos Verdes, CA
Chaparral Middle School, Diamond Bar, CA
Chapman College, Orange, CA
Cheesebrough-Pond's USA Company, Trumbull, CT
Chevron Chemical Company, Houston, TX
Chevron Chemical Company,

Florida Gulf Coast University, Ft. Myers, Fl
Florida Institute of Education, Jacksonville, FL
Florida Institute of Technology, Melbourne, FL
Florida International University, Miami, FL
Florida State University, Tallahassee, FL
Ford Motor Company, Dearborn, MI
Ft. McCoy K-8 School, Ft. McCoy, FL
Franklin & Marshall College, Lancaster, PA
Fred Hutchinson Cancer Research Center, Seattle, WA
Fresno Pacific College, Fresno, CA
Fugro-McClelland (Southwest), Inc., Houston, TX
General Atomics,

Lansing Community College, Lansing, MI
LaSalle University, Philadelphia, PA
Lawrence Technological University, Southfield, MI
Lexington Community College, Lexington, KY
Loral Space Information Systems, Houston, TX
Louisiana State University, Baton Rouge, LA
Loyola Marymount University, Los Angeles, CA
Loyola University, New Orleans, LA
Manatee Community College, Bradenton, FL
Marion County School Board, Ocala, FL
Massachusetts College of Art, Jamaica Plains, MA
Massachusetts Department of Education, Maiden, MA
Massachusetts Institute of Technology, Cambridge, MA
Massachusetts Institute of Technology, Westford, MA
Massasoit Community College, Brockton, MA
Master's College, The, Newhall, CA
McDonnell Douglas Aerospace, Houston, TX
McMaster University, Hamilton, Ontario
Mesa Community College, Mesa, AZ
Miami-Dade Community College, Miami, FL
Miami University, hshTwMcMa4.enth-9.5(Rouge6)-17.5( mount Universit9ty,)-7( )]TJ/F2 1 6Tf8.9386 0 TD0.0005 Tc0.003E[(  Tc[(Lafield, 

Space Center Houston, Houston, TX
Square D Company, Palatine, IL
SRI International, Menlo Park, CA
St. Edward's University, Austin, TX
St. Petersburg Junior College-Community College, Clearwater, FL
St. Thomas University, Miami, FL
Stanford University, Stanford, CA
Stanton College Preparatory School, Jacksonville, FL
State University of New York, Oswego, NY
State University of New York, Stony Brook, NY
State University System of Florida, Miami, FL
Stetson University, Deland, FL
Swarthmore College, Swarthmore, PA
Tallahassee Community College, Tallahassee, FL
TAV Associates, Boston, MA
Temple University, Philadelphia, PA
Texas A&M University, College Station, TX
Texas A&M University, Galveston, TX
Texas A&M University, Kingsville, TX
Texas Southern University, Houston, TX
Texas Tech University, Lubbock, TX
Texas Wesleyan University, Fort Worth, TX
The Union Institute,

# Appendix C

# Biographical Sketches of Members of the Committee on Undergraduate Science Education (CUSE)

## CURRENT MEMBERS

Marye Anne Fox (NAS*), North Carolina State University and CUSE Chair, is Chancellor of North Carolina State University in Raleigh, NC. Prior to assuming the Chancellorship position, Dr. Fox was Vice President for Research and the M. June and J. Virgil Waggoner Regents Chair in Chemistry at the University of Texas at Austin. Her recent research activities include organic photochemistry, electrochemistry, and physical organic mechanisms. She is a former associate editor of the *Journal of the American Chemical Society*. Previously, she was the director of the Center for Fast Kinetics has led an effort to develop instructional materials for integrating this field into the chemistry curriculum. Dr. Ellis leads the College Level One Team of the National Science Foundation-supported National Institute for Science Education (NISE), which is examining ways to make introductory college science, mathematics, engineering and technology courses more effective. He also serves on the Committee on Undergraduate Science Education of the National Research Council. Dr. Ellis received a B.S. in chemistry from Caltech in 1973, and his Ph.D. degree in inorganic chemistry from MIT in 1977.

Dorothy Gabel, Indiana University, is a professor in the School of Education at Indiana University and the coordinator of science education. She presently teaches and supervises a required introductory science course for prospective elementary teachers entitled "Introduction to Scientific Inquiry." Dr. Gabel's specialty is in chemistry education, and she is the author of numerous research papers in this area and of a high school chemistry text. She was the editor of The Handbook of Research on Science Teaching and Learning and has served as president of the Hoosier Science Teachers Association, the School Science and Mathematics Association, and the National Association for Research in Science Teaching Association.

James M. Gentile, Hope College,

editorial review board for that journal, for *Revista Genetica*, the *CUR Newsletter*, and *Mutation Research*. Dr. Gentile is currently the managing editor of *Mutation Research: Fundamental and Molecular Mechanisms of Mutations* and executive managing editor of *Mutation Research*.

**Ronald J. Henry**, *Georgia State University*, is the provost and vice president for Academic Affairs at Georgia State University (since July, 1994). One of his responsibilities is to develop Georgia State into a premier urban research university. Another responsibility is leadership to promote and recommend changes in public education systems that will improve student success at all levels, preschool through postsecondary (P-16) education, and into the world of work. Previously, he served as chief academic officer for Miami University (Ohio) and Auburn University. Dr. Henry serves as a member of the Georgia P16 Council. He served as an evaluator on the 1995 Education Pilot Evaluation Team of the Malcolm Baldrige National Quality Award and as an Examiner on the 1996 Board of Examiners. Dr. Henry received B.Sc. and Ph.D. degrees in applied mathematics from Queen's University, Belfast, in 1961 and 1964, respectively.

**Harvey B. Keynes**, *University of Minnesota*, is a professor of mathematics, past director of education in the Geometry Center, and director of the (science/engineering school) Institute of Technology Center for Educational Programs. His research interests are in dynamical systems and mathematics education. Professor Keynes directs the following projects: The University of Minnesota Talenteniv presiden4lTiH8.2 Pvuf is a professor13.4(of)-83ty Center3alenteniv en13.eer3.3(o.24.4(ss)-6( sy,)-6.3( ynes)

R. Heather Macdonald, College of William and Mary is associate professor of geology at the College of William and Mary, where she recently served as dean of Undergraduate Studies, Arts and Sciences. She is a past-president of the National Association of Geoscience Teachers (NAGT) and currently co-coordinates NAGT workshops on innovative and effective teaching in the geosciences. She also serves on the education committee of the Geological Society of America and the K-12

Chemical Sciences Division at the Lawrence Berkeley Laboratory. He also has served as chair of the Department of Chemistry and dean of the College of Chemistry at Berkeley. His many research interests include molecular energy transfer, the dynamics of chemical reactions, photochemistry, and spectroscopy. His research, including pioneering work on vibrational energy transfer among the modes of polyatomic molecules using laser methods, was recognized by the National Academy of Sciences, where he has been a member since 1986. His research also has been recognized by prizes and awards from the American Physical Society and the American Photochemical Society. He is the editor of *Chemical and Biochemical Applications of Lasers* and a member of the editorial board for *Laser Chemistry*. Dr. Moore has served on numerous disciplinary and education committees and boards of the National Research Council. His service to chemistry committees has included the Panel for Chemical Physics; the Committee on Atomic, Molecular, and Optical Sciences; and the AFOSR Chemical Sciences Review Panel. Committee assignments in education include the CUSE (chair from the committee's inception in 1993 until 1997), the advisory board to the NRC's Center for Science, Mathematics, and Engineering Education, the Committee on Information Technology, and the working group on Science Content Standards for the *National Science Education Standards*. Dr. Moore received his B.A. from Harvard University and his Ph.D. from the University of California at Berkeley.

**Isaac Abella**, *University of Chicago*, is professor of physics at the University of Chicago. His field is non-linear optical physics, ultra-fast transient phenomena, and laser interactions in atoms and ions in solids. He received a B.A. in physics and astronomy from the University of Toronto, and M.A. and Ph.D. in Physics from Columbia University, where he worked under Professor Charles H. Townes. He has been a fellow at the Joint Institute for Laboratory Astrophysics in Boulder, Colorado; visiting scientist at the Optical Sciences Division, Naval Research Laboratory, Washington, DC; guest scientist at National Bureau of Standards (NIST), Time & Frequency Division, Boulder Labs; and research fellow at Argonne National Laboratory. He has served as a member of the Education Committee of the American Physical Society; chair of Education Committee of Laser Science Topical Group, (APS); chair, Isaakson Prize Committee, American Physical Society (APS); and member of the National Science Standards Working Group of the National Research Council. He is a fellow of the APS and of the Optical Society of America and president of the Chicago Chapter of Sigma Xi. He was awarded the Quantrell Prize for Excellence in Undergraduate Teaching at Chicago. He is the resident master of the largest college residence hall at the University of Chicago.

**Neal Abraham**, *DePauw University*, is Vice-President for Academic Affairs and Dean of Faculty. He was the Rachel C. Hale Professor of the Sciences and Mathematics and Professor of Physics at Bryn Mawr College. A fellow of the American Physical Society, Optical Society of America, and the American Association for the Advancement of Science, with research interests in laser physics and nonlinear dynamics, Dr. Abraham has been actively involved in science education reform through the American Association of Physics Teachers, the Association of American Colleges, and Project Kaleidoscope (since its inception in 1989). Dr. Abraham coordinated regional PKAL workshops on maintaining a research-rich environment (1987) and on reforming introductory mathematics and science courses (1993). He currently serves as a mentor in PKAL's Faculty for the 21st Century program. He served as a founding member CUSE and is a co-author of its handbook, *Science Teaching Reconsidered*.

George R. Boggs, Palomar College, is the superintendent/president of Palomar College, a comprehensive community college located in San Marcos, California. Dr. Boggs is a commissioner for the Accrediting Commission for Community and Junior Colleges of the Western Association of Schools and Colleges. He has served on the boards of directors of the California Association of Community Colleges, the Community College League of California, and the American Association of Community Colleges, where he was board chair in 1993/94. He is a member of the Advisory Committee for Education and Human Resources for the National Science Foundation (NSF) and has served on several NSF panels. Dr. Boggs is a former chemistry instructor. He is the author of more than 30 articles and chapters in professional journals and books.

Denice D. Denton, University of Washington, is the dean of engineering and a professor in the department of electrical engineering at the University of Washington. She received the B.S., M.S. (1982), and Ph.D. (1987) in electrical engineering from the Massachusetts Institute of Technology. Her current interests include plasma deposition of polymers and the use of micro machining in solid state actuator design. Professor Denton was co-director of the National Institute for Science Education in 1995-1996. She is a recipient of the National Science Foundation Presidential Young Investigator Award (1987-1992), the American Society of Engineering Education AT&T Foundation Teaching Award (1991), the W.M. Keck Foundation Engineering Teaching Excellence Award (1994), the American Society of Electrical Engineers George Westinghouse Award (1995), and the Institute of Electronic and Electrical Engineering Harriet B. Rigas Teaching Award (1995). Dr. Denton is the chair of the NRC's Board on Engineering Education.

Michael P. Doyle, Research Corporation, has served as the Dr. D.R. Semmes Distinguished Professor of Chemistry at Trinity University in San Antonio. He has received many awards for his work, including the Catalyst Award of the CMA and the ACS Award. Dr. Doyle is a member of the AAAS, the American Society of Biological Chemists, and the NIH.

Ramesh Gangolli, University of Washington, is professor of the mathematics department at the University of Washington. After receiving his Ph.D. in mathematics from the Massachusetts Institute of Technology and teaching there for two years, Dr. Gangolli has been a visiting professor at many institutions, in addition to his years at the University of Washington. He is widely published in the field of mathematics, and has received awards from the Sloan Fellowship and NSF, among other foundations, organizations, and agencies. He has served on the advisory committee on Mathematical Sciences for the NSF, and is associate editor of the Journal of the Indian Mathematical Society. Dr. Gangolli was a founding member of the CUSE.

Frederick T. Graybeal, ASARCO Incorporated, is chief geologist for ASARCO Incorporated, an international mining company. His responsibilities involve the worldwide review of geological environments for future exploration programs, introduction of new exploration concepts and technologies, and evaluation of acquisition opportunities. He worked previously for American and Canadian exploration companies and was an instructor for one year in the Department of Geology at the University of Arizona. He is a former vice president of the Society of Economic Geologists and serves on the advisory committee for the Department of Geosciences at the University of Arizona. Dr. Graybeal received an A.B. in geology from Dartmouth College in 1960 and M.S. (1962) and Ph.D. (1973) degrees in geology from the University of Arizona.

Norman Hackerman (NAS*), The Robert A. Welch Foundation, served as president of Rice University from 1970-1985 and holds the title of president emeritus and distinguished professor emeritus of chemistry at

Rice University. Prior to going to Rice, Dr. Hackerman spent 25 years at The University of Texas, Austin, where he joined the faculty as an assistant professor of chemistry in 1945 and progressed to president in 1967. He is now professor emeritus of chemistry at The University of Texas at Austin. He received his A.B. and Ph.D. degrees from Johns Hopkins University. He taught chemistry at Loyola College and Virginia Polytechnic and worked as a research chemist for Colloid Corporation, Kellex Corporation, and the U.S. Coast Guard. Dr. Hackerman was a member of the National Science Board from 1968 to 1980 and chairman from 1975 to 1980. He was the editor of the Journal of the Electrochemical Society from 1969 to 1989. He is a member of the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences. He belongs to numerous scientific organizations. He is author or co-author of 225 publications. In addition to several previous awards, Dr. Hackerman received the American Institute of Chemists Gold Medal in March 1978, the Mirabeau B. Lamar Award of the Association of Texas College and Universities in 1981, the Distinguished Alumnus Award from Johns Hopkins University in 1982, Edward Goodrich Acheson Award of the Electrochemical Society in 1984, the Alumni Gold Medal for distinguished service to Rice University in 1984, Charles Lathrop Parsons Award of the American Chemical Society in 1987, the AAAS-Philip Hauge Abelson Prize in 1987, the Vannevar Bush Award of the National Science Board in 1993, and the National Medal of Science in 1993. Dr. Hackerman serves as chairman of the Scientific Advisory Board of The Robert A. Welch Foundation.

John K. Haynes, Morehouse College, serves as the David Packard Professor in Science and chair of Biology at Morehouse College. He received his B.S. from Morehouse in 1964 and his Ph.D. in Developmental Biology from Brown University in 1970. His research interests include regulation of cell volume in elasmobranchs and biochemical characterization of sickle cell membranes.

Eileen Delgado Johann, Miami-Dade Community College, is currently a professor of chemistry at Miami-Dade Community College, where she has been a full-time faculty member for 21 years. She has participated in numerous college activities, including the legislative committee and the student services committee. Dr. Johann has created interactive multimedia presentations in chemistry and nutrition and is the co-author of the nursing chemistry module series (inorganic, organic and biochemistry). Her professional affiliations include the Florida Association of Community Colleges, Two-Year College Chemistry Conference, American Chemical Society, and the College Hispanic Council.

William E. Kirwan, Ohio State University, is President of Ohio State University. Dr. Kirwan received his bachelor's degree from the University of Kentucky in 1960, and his master's and doctoral degrees from Rutgers in 1962 and 1964, respectively. He joined the University of Maryland as an assistant professor of mathematics in 1964. He was promoted to associate professor in 1968, to full professor in 1972, to chair of the Department of Mathematics in 1977, to vice chancellor for academic affairs in 1981, to provost in 1986, to acting president in August 1988, and to president in February 1989. During his tenure as president, the University of Maryland emphasized undergraduate education, selectively enhanced academic programs, recruited and retained distinguished faculty, achieved diversity goals for underrepresented minority groups, and successfully completed its first capital campaign. While serving as provost in the 1980s, Dr. Kirwan raised admissions standards, increased merit scholarships and graduate fellowships, and established an academic planning process. He is known for his long-range vision and for his talent as a consensus builder. Under his leadership, Maryland undertook a major

Columbia University and has taught at Brooklyn College, Queens College, Barnard College, Columbia University, and the University of California at Riverside.

Penny Moore, Piedmont High School, is a physics and mathematics teacher at Piedmont High School in Piedmont, California. She currently directs PRIME Science, an NSF-funded curriculum materials project that has published an integrated science curriculum for grades 6-10 (Kendall-Hunt). She directed Science for Science Teachers (SST), a program

# Appendix D

# Introducing the National Science Education Standards*

## WHAT ARE THE NATIONAL SCIENCE EDUCATION STANDARDS?

The National Research Council released the National Science Education Standards in December of 1995. The Standards define the science content that all students should know and be able to do and provide guidelines for assessing the degree to which students have learned that content. The Standards detail the teaching strategies, professional development, and support necessary to deliver high quality science education to all students. The Standards also describe policies needed to bring coordination, consistency, and coherence to science education programs.

The National Science Education Standards include standards for

- Content
- Teaching
- Assessment
- Professional Development
- Program
- System

## WHY DO WE NEED THE STANDARDS?

- Understanding science offers personal fulfillment and excitement.
- Citizens need scientific information and scientific ways of thinking in order to make informed decisions.
- Business and industry need entry-level workers with the ability to learn, reason, think creatively, make decisions, and solve problems.

* National Research Council. 1997. Washington, DC: National Academy Press; Available from National Academy Press, 1 (800) 624-6242. Mail your order to National Academy Press, 2101 Constitution Ave., NW, Lockbox 285, Washington, DC 20055.

- Strong science and mathematics education can help our nation and individual citizens improve and maintain their economic productivity.

## WHO DEVELOPED THE STANDARDS?

Committees and working groups of scientists, teachers, and other educators appointed by the National Research Council developed the *Standards*. They engaged in a four-year process that involved review and critique by 22 science education and scientific organizations and broad state and local participation of over 18,000 individuals, including scientists, science educators, teachers, school administrators, and parents. The national consensus that resulted from this process gives the *Standards* a special credibility. Educators throughout the country who use them to inform changes in science education programs can be assured that the *Standards* represent the highest quality thinking this country can provide its citizens.

## THE VISION OF THE STANDARDS:

All students, regardless of age, gender, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science, should have the opportunity to attain high levels of scientific literacy.

Guiding Principles behind the *Standards*

- Science is for all students.
- Learning science is an active process.
- School science reflects traditions of contemporary science.
- Improving science is part of systemwide educational reform.

## HOW DO STUDENTS LEARN SCIENCE?

The *Standards* are based on the premise that learning science is something that students do, not something that is done to them. The *Standards* envision an active learning process in which students describe objects and events, ask questions, formulate explanations, test those explanations, and communicate their ideas to others. In this way, students build strong knowledge of science content, apply that knowledge to new problems, learn how to communicate clearly, and build critical and logical thinking skills.

Through their study of science, students

- Experience the richness and excitement of the natural world
- Apply scientific principles and processes to make personal decisions
- Discuss matters of scientific and technological concern
- Increase their potential contribution to society and to the economy

## WHAT SHOULD STUDENTS KNOW AND BE ABLE TO DO?

The Content Standards describe the knowledge and abilities students need to develop, from kindergarten through high school, in order to become scientifically literate.

What is scientific literacy? Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. People who are scientifically literate can ask, find, or determine answers to questions about everyday experiences. They are able to describe, explain, and predict natural phenomena.

Scientific literacy has different degrees and forms; it expands and deepens over a lifetime, not just during the years in school. The Standards outline a broad base of knowledge and skills for a lifetime of continued development in scientific literacy for every citizen, as well as provide a foundation for those aspiring to scientific careers.

## HOW ARE THE NATIONAL SCIENCE EDUCATION STANDARDS DIFFERENT FROM THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE'S BENCHMARKS FOR SCIENCE LITERACY?

The documents differ in three ways. First, they divide content by different grade levels. The Benchmarks are statements of what all students should know and be able to do in science, mathematics, and technology by the end of grades 2, 5, 8, and 12; the Standards use grades 4, 8, and 12 as end points. Second, the Standards place greater emphasis on inquiry, including it as important science content as well as a means of teaching and learning. Third, the Standards offer a broader set of standards for improving science education. They address all components of education, including teaching, assessment, professional development, program, and system, recognizing that improvement cannot occur or be sustained in one segment of the system alone. There is, however, a high level of consistency between the two documents in describing the content to be learned. The National

Research Council believes that the use of the *Benchmarks* complies fully with the spirit of the content standards.

## WHAT IS INCLUDED IN CONTENT STANDARDS?

Content standards are divided into eight categories:

- Unifying concepts and processes
- Science as inquiry
- Physical science
- Life science
- Earth and space science
- Science and technology
- Science in personal and social perspectives
- History and nature of science

The content standards include traditional school science content but, in addition, encompass other knowledge and abilities of scientists. The first category of the content standards, unifying concepts and processes, identifies powerful ideas that are basic to the science disciplines and help students of all ages understand the natural world. This category is presented for all grade levels because the concepts are developed throughout a student's education. The other content categories are clustered for grades K-4, 5-8, and 9-12. Students develop knowledge and abilities in inquiry, which ground their learning of subject matter in physical, life, and earth and space sciences. Science and technology standards link the natural and designed worlds. The personal and social perspectives standards help students see the personal and social impacts of science and help them develop decision-making skills. The history and nature of science standards help students see science as a human experience that is on-going and ever-changing.

## WHAT DO TEACHERS OF SCIENCE DO?

The *Teaching Standards*

CONTENT STANDARDS

| | Grades K-4 | Grades 5-8 | Grades 9-12 |
|---|---|---|---|
| Unifying Concepts and Processes | Systems, order, and organization<br>Evidence, models, and explanation<br>Change, constancy, and measurement<br>Evolution and equilibrium<br>Form and function | Systems, order, and organization<br>Evidence, models, and explanation<br>Change, constancy, and measurement<br>Evolution and equilibrium<br>Form and function | Systems, order, and organization<br>Evidence, models, and explanation<br>Change, constancy, and measurement<br>Evolution and equilibrium<br>Form and function |
| Science as inquiry | Abilities necessary to do scientific inquiry<br>Understandings about scientific inquiry | Abilities necessary to do scientific inquiry<br>Understandings about scientific inquiry | Abilities necessary to do scientific inquiry<br>Understandings about scientific inquiry |
| Physical Science | Properties of objects and materials<br>Position and motion of objects<br>Light, heat, electricity, and magnetism | Properties and changes of properties in matter<br>Motions and forces<br>Transfer of energy | Structure of atoms<br>Structure and properties of matter<br>Chemical reactions Motions and forces<br>Conservation of energy and increase in disorder<br>Interactions of energy and matter |
| Life Science | Characteristics of organisms<br>Life cycles of organisms<br>Organisms and environments | Structure and function in living systems<br>Reproduction and heredity<br>Regulation and behavior<br>Populations and ecosystems<br>Diversity and adaptations of organisms | The cell<br>Molecular basis of heredity<br>Biological evolution<br>Interdependence of organisms Matter, energy, and organization in living systems<br>Behavior of organisms |
| Earth and Space Science | Properties of earth materials<br>Objects in the sky<br>Changes in earth and sky | Structure of the earth system<br>Earth's history<br>Earth in the solar system | Energy in the earth system<br>Geochemical cycles<br>Origin and evolution of the earth system<br>Origin and evolution of the universe |
| Science and Technology | Abilities of technological design<br>Understandings about science and technology<br>Abilities to distinguish between natural objects and objects made by humans | Abilities of technological design<br>Understandings about science and technology | Abilities of technological design<br>Understandings about science and technology |
| Science in Personal and Social Perspectives | Personal health<br>Characteristics and changes in populations<br>Types of resources<br>Changes in environments<br>Science and technology in local challenges | Personal health<br>Populations, resources, and environments<br>Natural hazards<br>Risks and benefits<br>Science and technology in society | Personal and community health<br>Population growth<br>Natural resources<br>Environmental quality<br>Natural and human-induced hazards<br>Science and technology in local, national, and global challenges |
| History and Nature of Science | Science as a human endeavor | Science as a human endeavor<br>Nature of science<br>History of science | Science as a human endeavor<br>Nature of scientific knowledge |

Teachers of science

- Plan an inquiry-based science program
- Guide and facilitate learning
- Assess student learning and their own teaching
- Design and manage learning environments
- Develop communities of science learners
- Participate in on-going development of the school science program

How can teachers apply the *Standards* in their classrooms? Individual teachers are encouraged by the *Standards* to give less emphasis to fact-based programs and greater emphasis to inquiry-based programs that engage students in an in-depth study of fewer topics. However, to attain the vision of science education described in the *Standards*, more than teaching practices and materials must change. The routines, rewards, structures, and expectations of districts, schools, and other parts of the system must endorse the vision, and provide teachers with resources, time, and opportunities to change their practice. Teachers can use the program and system standards to communicate this need to administrators and parents.

## HOW IS SCIENCE LEARNING ASSESSED?

The Assessment Standards provide criteria to judge progress across the system toward the science education vision of scientific literacy for all. They can be used in preparing evaluations of students, teachers, programs, and policies.

Assessments should

- Be deliberately designed for the decisions they are intended to inform
- Measure both achievement and opportunity to learn
- Clearly relate decisions to data
- Demonstrate fairness in design and use
- Support their inferences with data

Will the *Standards* help teachers test their students more effectively? Teaching and testing are integral components of instruction, and cannot be separated. As content and teaching strategies become aligned with the *Standards*, so must classroom assessments. The assessment standards identify essential characteristics of effective assessment policies, practices, and tasks at all levels. Teachers who use the standards will think differently about what to assess, when to do so, and the best ways to determine what their students are learning. They will consider carefully the fundamental understandings their students are working to learn, the place their students are in developing understanding, and a variety of alternatives to help their students demonstrate what they know.

*Will standardized tests change?* The *Standards* address the need for systems to reconsider the purpose, data analysis, and sample size in all large-scale assessments. There are already indications that changes in items on common standardized tests are being considered, as are the designs used by states, districts, and others who conduct large-scale science assessments.

## WHAT DO TEACHERS NEED TO KNOW AND HOW WILL THEY LEARN IT?

The *Professional Development Standards* make the case that becoming an effective teacher of science is a continuous process, stretching from pre-service throughout one's professional career. The professional development standards can be used to help teachers of K-12 science have the on-going, in-depth kinds of learning opportunities that are required by and available to all professionals.

*Professional Development Standards* call for teachers to have opportunities to

- Learn science through inquiry
- Integrate knowledge of science, learning, and teaching
- 

- Builds on teachers' current knowledge
- Encourages on-going reflection
- Supports collaboration among teachers

How will teachers improve their science teaching? Effective teachers of science have specialized knowledge that combines their understanding of science with what they know about learning, teaching, curriculum, and students. They develop this unique type of knowledge through both pre-service and inservice learning experiences that

- Deliberately connect science and pedagogy
- Model effective teaching practices
- Address the needs of teachers as adult learners
- Take place in classrooms and other learning situations
- Use inquiry, reflection, research, modeling, and guided practice

## WHAT IS AN EFFECTIVE SCHOOL SCIENCE PROGRAM?

The Program Standards address the need for comprehensive and coordinated science experiences across grade levels and support needed by teachers in order for all students to have opportunities to learn. The program standards will help schools and districts translate the Standards into effective programs that reflect local contexts and policies.

Program Standards call for

- Consistency across all elements of the science program and across K-12
- Quality in the program of studies
- Coordination with mathematics
- Quality resources-teachers, time, materials
- Equitable opportunities for achievement
- Collaboration within the school community to support a quality program

Quality Programs of Study

- Include all content standards
- Select developmentally appropriate content
- Emphasize student understanding through inquiry
- Connect science to other subjects

**Are the *Standards* a science curriculum?** Curriculum is the way content is designed and delivered. It includes the structure, organization, balance, and presentation of the content in the classroom. The *Standards* do not prescribe a specific curriculum but, rather, provide criteria that can be used at the local, state, and national levels to design a curriculum framework, a key element in a school or district's science program, or to evaluate and select curriculum materials. Effective science programs are designed to consider and draw consistency from the content, teaching, and assessment standards, as well as professional development, program, and system standards.

## HOW DOES THE SYSTEM SUPPORT SCIENCE LEARNING?

The System Standards call on all parts of the educational system—including local districts, state departments of