Section III:

Written Remarks Contributed as Part of the EHR Advisory Committee Public Hearings on Undergraduate SME&T Education

Written Contributions to the EHR Advisory Committee Public Hearing on Disciplinary Perspectives of Undergraduate SME&T Education

Convened October 23, 1995
At the National Science Foundation
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Invited Speakers:
"Disciplinary Perspectives on SME&T Undergraduate Education"

Listed in order of Testimony. Titles indicate the speakers' positions at the time of the Hearing.

Undergraduate Education in SME&T	**MRC Greenwood** *Dean of Graduate Studies, Vice Provost, Academic Outreach, University of California, Davis*
Biological Sciences	**Rita R. Colwell** *President, American Association for the Advancement of Science & Professor, University of Maryland, College Park*
Mathematical Sciences	**Alan Tucker** *Professor, State University of New York at Stony Brook*
Engineering	**Eleanor Baum** *President-Elect, ASEE & Dean of Engineering, Cooper Union (NY)* **Winfred Phillips** *President-Elect, ABET & Dean of Engineering, University of Florida*
Computer Sciences & Engineering	**Peter J. Denning** *Associate Dean for Computing, George Mason University (VA)*
Technology	**Don K. Gentry** *Dean of Engineering Technology, Purdue University (IN)* **Durward R. Huffman** *President, Northern Maine Technical College*
Chemistry	**Ernest L. Eliel** *Professor, University of North Carolina at Chapel Hill* **Angelica M. Stacy** *Professor, University of California at Berkeley*
Physics	**Robert C. Hilborn** *President, American Association of Physics Teachers & Professor, Amherst College (MA)* **Eric Mazur** *Professor, Harvard University (MA)*
Geological Sciences	**Tanya Atwater** *Professor, University of California, Santa Barbara*

Undergraduate Education in Science, Mathematics, Engineering, and Technology

MRC Greenwood

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Introduction

As some of you will know, I had the great pleasure of serving in President Clinton’s Administration from 1993 until May of this year. One of the greatest pleasures I have experienced was working with the Director of the National Science Foundation, Dr. Neal Lane; the Director of the National Institutes of Health, Dr. Harold Varmus, co-Chairs of the President's National Science and Technology Council committee on Fundamental Science, and the other distinguished members of the committee. This committee played a lead role in the extensive bipartisan consultation with many interested scientists and other individuals who are concerned about our nation's readiness to face the challenges of the fast paced, technologically dependent global workplace of the 21st century.

To help all Americans understand what was at stake and to articulate to the American public the importance of investing in science, technology, and education, President Clinton and Vice President Gore released, in August 1994, a statement entitled *Science in the National Interest. Science in the National Interest* provides an important articulation to the American people why it is that the government must continue to invest in scientific discovery, scientific leaders, science education, and the development of a scientifically literate public.

Many statements from a variety of organizations and from previous administrations have stressed the importance to the Nation of investing in research. Other statements have stressed the importance of education to our future but few, if any have clearly connected the importance of science education, science literacy, research, and our economic security.

If you read *Science in the National Interest*, you will note that this is not an esoteric document. Rather, it is about people, investing in people, and investing in their ideas and in their education in order to create our collective future.

Science in the National Interest articulates five goals. The first three:

- Maintain leadership across the frontiers of scientific knowledge.
- Enhance connections between fundamental research and national goals.
- Stimulate partnerships that promote investments in fundamental science and engineering.

are primarily directed to creating the knowledge base and the new tools that will shape the 21st century economy. The last two:

- Produce the finest scientists and engineers for the 21st century.
- Raise the scientific and technological literacy of all Americans.

are the main reasons we are here today. In fact, the last two goals, although the more challenging, are by far the most critical in the long run.

Our failure to accomplish these two goals will undermine our ability to accomplish the first three and they will ultimately undermine the wealth creation of this nation and its tax base. I firmly believe it will undermine the quality of life we have come to expect.

Today, as a research scientist, a dean, and a recent policymaker, I would like to argue that scientists must become increasingly involved in the national educational initiative that must commence and be sustained to ensure a quality future for ourselves, our children, and generations to come.

We must build partnerships that allow us to build on our successes, to understand our failures, and to identify new ways of doing business across sectors with new optimism. The National Science Foundation has been a leader in innovative programs to encourage high quality undergraduate teaching and to improve teacher training to affect improved quality in undergraduate teaching.

Nonetheless, let me take a few moments to review some sobering statistics, observations, and "factoids."

For example, I read [the following factoids] in the *Sacramento Bee*:

- In 1950, 60 percent of all jobs in the U.S. were unskilled
- In 1990, 35 percent of all jobs in theU.S. were unskilled
- In 2000, 15 percent of all jobs are projected to be unskilled

By the end of the decade:

- 44 percent of U.S. workers will be in the business of collecting, analyzing, synthesizing, storing or retrieving data
- In a 1989 survey of U.S. CEOs, two-thirds of them responded that they had difficulty in hiring because of lack of basic skills.
- People age 18-23 with difficulty in academic skills are five times more likely to receive public assistance and have a poverty level income.

Let me take a few moments to review some other compelling points that all of us need to be concerned about. Much of this information can be found in the very useful National Science Board document *Science and Engineering Indicators for 1993*, the latest edition.

While the recently released critical technologies report notes that the U.S. is still the leader in most technologies, the margin by which we excel is increasingly smaller. Some of this shrinkage is due to the understanding of nations with whom we trade and compete that scientific education and literacy are important to their future.

For many decades, the U.S. and the European countries have dominated the scientific workforce but:

- In 1990, six Asian countries produced more than one-half million Natural Science and Engineering (NS&E) baccalaureates, slightly *more* than the U.S. and Europe.
- Although the U.S. has twice as many scientists and engineers in R&D, Japan and the U.S. have equal proportions in the workforce.

- However, Japan's ratio appears to be accelerating as the U.S. levels off.

Another way to look at this is to note the following:

- Although the U.S. and Canada outstrip most nations in overall baccalaureate degree production, the percent of degrees that go to individuals with S&E majors is proportionately less than in Japan.
- More interestingly for the future, even in countries with limited overall participation in advanced education (such as Mexico and China) those who do get degrees in NS&E are a much higher proportion of the total baccalaureate production (e.g., 25 percent in Mexico and almost 50 percent in China).

Thus, one can conclude that, although our overall access to higher education is comparatively good, our proportional share of those skilled in S&E is dropping just when we project an increasingly competitive international market and a need for more science background.

Since economists who frequently disagree on many issues nearly unanimously agree that a nation's economy is a derivative of its workforce and its investment in science and R&D, this is an ominous trend that cannot wait for a more fortunate fiscal moment to fix. Indeed, one could argue that the present deficit that everyone is rushing to cut is only a symptom of a much more serious educational deficit that no amount of cutting can fix for the long term.

So, in short, scientists and science agencies, both public and private, need to become involved and become partners in solutions. The reasons in the final analysis are simple:

- The economy depends upon it;
- Science education and literacy is the business of scientists;
- It's the right thing to do; and finally
- There is the self-interested reason. If there is no national interest in science and no public competence and literacy in science, there will be no support for science in the national interest.

What can be done?

Form partnerships with other segments of higher education. The science and engineering (S&E) workforce, the knowledge creators of the future and those who can utilize this knowledge, is embedded in a complex system. Our higher education system has as its greatest strength its depth and its multiple routes of access for our citizens. Its greatest weakness is its formation of sectoral factions.

Our nation has a system in which:

- fourteen million students are enrolled in 3600 institutions;
- those fourteen million students earn 1.9 million degrees per year; and
- of those 1.9 million degrees, 500,000 are in S&E areas.

This is the system that produces our teachers, our researchers, our policymakers and our legislators. The components of the system have to learn to work together to maximize their collective strengths and to focus their selective strengths.

I currently work for and represent what is called a land grant Research I university, although I spent nearly a decade at a selective liberal arts college. I can tell you from personal experience that few faculty or administrators in either sector know much about the other. And both need to learn to work better with our colleagues in the comprehensive universities and the community colleges where many of the teachers of the future get their pre-service training.

As we discuss the need to work directly and creatively with teachers and students, we need also to work within the system that we share the greatest responsibility for and for which we should rightfully assume the responsibility.

Some scientists may well claim that they are not trained to work with pre-college teachers or students, but they cannot claim that they do not have the skills or the responsibility for the quality of the undergraduate general and more specialized, [science education] in their own institutions. In fact, in most of our institutions, the power of the faculty over the curriculum is virtually absolute, as many an administrator has learned. It's time for academics to take their academic senate responsibilities ever more seriously. The views of scientists will not be respected if they cannot improve the level of science and math competency where they have the most influence, in their own institutions.

Over the past five to seven years much has already been done, although I fear that this is not widely appreciated or understood. There are four areas of SME&T undergraduate education that I think are important to comment on today.

Improving the undergraduate teaching of students who will continue in careers associated with science or technical competence

There are two main concerns here: (1) modernizing and energizing the curriculum itself and introducing the use of ever more sophisticated information technology; and (2) drawing students of previously underrepresented groups into SME&T. Perhaps the most exciting opportunities combine the two. For example, at UC Davis we have a biology undergraduate scholars program that identifies talented students from nontraditional backgrounds and mentors them in the early and frequently career choice definitive courses in biology, chemistry, and math. Lately these students have been outscoring the rest of the class (e.g., 80 percent earned A's or B's in the Chemistry 2A class where the average grade is 2.3). In addition, 63 percent of them have participated in faculty research projects and many have gone on to graduate or professional school. The methodology used to encourage these minority students has now been more extensively used to improve the overall teaching of undergraduate biology majors.

Improve the science and technology literacy of all undergraduate students

In the information age we have already, no college educated person can expect to be fully equipped for a job or career without at least a working knowledge of modern scientific theory and a modicum of technical competence and know how. This will require our colleges and universities to revisit the general curriculum and revise the requirements to ensure that their students are prepared. This will not happen without the enlightened leadership of scientists and other academics. It will not work if all the scientific community is willing to offer is the usual array of introductory courses intended to introduce the student to the major. True literacy of all students will require science departments to become much more creative; to work collegially with other science departments and resource centers. Scientists must offer courses that the non-scientist likes and which are conceptually oriented, not just fact oriented. The "sage on the stage" will have to be replaced by the talented storyteller and the multimedia expert who has not only mastery of the material but mastery of the method of conveying the exciting and dynamic world of science.

Change the training of graduate students

Changing the way graduate students are trained to teach can make one of the most important impacts on the future of undergraduate teaching. We have experimented with a program at UC Davis entitled the "Certificate in College Teaching." This program, in existence now for over five years, is oversubscribed. In this program, graduate students have both a UC Davis mentor and a mentor from a four-year or two-year institution. The student participates in an extensive professional seminar on teaching methods, has his or her own teaching extensively taped and analyzed and develops multimedia curricular materials that are also expensively critiqued. At the end of the intensive one-year program, a certificate is awarded. Numerous students who have completed this program have used the formal portfolio that they have developed when applying for jobs and claim that it was a significant factor in their subsequent hire. Sadly, we can only offer this program for a limited number of students; but approaches like this have the potential to reshape graduate students' attitudes toward a more serious orientation to new teaching methodologies for the future.

Finally, be concerned about training teachers

No matter how talented a teacher may be, nothing substitutes for mastery of the material, love of the discipline, and curiosity (which leads to life long learning). More concern about the undergraduate background of those who will teach in K-8 is certainly warranted. NSF has several programs in the area of in-service training that are especially well and continuing attention is warranted.

Another suggestion is to work to develop communication majors that specialize in training science and technology communicators. Much of the public gains the fragmented knowledge it has on SME&T issues from television and print media. Very few communication programs around the country are serious about identifying well-trained science undergraduates and preparing them to be successful communications experts. It is clear that we need news professionals trained to understand science and science educators and scientists with a sophisticated understanding of the media.

In short, first-rate SME&T education for those who will become scientists and for those who will primarily use the fruits of SME&T is critical for the nation. I applaud your efforts to review the important work sponsored by NSF in this area and I urge you to continue to devote effort to improving the nation's SME&T training and opportunities. Thank you for inviting my comments.

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Disciplinary Perspectives of National Leaders and Undergraduate Education

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Introduction

Since 1988, AAAS has conducted two studies, one implementation project, and one planning project related to undergraduate education in science, mathematics, engineering, and technology (SME&T). These include:

(a) The *AAAS Project on Liberal Education and the Sciences* (1988-1990), funded by Carnegie Corporation of New York: a study of the role of the natural sciences in the liberal arts curriculum for all undergraduate students.

(b) *Investing in Human Potential* (IHP): *Science and Engineering at the Crossroads* (1989-1991), funded by NSF: a study of efforts by U.S. higher education institutions to increase the participation of women, non-Asian minorities, and people with physical disabilities in SME&T.

(c) *Access to Engineering: Recruitment and Retention of Students and Faculty with Disabilities in Schools of Engineering* (Five year project ending in January 1996), funded by NSF: effort to expand the concept of diversity within engineering education by promoting full inclusion of individuals with disabilities.

(d) The *Science Dean's Colloquium* (September 1994) funded by NSF: colloquium of 52 Deans of Science and other university administrators from the nation's major research universities.

Each of these projects included substantial input from collaborating individuals and organizations. The AAAS Project on Liberal Education and the Sciences was guided by members of AAAS Coalition for Education in the Science, a consortium of scientific and educational associations, a six-member advisory board, and 15 member study group. The IHP study included survey responses from 276 presidents/chancellors of colleges and universities, directors of nearly 400 recruitment/retention programs, and nearly 100 disabled student services offices, as well as intensive case studies of 13 colleges and universities. The Access to Engineering Project included intense work with five schools of engineering, a meeting of 60 deans and other administrators from schools of engineering, a survey of schools of engineering that included demographics on disabled students and faculty, and guidance by a 16-member advisory panel, including a number of engineers with disabilities.

In general, the four AAAS studies and projects have identified:

- model SME&T undergraduate programs and courses;
- what SME&T undergraduate students need to know in the sciences; and
- academic and administrative challenges to bring about change in undergraduate SME&T education.

Overall Finding From AAAS SME&T Undergraduate Studies and Projects

Perhaps the three most significant improvements in undergraduate SME&T education:

- *Efforts to Reform Calculus.* These efforts have included structural changes in calculus that have been spearheaded by the mathematics community (MSEB, MAA, and NCTM). These programs create a community for SME&T freshman and sophomore students and provide supplemental workshops to regular classroom work.
- *Expansion of undergraduate research programs.* Although undergraduate research programs have not been fully studied, it does appear that these programs motivate undergraduate students to stay in SME&T majors. These programs exist in the form of cooperative education programs: NSF Center for Research, National Institutes of Health Summer Program, Minority Access to Research Careers (MARC), Minority Biomedical Research Science (MBRS) Program, and other such efforts. NASA and the Department of Defense fund small summer programs for undergraduates with disabilities.
- *The notion of SME&T consortia and collaboratives.* In general, consortia and collaboration of college, and universities and/or national laboratories and corporations have been effective in strengthening undergraduate SME&T education. Activities include developing dual-degree and cross registration programs; centralizing science and engineering resources into centers; faculty developing; reforming undergraduate curriculum; and creating research opportunities at non-doctorate granting colleges and universities.

Perhaps the three most important challenges to SME&T undergraduate education are:

- moving from isolated model programs to structural reform in undergraduate education;
- orienting faculty, particularly faculty in lower division SME&T classes, to innovative instructional and assessment strategies; and
- creating a forum for science deans to exchange information and monitor changes.

Both the *AAAS Investing in Human Potential (IHP): Science and Engineering at the Crossroads* and *The Liberal Arts of Science: Agenda for Action* identified a host of model undergraduate education programs. Pages 143-145 of the IHP Report presents a model for evolution of intervention programs for minorities, females, and disabled students at colleges and universities. This model includes five levels of programs.

1. *Isolated projects* were numerous, and involved the commitment of individuals to address particular barriers to participation. These projects were often not connected to any other efforts and relied on soft money or volunteer activity for their continuation.

2. In other instances, *individual schools or departments* undertook activities to address their own particular problems, such as high failure rates in calculus. These activities had little or no connection to other efforts in the institution, and addressed only a small part of the overall system of problems which minorities, women, and students with disabilities face.

3. At the next level were *formalized, coordinated program activities* in one part of the institution, such as a college of engineering, where recruitment and retention of female and minority students were coordinated through the office of the dean. Funding for these programs included external grants but relied increasingly on hard dollars from the institution. Most frequently missing from these programs were ties necessary to modify required introductory courses in the sciences and mathematics. There was often

reliance on programs to equip the students to survive instead of also taking on the issue of the quality and cultivation aspects of courses.

4. In a few instances, institutions created *centers* for the coordination of large parts of the process of recruiting, retaining, tracking, and advancing students to graduate education. *One of the most notable examples of this is the Comprehensive Regional Center for Minorities in Puerto Rico.* In this case, the center formed an organizational overlay to the mission of the institution to educate particular groups of underrepresented students.

5. Not found among any of the institutions was a model of *structural reform* where the structure of courses, pedagogical techniques, institutional climate, and systems for recruitment and retention co-existed with a supportive administrative structure. The regular support of departments and programs provides mechanisms to support the achievement of all students committed to education in science and engineering.

The *Liberal Art of Science: Agenda for Action* report also profiles SME&T programs and courses (pages 73-106). These profiles are grouped into four categories:

> *Programs involving the core curriculum.* These programs either constitute an institution's core science requirements for all students or are voluntary alternatives to the institutions core science requirements. Examples of programs include Introduction to the Natural Sciences at Lehman College; Learning Science Through Inquiry; Natural Science Division I Requirement at Hampshire College; and Science in Modern Life I and II at Brooklyn College.
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> *Program constituting a major.* Programs in this section represent some of the innovative, interdisciplinary, baccalaureate programs that are emerging in American colleges and universities. Examples of programs include The Curriculum in Science and Culture at Purdue University; the Liberal Arts and Science Program at Utah State University; and the Science in Society Program at Wesleyan University.
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> *Full-year courses and course sequences.* These are examples of initial courses designed to introduce students to science and the scientific enterprise. Examples of programs include Chemistry of Our World at Wright State University; Foundation of Science at Hunter College; and The Theory and Practice of Science at Columbia University.
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> *One-semester courses.* These examples represent innovative courses that effectively integrate science in a liberal arts context and/or teach science as it is practiced. Examples of courses include *Ways of Knowing* at Macalester College; *Role-Playing Laboratories in Analytical Chemistry* at St. Olaf College; and *Science and Technology in the Modern World,* Kean College of New Jersey.

Both the IHP study and the Liberal Art of Science Project offer guidance about how to move from isolated model programs and courses to structural reform in SME&T undergraduate education. Of particular note are pages xi and xix in *The Liberal Arts of Science: Agenda for Action* report. This section outlines what undergraduate students should take from their college education including understanding, knowledge, skills and attitudes concerning aspects of science. These include understanding:

- scientific values and ways of knowing;
- collection, organization, and classification of information;
- scientific laws, devising models and developing theories;

- the limits of scientific knowledge;
- the vocabulary and terminology of science; and
- the role of mathematical concepts in science.

In terms of integration concepts, undergraduate students need to understand:

- scale and proportion;
- change and evolution;
- causality and consequences; and
- dynamic equilibrium.

In terms of the context of science, undergraduate students need to understand:

- the historical development, intellectual, and cultural contexts of science; and
- the ethical, social, economic, and political dimensions of science.

These high goals for scientific understanding require new instructional strategies at the undergraduate level, including:

- goal-oriented instruction that brings meaning into day-to-day problems encountered by scientists;
- hands-on experimental and laboratory activities;
- activities promoting independent learning and analysis including finding, reading, and analyzing information from a variety of sources;
- group discussion and projects;
- opportunities for writing and communicating science;
- demonstrations of cross-disciplinary content including interconnections among the sciences themselves and connections to liberal arts, humanities, the fine practical arts, and the social sciences;
- integration of mathematics with the study of those scientific topics whose explanations are based on mathematical concepts; and
- assessment of students' abilities to analyze scientific problems, to generate reasonable hypotheses, to evaluate evidence, and to raise questions about science and technology in their own lives and the society in which they live.

Scientific understanding cannot be measured adequately by true-false, multiple-choice, or other similar tests. Papers, projects, essay tests, oral presentations, and other forms of assessment must also be used.

As indicated, one of the biggest challenges for restructuring SME&T undergraduate education will be encouraging, preparing, and orienting college and university faculty to utilize innovative teaching and assessment strategies. Unlike K-12 teachers, college and university faculties are not required to take teaching courses.

Pages 3 to 6 of *The Liberal Arts of Science: Action Agenda* also address academic and administrative changes needed at the undergraduate level to implement this new SME&T initiative, including:

- increasing the time commitment for science to the equivalent of 15 to 16 semester hours of instruction for all students and decreasing class sizes to one faculty for every 20 to 30 students;
- re-conceptualizing the current structure of the curriculum and doing away with survey courses. Rather, it is critical that education in the sciences become a well-integrated part of the broader liberal education program;
- fostering collaboration of science with other liberal art faculties;
- identifying a mechanism to review current curricula, design programs, encouraging the developing of courses, and providing on-going monitoring and assessment;
- recognizing the need for institutional curricular reform including financial support, promotion and tenure, reduced teaching loads, and awards and prizes; and
- external support from scientific, professional, and educational societies, accrediting agencies, state and federal government, and private and corporate foundations.

As colleges and universities move to restructure SME&T at the undergraduate level, a leadership forum will be needed to exchange information, define benchmarks and collect data. However, as made clear by the AAAS Science Dean's Colloquium, unlike engineering deans, science deans lack a common forum to discuss concerns about SME&T undergraduate education. As part of the AAAS Colloquium, science deans outlined topics they would like to address. Topics include:

Administrative Concerns

- NSF funding procedures;
- Improving the image of the research university;
- Responding to budget cuts and reorganization;
- Difficulties in dealing with the K-12 system, as well as state and federal education agencies;
- Dialogue between research universities and "official" Washington;
- Strategies for dealing with declining federal funding; and
- Need for development activities in a new fiscal climate.

Curriculum and Teaching Issues

- Launching interdisciplinary degree programs, such as the science-oriented MBA and environmental studies, and science and public policy options;
- Offering degrees in the sciences that are intended to lead to professional careers in journalism, business, etc.;
- Organizational structure of undergraduate biology education;
- Encouraging better teaching;
- Curricular revisions as a mechanism for fostering interdisciplinary research and reaching less traditional science students;
- Exchange of benchmark data; and
- Tensions between major and non-major courses.

Faculty Development

- Mentoring of female and probationary faculty and graduate students;
- Improving faculty diversity;
- Discussion of the faculty reward structure, including tenure, promotion, and post-tenure review;
- Faculty resistance to programs for female and minority students;
- Evaluation and rewards of faculty for undergraduate teaching; and
- Improving faculty teaching.

4. Outreach Efforts

- University relationships with secondary/elementary school teachers and students; and
- Relationship between college of science and college of education.

5. Student Issues

- Efforts to stem student attrition; special sections for high-risk students; remedial instruction;
- Programs to promote undergraduate student research; and
- Changing employment opportunities for students.

In addition, the deans are interested in how interdisciplinary centers (science, mathematics, and technology) are formed and operate. Specifically, they were interested in a center's role with regard to K-12 outreach, as well as the sharing of personnel and programs between the center and academic department, the types of faculty and staff appointments at such a center, and evaluations of faculty outside departmental and disciplinary frameworks.

All of the AAAS studies and reports outline concerns about the changing demographics, particularly concerns about increasing the participation of minorities, women and persons with disabilities in SME&T. Minorities and females have made some gains in science, but we need to build more efforts to involve disabled persons in science. In the IHP study and the *Access to Engineering* effort, AAAS staff found that unlike efforts for minority and female students in SME&T, most colleges and universities do not have targeted efforts for disabled students. For these students, the disabled student services (DSS) is the primary source of help. However, disabled students who major in SME&T often find that the DSS has not encountered their specific need before, especially in laboratory courses or when specific technologies or services are required. In addition, most SME&T faculty and administrators are uninformed about the assistive technology that students and engineers with disabilities use today. The IHP report, Chapter 4 on "Science and Engineering Students with Physical Disabilities: Who Smoothes the Path?" includes making SME&T accessible to students with disabilities.

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Comments on Undergraduate Education Review of the NSF Directorate of Education and Human Resources

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I would like to organize my remarks along the lines of the input on the [EHR Advisory Committee] review solicited by Dr. Robert Watson from academic and business leaders last summer. My suggestions draw, in part, on the thoughtful comments of fifteen such letters written by mathematical scientists.

> **What are the most significant improvements in undergraduate SME&T education you have observed in our nation during the past ten years?**

Leaders of the mathematical sciences community are in general agreement about the three major improvements in undergraduate SME&T education in the past ten years. They are:

- increased use of technology;
- increased attention to teaching and learning; and
- the calculus reform movement.

Some have also specifically cited efforts related to the latter two items, such as the involvement of professional societies in instructional reform and the creation of good materials to support innovative instruction.

Increased Use of Technology

Technology has had two types of impact:

1) In the way that mechanical devices have augmented the physical capabilities of humans, computing devices have augmented the mental capabilities of humans. In the learning process, technology provides enhanced computational and visual experiences as well as numerical assistance for students, giving students more insight into physical and mathematical processes. Students can study more realistic problems, which previously were intractable with pencil-and-paper approaches. With simulation and computer graphics software, students can explore and discover mathematical phenomena, thus making mathematics more like a hands-on, experimental science. This technology promotes active learning and facilitates undergraduate research in mathematics.

   The advent of modestly priced graphing calculators and widely affordable personal computers has made these technological possibilities a working reality for millions of undergraduates. Faculty interest in utilizing technology is exploding. Attendance at an annual conference on educational technology in mathematics has grown in six years from a few hundred to two thousand.

   NSF Instrumentation and Laboratory Improvement (ILI) program has made a substantial contribution to the availability of technology in mathematics departments. The highly leveraged format of the ILI program, which requires technology-based curricular development (plus extensive cost-sharing), has prodded faculty to think creatively about how to use new technology effectively. NSF Faculty Development grants have supported scores of workshops to train mathematical science faculty in the use of educational technology.

2) The use of technology in learning and educational reform generally, has been revolutionized by electronic communication that effortlessly connects pairs of educators and students. The Internet's Worldwide Web opens up unlimited amounts of information to scholars and students, irrespective of the capacities of one's local library or computer center. The isolation in which individual educational reformers used to work has been eliminated. Students can access critical databases to undertake truly realistic class projects. NSF has played an important role in supporting NSFnet and local access efforts as well as educational software projects.

Increased Attention to Teaching and Learning

The increasing realization that *how* mathematics is taught is as important as *what* mathematics is taught is a signal development in undergraduate mathematics instruction. Its consequences will be reshaping instructional practices in the mathematical sciences for years to come. NSF curriculum grants and ILI grants were absolutely critical in stimulating a rethinking of instruction that started with questions about 'what' but inexorably led to questions about 'how.'

This realization has led to growing interest in research about effective instruction and student learning. The wide interest in cooperative learning, student-centered discovery learning, projects and writing in mathematics courses was unimaginable a decade ago. Eight years ago at the annual joint American Mathematical Society/Mathematical Association of America meeting, the only contributed paper sessions were on research topics. Now, contributed paper sessions have hundreds of papers on pedagogy and on curricular reform. Faculty interest in pedagogy has had anticipated impacts on improved classroom instruction. It has also had unanticipated impacts such as a growth of undergraduate research opportunities in which faculty are now more likely to treat students like colleagues.

A few months ago, there was a major article in the Notices of the American Mathematical Society on the effective instructional practices developed at the mathematics department at the State University of New York College at Potsdam (in some years, over 15 percent of Potsdam's graduates have been mathematics majors). For this research-centered society to have an article extolling mathematics instruction at a state college represents a major change of professional culture.

My favorite quote about pedagogy is a question posed to me 6 years ago-- before I understood fully the power of the 'how'-- by the chair of the Potsdam mathematics department. He asked, “Why have Math Association committees spent so much time writing reports about curriculum for the mathematics major? What does using just the right curriculum have to do with training mathematicians?"

The Calculus Reform Initiative

Introductory undergraduate mathematics curriculum and instruction had a poor reputation a decade ago. Today, collegiate mathematics is viewed as a leader in SME&T undergraduate instructional reform. The calculus reform effort is a principal reason for this change. Hundreds of thousands of students are now being taught in calculus reform classes where students are more active learners and faculties are more active teachers. The best selling calculus text last year (over 80,000 copies sold) was a reform text. Calculus courses now focus on numerical, visual and applied interpretations of calculus as well as algebraic techniques. Students make extensive use of technology, engage in cooperative learning, write about their mathematical thinking and learn to attack open-ended, less structured problems.

Calculus reform has proved to be a stimulating case study in technological and pedagogical innovation. Use of technology has had a symbiotic two-way relationship with calculus reform. Graphing calculators and computer software like DERIVE called into question the traditional drill in graphing functions and symbolic differentiation and integration. At the same time they permitted realistic problems involving integrals which could only be evaluated numerically and permitted visual and numerical exploration of the behavior of whole families of functions. Pedagogical innovation became a natural solution for faculties who were trying to break students free of deeply ingrained habits of mindless 'plug and chug' exercises. To make students think carefully about model building and the analysis of calculus-based models, instructors turned to cooperative learning, open-ended projects, and writing assignments. Interest in instructional innovation sparked by calculus reform is stimulating faculty to rethink how they teach differential equations, linear algebra, and other mathematical sciences courses.

The accompanying map shows the broad distribution of NSF calculus reform awards by state. Subcontracts associated with major awards, along with the scores of calculus reform workshops, have extended the impact even further. The true success of the calculus reform movement is found in the 1000+ institutions that have implemented calculus reform without a grant.

As an aside, I would like to give a special salute to program officers at NSF who displayed laudable cooperation and enterprise to steer additional funds to the calculus reform initiative as they started to recognize the magnitude of the impact that was possible. The $18,000,000 finally spent on awards in the Calculus Reform Initiative from 1988 to 1993 was several times what was directly allocated. The primary support for NSF calculus reform initiative was through the Course and Curriculum Development Program in the Division of Undergraduate Education in cooperation with the Division of Mathematical Sciences. DUE Programs in Faculty Enhancement, in Instrumentation and Laboratory Improvement, and in Teacher Preparation, as well as programs in the Division of Research, Evaluation and Communication (REC) and the Division of Elementary, Secondary, and Informal Education (ESIE), contributed additional funds.

What are the three most important problems you and collaborating individuals and organizations encounter in your efforts to assure that the best possible education is delivered to undergraduates in the areas of SME&T?

While there was near unanimity about the improvements in the past decade, leaders in the mathematical sciences community showed great diversity of opinion when it came to future problems. The following three topics were each cited by about half the respondents:

- changing faculty values and attitudes;
- serving a more diverse, and often under-prepared, student body; and
- equipment needs

Other problems cited by several respondents were

- inadequate coordination across disciplines; and
- responding to Standards-based changes in K-12 instruction

Other challenges mentioned were: the lack of diversity in SME&T faculty and graduate students; faculty development programs; challenges of instruction delivered by a growing number of part-time faculty; and more research about effective methods of student assessment. In the following discussion, I will focus on possible contributions by NSF, but these contributions are assumed to be occurring in cooperation with professional societies and individual institutions. A key to the success of the calculus reform movement was the close working relations that existed from the outset between NSF Principal Investigators and professional societies.

Changing Faculty Values and Attitudes

University faculty still gets promotion and tenure for research. Given the existing priorities, too few university faculties have an incentive to make a substantial investment in instructional activities. The increased interest in teaching and pedagogy among some university mathematical sciences faculty is supported by a number of department chairs. However, it has limited support from most senior faculty (who populates the tenure committees).

There was a case around 1940 of a talented mathematician being denied tenure by a leading Ivy League institution, because despite outstanding research the person was also a good teacher. Some senior faculty argued that his interest in good teaching was a ‘demon seed’, which in the future would consume the man and destroy his research. Remnants of that thinking are still alive today at some institutions, both colleges and universities.

Along with a greater general interest in teaching, faculties need to ensure that their instruction is geared towards the educational needs of all their students and society, rather than just the needs of advanced training in their discipline.

I believe that the university mathematical sciences community is moving slowly to take a more positive view of teaching. Mathematics departments owe their large size primarily to heavy freshmen service teaching. A number of leading research mathematicians have become aware of the importance of good teaching in 'paying the bills' for mathematics. NSF programs have helped to start a change of culture and can continue to do so. The systemic reform theme in the new *Mathematical Sciences Throughout the Curriculum* initiative attacks this problem head-on. There are a variety of efforts that NSF might undertake to enhance the stature of instructional excellence: increasing funding across-the-board in DUE; awarding less-structured individual investigator grants in instruction similar to NSF research grants; and placing a greater weight on instructional activities in NSF 'research' grants.

Serving a More Diverse, and Often Under-Prepared, Student Body

Because of the long, sequential nature of learning in mathematics, it is easy for students to accumulate a growing deficit of mathematical skills needed for undertaking college-level mathematics. Unfortunately, the increasing number of students with inadequate preparation for college mathematics is occurring at the same time that an increasing number of college disciplines are using more mathematics. Thus, to get students from where they are to where they need to be for the mathematical requirements of their majors and the workplace is posing a problem. The diversity of student backgrounds requires creative instructional strategies that empower all students to help themselves grow mathematically, for it is not feasible to have instruction that is individualized to each student. Additional research about how different types of students learn mathematics is also needed.

This is a challenge that, I believe, needs to be shared between mathematical science departments and client disciplines. Growing NSF support for advanced technology education programs illustrates the positive force that NSF can play in fostering the development of new curriculum and instructional styles geared towards workplace needs. I would like to see NSF support for pre-calculus reform expanded. A new program targeted at developmental mathematics is needed. While this instruction is remedial in its mathematics content, it is also some of the most challenging teaching in post-secondary education.

Equipment Needs

Mathematics departments have now joined science departments as laboratory disciplines. In mathematics, it is computer laboratories. The costs of purchasing more computers as more mathematics courses use computers, and the costs of replacing outdated PCs, are slowing efforts at instructional reform in mathematics to a crawl at many institutions. NSF ILI grants have helped hundreds of institutions introduce and upgrade their computer facilities. Hopefully, the ILI, program can be continued and expanded.

Inadequate Coordination Across Disciplines

Faculty today tend to be much more closely linked with other researchers in their specialties at other institutions than with local faculty in their own and other departments. Undergraduate education is a collective undertaking of the faculty and requires much greater educational day-to-day exchange among faculty. Educational innovation, like cooperative learning, cannot flower unless new instructional strategies are shared and coordinated among departments.

Instruction today is too narrowly focused on the subject of an individual course or the point of view of a particular discipline. The scientific and business workplace today is characterized by multidisciplinary thinking that draws on the paradigms and problem-solving strategies of many different disciplines. Many business groups, such as the risk assessment divisions of major banks, value physicists, mathematicians and engineers for their common training in quantitative problem-solving. It is as if faculty in these different disciplines see themselves as specialists in Bach or Tchaikovsky or jazz, while the world wants broadly trained musicians. Faculty in quantitative disciplines must collaborate more fully to give students this broader, multidisciplinary point of view in their training.

The new NSF interdisciplinary consortia in chemistry and mathematics, joining related efforts underway in engineering, are of critical importance and should be expanded. It would be helpful if funds were made available to support many smaller interdisciplinary efforts involving faculty in a group of departments at one college.

Responding to Standards-based Changes in K-12 Instruction

The post-secondary mathematics community has been largely supportive of the mathematics Standards developed by the National Council of Teachers of Mathematics. The visions of content, instruction and assessment contained in the NCTM Standards and the current efforts at enhancing undergraduate mathematical sciences education have a great deal in common. Each initiative's primary goal is to enhance student learning in mathematics and to make mathematics truly accessible to everyone. Since studies show that teachers tend to teach the way they were taught, instructional reform in collegiate mathematics has an important second order effect on instructional reform in the schools.

However, there are a number of further actions needed to support the NCTM Standards. Colleges and universities need to rethink their entrance standards and placement exams in mathematics, their pre-calculus instruction, and their quantitative literacy requirements in light of Standards-based changes in K- 12 instruction.

Unfortunately, to date the pre-service mathematics training of teachers has changed little to reflect the values of the Standards. The instruction needs rethinking in both mathematics courses aimed specifically at pre-service teachers and core mathematics courses which, at some institutions, have large numbers of prospective secondary school mathematics teachers. For some mathematical sciences faculty, this rethinking may entail additional professional development in new educational technology or pedagogy; for others, it might mean working cooperatively with faculty in mathematics education. Better preparation of doctoral students for college teaching is a related concern, which can be addressed hand-in-hand with better preparation of K-12 teachers.

NSF can help with support for Standards-based reworking of introductory mathematics instruction and of the mathematical preparation of K-12 teachers.

The diversity of opinion on future problems and the complexity of these problems - institutional commitments, engaging all faculty, reaching and properly serving all students, coordination across the disciplines, and more – suggests the breadth and depth of the educational reform needed in undergraduate SME&T instruction. These are daunting challenges, but they also represent exciting opportunities.

I would like to take editorial license to close this presentation with a nagging personal concern, which, I fear, will overshadow many educational reform efforts in this country.

Ambivalence and Complacency About the Value of Education

In many nations, young people receive a strong, clear message from their parents, and from society generally, to develop their minds as preparation for success in later life. I find little of this message in this country. In Asian countries, parents are constantly complaining about the poor job their schools are doing, while surveys of American parents show satisfaction with the performance of their schools. Many in our society still believe deep down that the frontier spirit of enterprise, rather than education, is the key to success in life. American teenagers in our materialistic society, with limited parental guidance to concentrate on studies, are spending too much time on part-time jobs to make car payments (immediate gratification) rather than on doing homework (a long-term investment).

However, a workforce strong in SME&T skills is critical to maintaining our national and personal economic well-being. NSF needs to work with SME&T professional organizations and friends in business to publicize better that entrepreneurial spirit is not a substitute today for investing deeply in one's own education and for obtaining a solid scientific and mathematical literacy.

Almost everything NSF does indirectly impacts this issue. NSF needs increased efforts to upgrade the mathematics and science expertise of schoolteachers at all levels. The typical college graduate spends only about 10 percent of his/her college time in non-remedial SME&T course work. I would like to see NSF work with SME&T faculty to develop strategies to expand the SME&T experiences of all college students.

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Testimony Before NSF Undergraduate Review Subcommittee "Disciplinary Perspectives of National Leaders in Undergraduate Education"

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Thank you, Mr. Chairman, for this opportunity to address the subcommittee on the important issue of undergraduate education in engineering, science and mathematics. This is an enormously important topic in today's competitive, high-technology world. My remarks will focus on engineering education. I am speaking today on behalf of myself, as President of the American Society for Engineering Education (ASEE) and past chair of the ASEE Engineering Deans Council (EDC), and my colleague, Winfred Phillips, President of the Accreditation Board for Engineering and Technology (ABET).

Engineers play a vital role in the technological and economic life of society. They develop new manufacturing processes and products; create and manage communications and transportation systems; address environmental problems, devise pioneering health care devices and, in general, make technology work. In the words of Richard Morrow, past chairman of the National Academy of Engineering, "the nation with the best engineering talent is in possession of the core ingredient of comparative economic and industrial advantage."

Engineering education in the United States has served the nation well; providing a breadth of programs across more than 500 institutions. But there is wide recognition that engineering education must respond to new challenges. Along with technical skills and intellectual development, engineering graduates must learn how to work as part of teams, communicate well, and understand the economic, social, environmental and international context of their professional activities. In addition, engineering education programs must find ways of attracting a broader mix of students that better reflect the social and ethnic diversity of the country. Taken together, that’s a tall order.

We in the engineering education community are addressing these issues with assistance from a variety of sources, including our industry partners, academic colleagues, and at the federal level particularly, the National Science Foundation. The vision and support that NSF provides for improving engineering are key to the experimentation and knowledge-building that are necessary for real change. Equally important, as a premier funding agency of academic research, NSF’s support of research in educational topics and methodology provides legitimacy and prestige for this type of faculty activity.

Last year, with NSF support, ASEE published a major report, *Engineering Education for a Changing World*, which laid out general principles for addressing these issues. More than 60 schools are using the report in their strategic planning processes.

We suggested in the report that engineering education programs needed to be three things:

- Relevant to the lives and future careers of students;
- Attractive to students with a wide variety of backgrounds and career interests; and
- Connected through partnerships and integrated activities with the wider community.

This community would include not only other colleges in the university, but K-12 schools, community colleges, industry and government.

Rather than suggesting that all engineering schools change in the same way, we called for each school to establish its own mission, based on whom it served and its comparative advantages. Some schools might focus on educating students for professional engineering practice through the master's level; others might offer a combination of traditional technology-based engineering with a strong emphasis on broader management and decision-making skills; while others would focus on preparing students for research and teaching careers.

This type of significant experimentation in the undergraduate curriculum would be fostered through proposed changes in the criteria for engineering programs of the Accreditation Board for Engineering and Technology (ABET). The proposed changes, which are now being reviewed by the engineering professional societies that comprise the organization, would provide greater flexibility. In concert with ASEE, industry and the EDC, ABET has proposed that each engineering school adopt a mission statement. Further, it should develop goals consistent with the mission and implement outcomes assessment.

Several state governments, along with parents and students themselves, are demanding methods for assessing the quality of engineering education programs. Given the diversity of engineering programs throughout the nation, however, we believe that no one test or prescriptive set of criteria would be inappropriate for all engineering colleges. ASEE is serving as the secretariat for a group of engineering professional societies that are seeking to identify successful assessment strategies and principles. The aim is to develop a broadly supported array of assessment tools that engineering colleges could use, based on their own needs and programs. The Joint Task Force 011 Engineering Education Assessment, consisting of ASEE, the Engineering Deans Council, the National Society of Professional Engineers, ABET and the National Council of Examiners for Engineering and Surveying, expects to have an outline of recommendations by early next year.

A potential breakthrough for making technical subjects exciting and accessible to all students is the use of the Internet. Electronic courseware that uses interactive media and provides access to a world of information will make learning more interesting and enable students to better understand technical material. But how will faculty and students know what's best among the many offerings? ASEE is working to develop a system for peer reviewing multi-media courseware in engineering education over the Internet.

We would like to commend the National Science Foundation for its various programs that are promoting the type of experimentation and risk-taking that will lead to real improvements in engineering and other technical education. The largest and potentially most influential program in engineering education is the Engineering Education Coalitions, consortia of engineering colleges whose purpose is to promote comprehensive change. This program has promoted discussion about teaching, learning and curriculum among faculty on many campuses and has begun a process of sharing resources.

A vital element in any broad reform effort is the dissemination and discussion of research results. We encourage the Foundation to strengthen this aspect in its grant programs: encouraging grant recipients to demonstrate specific strategies for dissemination of their findings, as well as encouraging presentations on educational research at meetings of the various professional societies. For example, the Division of Undergraduate Education (DUE) this year sponsored a Project Showcase at the ASEE annual conference in which engineering grantees funded by the Division displayed and discussed the results of their projects. Nearly 2000 engineering faculty members attended the Showcase. This type of face-to-face interaction, in which faculty members can ask questions and develop contacts with the grantees, is a valuable complement to written articles and more formal presentations. We hope this kind of effort will continue.

We also commend the Foundation for its ongoing sponsorship of conferences and workshops in undergraduate education. These are a valuable way for groups of people to talk about undergraduate education in mathematics, science and engineering and to help chart new policy directions. We hope these efforts will also continue.

The engineering directorate of NSF has consistently and effectively promoted the integration of education and research. Its programs have stimulated an increased emphasis on undergraduate education and research in all programs. We encourage further integration between EHR and the engineering directorate to ensure a sound continuum in mathematics, science and engineering education: K-12 through Ph.D.

We would also like to single out efforts to promote university/industry partnerships, such as NSF's GOALI program. GOALI enables industry representatives to spend time on campus and faculty and students to spend time in industry. This effort to bridge the gap between academe and industry and form real partnerships is especially important in engineering. We urge the Foundation to expand activities that encourage these collaborations in research and education.

At a time of great technological change and a greater need for citizens with technological understanding, we hope that NSF will sustain and increase its programs for improving undergraduate education. This is an important investment in our future and we look forward to working with you in this endeavor.

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Undergraduate Education in Computer Science & Engineering

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By all accounts, undergraduate education in Computer Science and Engineering (CS&E) is flourishing. There are 154 Ph.D.-granting CS&E departments in the U.S., and several times that number granting BS degrees. Enrollments have been steady or increasing for the past several years as public interest in the discipline has increased with the explosion of the Internet, Worldwide Web, computational science, and information-based engineering. There is strong agreement on the basics, the core of the discipline, as registered in the 1989 ACM/IEEE report *Computing as a Discipline*, and incorporated into the guidelines of the Computer Science Accreditation Board (CSAB). The faculty share a growing concern for cooperation with industry, reflected in the growing use of senior design projects and the 1994 call of the CS department chairs for faculty to spend at least a year in industry as a condition of tenure. The faculty have responded well to the Hartmanis report, *Computing the Future* (NRC, 1994), which called for more attention to be paid to the undergraduate curriculum. For example, they are getting better and better at offering "introduction to computing," where they are developing a new view of computation based around interactions with machines rather than programming. In the lower divisions especially, they are beginning to employ undergraduate teaching assistants (UTAs) to provide supplemental instruction and help for peers, lessening failure rates and increasing retention without decreasing faculty involvement. They are including more team projects, many on topics of concern to students, more student presentations, and more written reports in their courses. After a slow start, they are now responding in numbers to cross-disciplinary work, especially in computational science, biotechnology, quantum computing, information retrieval in the humanities, and graphics for the arts. They are making good use of educational technologies such as Lotus Notes, interactive TV, CD-ROM, class web pages, Internet searching, computer-based lab projects, simulations, and workbenches in their classes. They are engaged in lively debates on how much to increase instruction in basic systems integration and how to reach students to design for human concerns, debates whose outcomes can only have positive effects on curricula.

Remaining Trouble Spots

I mark the 1988 publication of Charles Sykes's best-seller, *ProfScam*, as the beginning of the modern art of university bashing. A dozen or so additional books and innumerable editorials have since appeared on the same subject. The principal complaints lodged by these writers include: 1) faculty are more interested in research than in teaching; 2) graduates lack competence in their fields; 3) tuition and costs are rising faster than inflation without a corresponding increase in value; 4) faculty spent too little time in the classroom; and 5) faculty hide behind tenure and academic freedom rather than address problems. These writers have clearly struck a resonant chord: not only have their works been best-sellers, but the chord has hummed in state legislature across the land, producing sharp cuts in higher education in most states and in the federal budget for research, and producing new laws that attempt to bring faculty and their administrations to account for their reluctance to address well-known problems.

In my mind, these criticisms add up to customer dissatisfaction with universities on a massive scale. Many faculty do not like the notion that students, parents, and employers are their customers – and yet students, parents, and employers are genuine, money-paying, satisfaction-seeking customers whose discontent is being felt. The successes, improvements, and innovations I listed earlier demonstrate some real progress on the problems cited by the critics, and I daresay many critics would be pleased at the progress that has been made. At the same time, if we make an honest report card for ourselves, we can see that we have a long way to go before we will win back the full confidence and loyalty of our customers.

Research: University research is a big enterprise, seen by most faculty as integral to the mission of a university. Faculty still place more emphasis on research than on any other factors for promotion and tenure. Few undergraduate students come into contact with faculty research. The complaint that students learn more about advanced technologies from the Discovery Channel than from their professors has considerable merit. In my view, we can go a long way toward resolving this problem by finding ways to connect research to undergraduate curricula. Some of these ways will involve technologies that facilitate the "feedback path" from research to curriculum, while others will involve new faculty practices such as organizing technology shows or engaging undergraduate students in their own research projects.

Student Competence: In response to pointed criticisms by business people, we have made good progress with team projects, senior design projects, co-op programs, and more emphasis on good presentations and written reports. But there is much more we can do. Few of us can give a cogent answer to the questions: "At what must the educated engineers (computer scientists) of the 21^{st} century be competent? How will we know that they are?" Few CS&E undergraduate programs have made a clear statement of the promises they make to their students about the kinds of competence they will have on graduation. Fewer have agreements with business people that those are the competencies required for work and even fewer still have any means of demonstrating that students are competent. Until we address these questions – in co-operation with business people – we will forever be playing a game of catch-up, a game of responding to pointed criticisms, rather than a game of anticipating what is needed before it becomes a business necessity.

Tuition: As faculty, we do not pay much attention to reducing the costs of education – we see that as the job of administration. When we do think about it, we speak of using information technology to improve communication with students, to automate some parts of the process such as keeping records or grading, to provide learning environments that students find more engaging, and to reach more students through distance learning. We complain when undergraduate class size reaches 50 students, but seldom investigate the question of how to organize the teaching of 500 students effectively.

Classroom Time: Most faculty I know spent 15-20 hours a week on each class – 3 in the classroom, several more in preparation, several more in coaching students, and several more in grading and giving feedback. Virtually everyone is using e-mail to permit students to have access to them around the clock. Faculty accessibility is becoming less of a complaint. I don't think there is a problem on this issue, but the word may not be out.

Tenure: Criticisms of the "tenure system" stir deep resentments among the faculty. Instead of recognizing these criticisms as frustration on the part of critics about our lack of response to their real criticisms, we react with great defensiveness, which only fans the flames. We would do far better to respond directly to the criticisms about our effectiveness in research, conferring competence, and teaching. In any case, the growing wave of "post tenure review" processes being mandated by state legislatures is going to render tenure a fond memory.

As you can see, I rate the first three items on the last as the remaining trouble spots among the main issues raised by the critics of higher education.

New Trouble Spots

I would like to turn now to some areas in which we are not paying much attention, areas that will surely become trouble spots unless we do pay attention to them. These may offer even bigger challenges than the ones we are now dealing with. In discussing these aspects, I do not want anyone to think I am suggesting that "something is broken, throw it out and start over." I do suggest that we pay serious attention to these areas before they turn into real problems. There are two:

- The demise of the university
- Effective teaching in the age of the Internet

Demise of The University

Four assumptions lay behind our historical conception of a university: 1) the library; 2) a community of scholars (formed around library) drawing on each other's knowledge in different disciplines; 3) teachers working with small groups of students; and 4) offering a period of schooling; helping one to transform from adolescent to adult, and granting a credential for entering work.

Information technology is undermining these assumptions. Consider each in order: 1) Digital libraries will soon become a reality and will make the content and services of libraries available at every desktop. The unique role of a university library will disappear. 2) As the quantity of scientific records has increased, more scientists have become specialists of increasing depth in narrower fields. The university has fractionated into specialties in departments and sub-departments. The local community of scholars has been replaced with a professional community of specialists around the nation and the world, held together by telephone, fax, Internet, and conferences. The individual has become the representative of the specialist community on campus. Most educational technologies developed to date are tools to help the "solo individual" navigate in a complex world of specialties; few of these technologies promote the kinds of local community that used to characterize the university. 3) Mass education has largely done away with the small undergraduate class. A typical class costs close to $40K to produce and often requires 40 students just to break even. Commercial firms are beginning to make education offerings at prices lower than universities, and with stronger promises of certifiable competence (e.g., Novell network engineer). A few examples already exist of a master teacher leveraging himself effectively for thousands to tens of thousands of students, and more of this can be expected as entertainment moguls meld their skills with those of flamboyant professors. 4) Specialties change so rapidly that most people can expect to change careers every 5-10 years during their working lives. It is no longer true that four years of university prepares one for life. This is producing a massive growth of interest in professional education that universities are unable or willing to accommodate.

Our immediate response to these threats has been to invest more heavily in information technology at universities. This provides temporary help but does not change the underlying phenomenon, which is that information technology is rendering the university obsolete.

What roles can universities fulfill that people would find valuable? How do we begin to position ourselves for these new roles? I think these are important questions that few of us are examining. Every one of us must think deeply about these questions. I suspect that we are underestimating the speed at which the traditional university is approaching its disintegration. I see at least two new roles for the university:

Professional education: The university can extend its educational offers for the 45 years of professional life people will have, and not focus primarily on the four years immediately preceding professional life. It can offer smaller programs, say one year in length, leading to certificates of competence. People will market themselves by an evolving portfolio of certificates rather than as the holder of a BS, MS, or Ph.D. degree. These programs can reach into much higher levels of competence than now covered by any university program – e.g., experts, virtuosi, and masters.

Community building: The university can be a counter-force against the march of increasing specialization and fragmentation. It can regain its old capacity to foster community involvement, entrepreneurship, and solidarity.

These suggestions are painfully brief; in my limited space here, I intend only to point a direction for future, in-depth investigations.

Effective Teaching in the Age of the Internet

In the last few years, effective teaching has come to occupy a high place in the concerns of every faculty member, as it should. Our notions of teaching are strongly influenced by our notions of learning, which have been heavily imbued with vocabulary from information technology and cognitive science during the past generation. In my mind, the customer-relation problems I discussed earlier are not caused by inadequate understanding of learning, but by inadequate understanding of teaching. The rapid advances of information technology have exacerbated them, which draw attention to the processes of learning.

How many of you as teachers have been offered training (or even forums) in teaching effectiveness at any time in the past five years? Ten years? Did you accept the offer? When I ask these questions I find there are few "yes" to the first two and even fewer to the third.

I suggest that we as a profession undertake an investigation of effective teaching in the age of the Internet. I use the phrase "way of the teacher" to describe the attitudes, skills, and practices of the effective teacher. I will offer a glimpse of what these are and how we might learn them.

The Way of The Teacher asks us to think deeply about who we "are" as professors and who we need to become in order to be capable of educating people for competent life and work in the 21st century. Before we can say who we must become, we need to understand who we are now. We are specialists who like to congregate with our professional communities, who are other scholars like ourselves. Although we admire or loathe the giants of our industry (for example, Allen, Andreesen, Cerf, Clark, Frankston, Gates, Gilder, Joy, Kahn, Lynch, Metcalfe, Moore) we do not move in their circles; we orbit them, not they us. Many of us feel increasingly disconnected from their world; we do not know how to move in it. We see our jobs as teacher to transmit information to students; we are the authorities who choose what to transmit, verify that it has been received, and generate more of it through our research. We do not see students, parents, and employers as customers; only funding agency program managers routinely command this treatment. We focus a lot on teaching process and look to cognitive science for "laws of learning" that we can use to optimize the process and support through information technology. I suggest that most of the breakdowns that frustrate us and leave us unsettled are related to this information-oriented way of being.

Stephen Covey tells the story of a businessman who went to Chicago to close an important deal. He drove his rented car from O'Hare toward downtown, confident that the detailed map and directions from his associate would get him there on time. Within a few minutes he began to get confused, for he was unable to match the expressway exits to his map and directions. He got off the expressway but could not locate his position on the map. He called his associate, who said to him, "Your problem is that you gave up too easily. Get back in your car and try harder." And so he did. He tried harder. He continued driving through Chicago's streets, utterly unable to match his position with the map. After a while he became very angry.

He again called his associate, who now said to him, "Hey what are you getting mad at me for? I faxed you a great map. Your problem is your attitude. Fix your attitude and you will get here." And so he tried to improve his attitude. He was hopelessly lost with a smile. He spied a sign to O'Hare, drove there, and returned home without the deal. The next day he told his secretary the said tale. She asked to see the map. "Omigosh!" she exclaimed, "This is a map of my hometown, Detroit! They faxed you the wrong map!"

And so it is with teaching. No amount of trying harder or attitude adjustment is going to help us become more effective as teachers in Chicago, or more involved in the dynamics of the computing industry, if we are trying to find our way with a Detroit map.

I suggest that the way of the teacher begin with a map of the human being, not a schematic of an information-learning process. A new map can rest on premises such as the following six: 1) We are beings who construct narratives about ourselves and those around us based on our experiences and on conversations we have had with others. 2) We coordinate, communicate, and learn in language. Breakdowns – events that interrupt our progress toward our goals – are the moments at which we do most of our learning. 3) Learning in the workplace is hardly different from learning elsewhere. 4) The Internet is a communication space that vastly enlarges the scope of those whom we can talk with and transact with, and also enlarges the number of breakdowns that we encounter and the kinds of things we can learn. 5) Technology is equipment and tools that augment human capabilities and enrich the space of actions we can take together. 6) Design is a conversation we have with others in which we plan and describe technologies that may be implemented and put to practice.

I speculate that from these interpretations we can build a new way to approach the bases of effective teaching. Education, communication, reading, listening, seductive writing, trust, compassion, fear and self-esteem, service, assessment, diversity, seriousness, humor, invention, innovation, historical sensibility, coaching, educational technology, professional education, and lifelong learning – a new map for teaching. The goal of such an investigation would be power a new map showing effective teaching as a set of skills and practices that can be learned, not a gift given to a few select teachers.

Summary

1. The field of CS&E is making good progress in responding to complaints from our customers about what we are teaching our undergraduate students.

2. The field of CS&E still has much work to do on current trouble spots: to integrate research with undergraduate education, to reduce the "unit cost" of teaching courses, and to define and test for competence.

3. In concert with other fields, CS&E must participate in serious investigations of new trouble spots, which will pose even more serious challenges than the current trouble spots:

   The factors, arising from information technology and the large increase in scientific information that are dismantling the assumptions underlie the university as an institution. Among the possible new roles of universities are professional education and cross-disciplinary community building.

   The need for a "map" of effective teaching in the age of the Internet and for training of teachers. Effective teaching can be approached as a set of skills and practices that can be learned, not as a gift given to a select few. This map would shift attention from the teacher as a facilitator of information processes to the teacher as cultivator of competence in human beings.

*Since 1991, **Peter Denning** has been Associate Dean for. Computing and Chair of the Computer Science Department in the School of Information Technology and Engineering at George Mason University. He was the founding director of the Research Institute for Advanced Computer Science (RIACS) at NASA Ames Research Center beginning in 1983. He joined the Computer Sciences Department at Purdue University in 1972 and was head of the department from 1979. He was an assistant professor of Electrical Engineering at Princeton University from 1968, after completing his Ph.D. at MIT in EE. In 1980, he was one of the four co-founders of CSNET, NSF-sponsored project that built the first community network and initiated the transfer of the ARPANET technology from defense contractors into today's Internet. He was President of the ACM (Association for Computing Machinery 1980-82). He has led several significant projects including bringing operating systems into the core of computer science (1971), the Snowbird report "A discipline in crisis" (1980) that helped start NSF CER program, the ACM/IEEE report "Computing as a discipline" (1989) that defined the core of CS&E, and the Center for the New Engineer (1983) at GMU that is building technologies to support effective teaching and learning for engineering. He has received the Computing Research Association Award, the ACM Distinguished Service Award, two best-paper awards, three scientific society fellowships, and two honorary degrees.*

Engineering Technology Education
(Bachelor of Science or Four-Year Degree Component)

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Engineering Technology programs are relatively young in the overall developmental history of higher education in the United States. Their growth and development resulted from an evolution of social, economic, and technological events, including defined needs of industry. Engineering education in the U.S. was generally patterned after the École Polytechnique of Paris, France, founded in 1794, the first school to prepare professional engineers. The Rensselaer Polytechnic Institute was founded in 1824, becoming the first institute of its kind in the United States.

The industrial revolution in the 19th Century greatly expanded the need and scope of engineering education in the U.S. and continued the movement leading to the creation of engineering technology programs. The "Land-Grant College Act" or the "Morrill Act" of 1862 greatly expanded the number of institutions offering engineering programs and made engineering education a major part of public higher education. The mechanical engineering programs that developed under this movement were the genesis of many engineering technology programs operated at major institutions today such as Penn State, Purdue, and Texas A&M.

Many technical institutions were developed in cities across the U.S. under the federal war training programs developed during and following World War II. This movement created training programs for the defense industry needs. These programs remained in many cities at the end of the Act to form the nucleus for education programs that contributed to the development of engineering technology programs. The Servicemen's Readjustment Act of 1944, which provided for 48 months of education and training for all World War II veterans, also played a major role in the evolving education program not yet named engineering technology.

Another development that had a dynamic impact on the growth and development of the current programs called 'engineering technology' was the creation of community colleges in this country. Many two year programs in engineering technology today are operated through this educational delivery system. These programs had the advantage of responding quickly to the needs of industry and reaching regionally bound students.

Many engineering technology educators point to the Grinter Report issued in 1955 and the launching of *Sputnik* as the basis and emphasis for the development of four-year engineering technology programs.

Dr. L. E. Grinter, former Dean of Engineering at the University of Florida and Chairman of the Engineering Education Evaluation Committee, which proposed a bifurcation of the engineering curriculum in the preliminary report but excluded such language from the final report, later summarized the situation clearly in an article written for the *Journal of Engineering Technology:*

> "Engineering faculties ... were unable to agree with the concept of bifurcation of engineering curricula. The committee's objective was to provide a dual choice [within engineering schools] for each student of either a scientific or a more pragmatic orientation

> of his program in engineering. Nevertheless, the natural forces of student desire and employer need; have brought about a nearly complete solution through the development of four-year [engineering technology] curricula. Finally, we can see so much future development of computer-aided research ... that the extraordinary growth of enrollment in engineering and [engineering technology] curricula may seem a wise preparation for expanding future industry." (L. E. Grinter, Engineering and Engineering Technology Education, *Journal of Engineering Technology*, March 1984, 1 (1): 6-8).

From these early events in the evolution of engineering technology comes a set of basic beliefs or principles from which the programs have developed.

Founding Principles that have made Engineering Technology Successful

I presented a paper at the 1994 ASEE Annual Conference on the principles that have made Engineering Technology successful from its beginning. Those comments were condensed in a *Last Word* article for the February 1995; *ASEE Prism* entitled "Stay the Course."

"The engineering technology programs:

- emphasize the teaching of industry-standard technological information and skills;
- prepare graduates to be immediately productive in society;
- integrate general education and technical courses within the curriculum;
- provide application-oriented instruction and are laboratory based;
- apply mathematics and natural science as an integral part of the learning environment;
- place a strong emphasis on communication skills - both oral and written;
- focus primarily on analyzing, applying, integrating, implementing, and improving existing technology and the practice of these skills;
- provide for problem solving, lifetime learning, and teamwork skills;
- are taught by faculty with industry experience as well as with appropriate academic preparation for the field; and
- are responsive to changing market demands.

These principles for engineering technology education are as reliable today as they were 35 years ago. In fact, business and industry may even recognize the importance of these traits and skills in our graduates or products more today than ever before."

The Spectrum of Engineering Education

As the field evolved, much time and effort has been spent defining the field. Few fields of education have been more studied or had more reports issued on their development. One such report, "The Engineering Technology Education Study – Final Report" issued in 1972 defined engineering technology as:

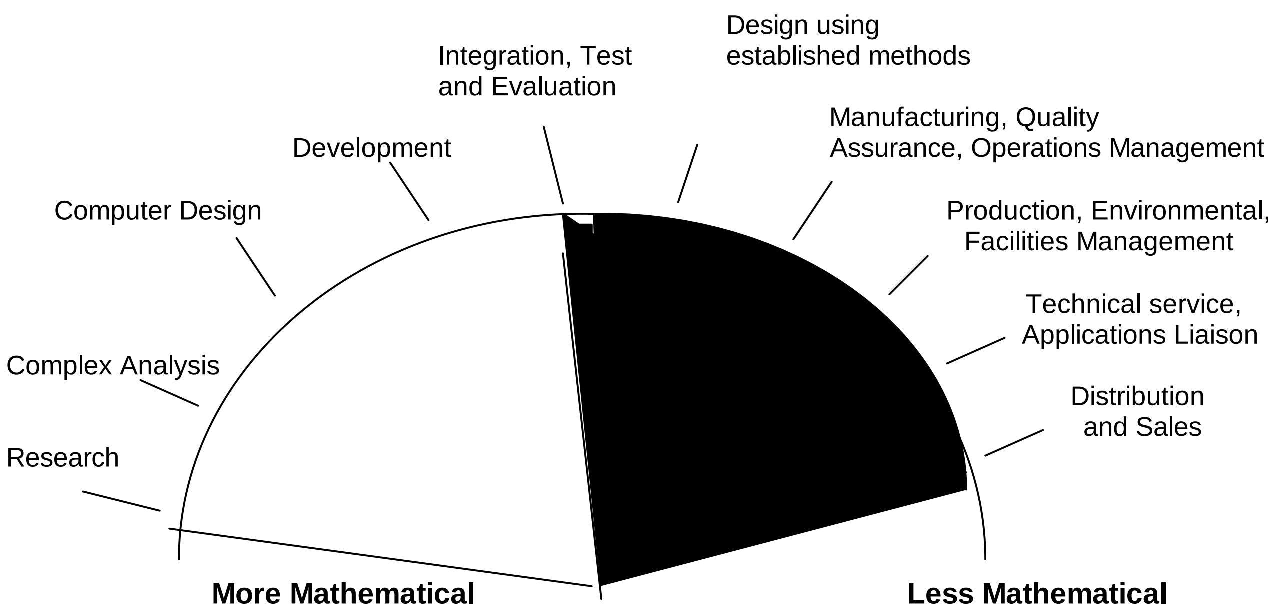
> "Engineering technology is that part of the technological field that requires the application of scientific and engineering knowledge and methods combined with technical skills in support of engineering activities; it lies in the occupational spectrum between the craftsman and the engineer at the end of the spectrum closest to the engineer."

The field continued to evolve and grow and in 1992 the Engineering Technology Council (ETC) of the American Society for Engineering Education (ASEE) adopted the following definition that is used in practice today by the Technology Accreditation Commission (TAC) of the Accreditation Board for Engineering and Technology (ABET) to define engineering technology programs:

> "Engineering technology is the profession in which a knowledge of mathematics and natural sciences gained in higher education experience and practice is devoted primarily to the implementation and extension of existing technology for the benefit of humanity. Engineering technology education focuses on the applications aspects of science and engineering aimed at preparing graduates for practice in that portion of the technological spectrum closest to the product improvement, manufacturing, and engineering operational functions."

The place of engineering technology in the spectrum of job functions in industry was best defined by Robert L. Mott, Associate Dean for Engineering Technology Programs, University of Dayton, in an article in the Fall of 1992 issue of the *Journal of Engineering Technology*.

Figure III.1



Spectrum of Engineering Technology and Engineering Job Functions in Industry.

Graduates of bachelor of science degree engineering technology programs are employed across the technological spectrum, but more prominently in applications, implementation, and production-oriented positions, as well as in technical sales and customer service.

The word "engineering" is used as a noun when describing engineering programs in academic institutions or by association boards, and as an adjective when describing technology programs. The word "engineer" is used in industry to generally denote the function of the position or the job, such as design engineer, process engineer, manufacturing engineer, production engineer, sales engineer, or service engineer.

Therefore, the spectrum of engineering is very relevant to the understanding of the field and how the graduates are utilized in industry.

Continuing Challenges for Engineering and the Role of the National Science Foundation

Many of the issues identified in the 1986 National Science Board report, *Undergraduate Science, Mathematics, and Engineering Education* (NSB 86-100), continue as issues today. Although much progress has been made through National Science Foundation and other federal programs, the following issues are identified for continued focus:

Students

- Preparedness of entering students, specifically in the areas of mathematics and science continues to be a concern identified by engineering technology educators; and
- The need to provide applications-oriented educational programs beyond the baccalaureate degree for bachelor of science degree engineering technology graduates.

Faculty

- Acquiring faculty with appropriate academic preparation and industrial experience;
- The need to develop incentives and rewards for faculty who teach comparable to those who do research;
- Need to develop more Master's Degree Programs to provide faculty for technology institutions.

Instructional Delivery

- The continued growth of the global economy and the rapid expansion of technology will continue to impact curriculum development, and points to the need for the development of an adaptive workforce with the capability to learn throughout their careers;
- The Advanced Technological Education program – the need to recognize the important role that can be played by four-year institutions in the overall improvement of engineering technology programs in relationship to two-year institutions. Some of these roles are:
    - to use four-year programs as model showcase sites for laboratory and curriculum development;
    - the development of model curriculum for two-plus-two programs;
    - faculty professional development centers; and
    - to model the use and implementation of ever-changing technology.
- Partnerships and outreach programs to business and industry will continue to be a major key to the future growth and success of the undergraduate programs. More replication of successful models needs to be supported.
- Sustaining the high quality laboratory base of programs while facing the combined forces of cost escalation and rapidly changing technology is a major concern of all engineering technology institutions. The National Science Foundation's Instrumentation and Laboratory Improvement program needs to develop a much larger role in supporting this effort.

None of these challenges is insurmountable. The engineering technology community is prepared to work with the National Science Foundation and others to find the most appropriate solution to these and other continuing concerns. The greatest impact will be felt when we all target mutually agreed upon solutions. Engineering technology educators greatly appreciate the recognition of our programs by being included in your deliberations.

***Don K. Gentry** has been a faculty member and administrator in the Purdue University School of Technology for 14 years; has served as Dean since 1987, is an active member of ASEE, campus representative for the Engineering Technology Council (ETC); and a board member of the Engineering Technology Leadership Council (ETLC). He holds a B.S. and M.S. from Purdue University and a Doctorate of Education Administration from Indiana University. lie has had over 30 years of experience in education.*

Appendix

Scope of the engineering technology programs today:

- As of October 1994, 173 institutions operated 450 TAC-ABET accredited associate degree programs and 113 institutions operated 320 bachelor of science (B.S.) degree TAC-ABET accredited programs Two-birds of the B.S. degree programs were in the electrical/electronic, mechanical, and manufacturing disciplines.
- Over 6,500 Engineering Technology B.S. degrees were graduated from TAC-ABET accredited institutions in 1992-93, while the total enrollment in B.S. level engineering technology programs was 36,871.
- The largest public institution producers of B.S. degree graduates are: Purdue University in West Lafayette, Indiana, and Southam College of Technology in Marietta, Georgia. The largest private institutions are the DeVry Technical Institute System, operating in seven states, the Wentworth Institute of Technology in Boston, Massachusetts, and Rochester Institute of Technology in Rochester, New York.

Enhancing Science, Mathematics, Engineering and Technology Education at the Two-Year College

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It has been gratifying in recent years to observe the increased interest and leadership, especially at the two-year college level, that the National Science Foundation has placed on science, mathematics, engineering and technology education. This significant leadership role and emphasis is evidenced by such publications from the Division of Undergraduate Education (DUE), Directorate for Education and Human Resources as shown in the attached bibliography. DUE's major programmatic areas of Instrumentation and Laboratory Improvement, Curriculum and Course Development, Undergraduate Faculty Enhancement, NSF Collaboratives for Excellence in Teacher Preparation, and Advanced Technological Education are critical leadership initiatives for enhancements in two-year educational programming. It is very important for all of these initiatives to continue, with periodic reviews and enhancements as needed. The information and recommendations contained in a number of NSF publications listed in the bibliography have been and will continue to be beneficial to administrators and faculty of two-year colleges. Director Neal Lane's interview published in the September 19, 1995, *Community College Times* is again indicative of NSF's leadership's view of the importance of two-year education in preparing highly qualified technicians and technologists for the future workforce.

The individuals comprising the engineering and science technician segment of America's workforce are typically expected to have an applied background with a theoretical base at a level that enables those technicians to be productive at or shortly after employment. The rate of change of technological innovation and the integration of these new concepts into curricula offerings necessitates frequent updating of these programs. The rate of change is illustrated in part by the comments of Sir Robert Telford, Life President of Marconi Cie, in his keynote address to a 1994 conference entitled *Technologies Role: New educational potential and obstacles of distance and flexible learning infrastructures in the context of regional development*[1]. He began his address by stating that, "The success of a company/country is a function of the sum of the competencies of the employees/populations." He also provided information about his recent visit to a Marconi plant in Italy and noted the following interesting facts:

- The products that the plant was producing in 1990 had been replaced with new products;
- In 1992, one-third of the orders were for products that did not exist two years earlier;
- Production time has been cut drastically. A couple of years previously, where it had taken 40 minutes to assemble a mobile phone unit; it now took 12 minutes;
- Employees operating the microelectronics production line are required to have university degrees;
- Knowledge is doubling every 10 years;

[1] Telford, Sir Robert, *The role of education and training as a strategy for a regional development policy. What are the criteria for success and/or failure?* Keynote Address for Technologies Role: New educational potential and obstacles of distance and flexible learning infrastructure in the context of regional development, Nancy, France, May 1994.

- There is an increasingly higher level of competition; and
- There is a shift to a lifetime of learning

Such rapid change requires graduates capable of learning new material independently and quickly. Students in their college work must develop these skills. Hence, pedagogical methods involving various media sources, including the Internet, must continue to be integrated into the learning process. Therefore, it is important for initiatives to encourage institutions and faculty to continue to develop and disseminate new methods to foster independent experiential learning. Advisory committees continue to communicate a need for additional knowledge and skills in the various areas external to the major discipline and within the discipline as a result of new technology and/or methods in the workplace. In the book *Future Tense*[2] it is noted that the following traits in an individual's skill portfolio will help that individual succeed in the organization of the future.

- *Reasoning*. Can these young people think straight? Can they tell stories that make sense? Can they develop logical arguments?
- *Communication*. Can they read, write, talk, present, listen, respond, and sell an idea? Three of these are good, five, great, and seven exceptional.
- *Cross-cultural skills*. Can they deal with diversity (race, gender, religion, ethnicity, culture, physical attributes, functional areas, training, and background)?
- *Global experience*. Have they been outside the United States? Can they speak a second language? Are they keen to try?
- *Team orientation*. Have they performed in a musical or theater group? Did they play team sports? Can they play on teams? What role do they like on teams?
- *Technological literacy*. Do they have a core of technologies they can use or learn, particularly computer and communications technologies: PCs, local area networks, e-mail, work processing, and spreadsheets? Are they interested in new technologies as tools?
- *Track record of achievement*. Have they had successes in any field? What are the interests that motivate them? How do they feel about success?
- *Quick study*. What can they learn? How fast? Do they seek out learning situations?

A comprehensive task force within the Maine Technical College System, identified in its report, Skills For The 2Ist Century3 has reached similar conclusions.

Engineering technology programs accredited by the Technology Accreditation Commission of the Accreditation Board for Engineering and Technology (TAC of ABET) generally have program criteria developed by the responsible professional society. These criteria along with the general criteria for accreditation by the TAC of ABET establish a minimum standard for these programs. Over the years, the credit hour content of many of these programs has continued to creep upward. Recognizing the heavy student workload, some programs have reduced the required number of credit hours to make the program more attractive to students while incorporating advances in technology. Others have addressed these concerns be expanding some two-year engineering technology programs to the baccalaureate level. A third alternative under consideration by others is to offer an advanced post-associate certificate for technical workers to provide the expanded knowledge and skills needed by their employers.

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[2] Morrison, Ian and Schmid, Greg, *Future Tense: the business realities of the next ten years*. William Morrow and Company, Inc. New York, NY, 1994.

In my letter of August 4, 1995, to Dr. Watson, I referred to the result of the foregoing pressures as curricula compression. This presents a formidable challenge to faculty and administrators given the typical problems of eroding resources, academic preparation of entering students, and others as listed on page 22 of *Technical Education in Two-Year Colleges*[4].

Another major concern exists with the transition to the information age economy and the downsizing of many businesses. This has negatively impacted the availability of jobs for technical workers in various areas of the nation. While NSF is not directly engaged in economic development initiatives, it is important to recognize these economic conditions and to encourage economic development activities by various agencies of federal and local governments.

The importance of the appropriate level of academic competencies of incoming students is worthy of special note. Tech Prep and other initiatives at the secondary level are helping. Continued emphasis by appropriate government agencies should be directed toward the successful existing initiatives, toward teacher preparation programs and toward professional development activities to assure appropriate academic achievement by students at the secondary school level. Associated with the secondary school activities is a need for guidance counselors to understand the opportunities available to science and engineering technicians and technologists and the academic preparation required for these careers. Appropriate counseling and encouragement would assist many students in being better prepared academically to enroll and be successful in these curricula at the two-year college.

From my perspective, there will be a need for continued improvement and/or revision of teaching techniques for the foreseeable future to continue to incorporate technological changes into the teaching and learning process. Until there is substantial improvement in the economies in many states and/or regions of the nation, resources at the local level will continue to be limited. Consequently, the continued leadership of NSF is most important in such initiatives as the ATE program and dissemination of the results of promising practices. Efforts based on the results of such initiatives as well as work previously disseminated can be most useful to two-year mathematics, engineering technician and science technician programs. Please continue these programs, expand into other activities that look promising, and encourage other government agencies and/or departments to support the technician segment of the workforce of American.

Thank you for the opportunity to offer this testimony.

***Durward R. Huffman** serves as president of Northern Maine Technical College, one of seven colleges in the Maine Technical College System. 11e also serves as the academic officer for the system. He has technical college administrative experience at all levels and has taught at both associate and baccalaureate levels. He has an Ed.D. in higher education from the University of Sarasota; a masters degree in electrical engineering from the University of Colorado; and a bachelor of science degree in electrical engineering from Heald Engineering College. He is a registered professional engineer, and his industrial experience includes the design of electrical power systems and process control systems. He holds professional membership in the American Society of Engineering Education, the American Technical Education Association, and the Institute of Electrical and Electronics Engineers. He is presently serving as a member of the Community and Workforce Development Commission of the American Association of Community Colleges and is active in various community organizations. His activities in accreditation include service on regional teams and on TAC/ABET teams He has*

[4] Burton, Lawrence and Carin A. Celebuski, *Technical Education in 2-Year Colleges*, HES Survey Number 17, NSF, Division of Science Resources Studies, 1995.

served as chair of the Technology Accreditation Commission of the Accrediting Board for Engineering and Technology and is editor-in-chief of the Journal of Engineering Technology.

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Undergraduate Education in Chemistry

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I believe it is worth stating at the beginning that undergraduate education in chemistry in the U.S. is in quite good shape overall, thanks to the operation of the American Chemical Society's Committee on Professional Training (CPT) over some 60 years. Students in the approximately 60 percent of U.S. chemistry departments that are ACS approved (about 90 percent of all undergraduate chemistry majors) are well prepared for continuing graduate studies in chemistry as well as many areas of molecular biology, polymer and materials science, environmental science etc. Provided, of course, they follow the ACS approved curriculum. (Only about 50 percent of chemistry majors do.) The possibility of specialization in the last two years of study, e.g. in biochemistry, environmental chemistry, polymer science, etc. now provided in the approved curricula has enhanced their value. It is less clear if these curricula prepare a chemistry B.S. well to enter directly into industry. Our industrial colleagues complain about problems in oral and written communication, lack of experience with teamwork, and lack of knowledge of industrial needs and practices.

While chemistry curricula for chemists may need no more than fine tuning, it must be remembered that the majority of students taking freshman and sophomore chemistry are not chemistry but biology majors, pre-pharmacists or pre-medical students. The needs of that majority may not be the same as those for chemists.

Finally it must be said that the standard freshman chemistry course is not particularly suitable as a terminal course for majors in the humanities, fine arts or social sciences who need a science course to fill a distribution requirement. Few such majors take chemistry; they tend to prefer biology, geology, or psychology. As a result – and especially – if they are among the 45 percent of all students who have evaded chemistry in high school – they may never learn about the chemistry (food, materials, environment, etc.) that is so important in everyday life.

Suggestions

1. A number of departments have adopted a sequence of one semester of general chemistry followed by two semesters of organic chemistry and one semester of more advanced general-inorganic-analytical-physical chemistry – such a sequence may be preferable especially for those not majoring in chemistry.

2. A course of the type based on "Chemistry in Context" should be taught for non-science majors.

3. CPT requires 400 hours of laboratory. This requirement should not be shaved. In general, U.S. students are not as proficient in the laboratory as students from Switzerland, Germany, and many other countries are.

4. A seminar course for seniors would assist them in acquiring ability with oral presentation of ideas.

5. The grading of laboratory notebooks and reports should be done with care and thoroughness and should include correction of bad English.

6. It is strongly recommended that chemistry majors be involved in research projects, at least during their senior year.

7. Co-op programs are ideal for acquiring familiarity with industrial operations (including teamwork). Short of that, a chemistry major might profitably spend one or two summers in an industrial laboratory.

***Ernest L. Eliel** is W. R. Kenan Jr. Professor emeritus in the Department of Chemistry, University of North Carolina at Chapel Hill. His research interests are in the area of organic chemistry, especially stereochemistry. In the latter area he has authored, co-authored and edited several influential books, including* Stereochemistry of Carbon Compounds *(McGraw Hill, 1962),* Conformational Analysis *(Wiley, 1965),* Topics in Stereochemistry *(21 volumes, Wiley, 1967-94) and* Stereochemistry of Organic Compounds *(Wiley, 1994). He is the author or co-author of about 300 scientific papers in the area of chemistry. Dr. Eliel has taught undergraduate courses (both lecture and laboratory) as well as advanced organic chemistry courses at the University of Notre Dame and the University of North Carolina at Chapel Hill over a period of more than 40 years.*

Strategies for Revitalizing Undergraduate Education: A Perspective from Chemistry

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I think it is fair to say that I have goals, as do many of my colleagues, for all undergraduate students attending our institutions. As the role of science and technology in our lives expands, it becomes increasingly evident to us that we need to ensure that students leave our institutions with the scientific and technological literacy necessary for them to be able to participate in improving society and to lead productive lives.

In this testimony, I want first to highlight some needs of our society with regard to science and technology. Then I hope to paint a picture of the current state of affairs with regard to undergraduate education in chemistry. I will follow this with a discussion of some of the constraints placed on faculty with regards to their role in chemistry education. Finally, I will leave you with a few key recommendations.

What are the needs of society?

There is a need for continued development of science and technology, for better living. For example, we need a sufficient food supply, non-polluting and renewable energy sources, and a cure for cancer. There is a clear need for students educated in science and technology who will spend their careers seeking and implementing processes and products to meet the ever-increasing needs of society. As chemists, we have a unique opportunity to educate most of these students; they are required to take our first-year chemistry course before going on in studies of science and technology.

Second, there is a need for citizens who are scientifically and technically literate. As the role of science and technology in our lives increases, we continually face decisions that require a certain degree of such literacy. Should we use pesticides or eat genetically engineered fruits? Are electric cars better? Is vitamin C a magic cure? All citizens must have some degree of scientific and technological literacy to use technology effectively and make informed decisions.

What is the current state of affairs in chemistry?

The undergraduate chemistry curriculum is much the same as it was 30 years ago. The curriculum is focused on basic knowledge necessary for advanced studies in chemistry despite the fact that more than 90 percent of those enrolled in the large freshman chemistry courses will not become chemists, and despite the changing needs of industry and the need for better teacher preparation.

What takes place in our classrooms?

The methods presently used in most institutions for teaching chemistry involve faculty transmitting chemical principles with chalk in hand to large numbers of students using a lecture format. This manner of teaching has a long history, with origins in the old European system where the professor describes his knowledge from the front of the lecture hall to an eager audience of a generally well-prepared, ethnically and culturally homogeneous group of young men. Times have changed.

Certainly, a highlight of our curriculum is our laboratories. Students have the opportunity to do hands-on experiments. Unfortunately, many of the laboratory experiments offered to the students require merely following a recipe from a science cookbook. Furthermore, although the National Science Foundation deserves credit for putting some new instrumentation into these laboratories, I would say that still, compared with the laboratories at many, many institutions, my kitchen is better equipped.

The textbooks have grown larger and more colorful, but contain few meaningful descriptions of the process of science and applications of the scientific method. The role of science in society and "real" examples of contributions of science to society is absent. Moreover, since a small fraction of faculty participates in writing these textbooks, most faculties have little opportunity to define and/or reshape the curriculum.

The exams are written for convenience of grading rather than true assessment of conceptual knowledge, and thinking skills. Few of us recognize the impression with which these exams leave the students. Do we really want students to believe that all problems are solvable, and moreover, that there is always one correct solution?

While this is the state of affairs in many of the freshman chemistry courses throughout our country, the Division of Undergraduate Education at the National Science Foundation has taken a leadership role in revitalizing the curriculum. Several major chemistry curriculum reform efforts are underway. Presently, there is a substantial community that has emerged and is engaged in building a vision. We want to enhance the quality of education that we offer students taking chemistry courses, build consensus throughout the entire community regarding this vision, and develop and implement materials to revitalize our courses. New technologies are being employed extensively, and research in cognitive science is being embedded.

What constraints are placed on faculty?

Chemistry faculty continues to be rewarded for research. Not only are activities in education not rewarded, but also such activities hold faculty back from promotion because they come at the expense of research. Doing a good job in the classroom is perceived to require minimal intellectual effort compared with research activities. While strict requirements for review of research are imposed, there is little assessment of teaching and, thus, no accountability. In short, tenure and promotion are tied to research. Spending time teaching counts against faculty because it takes time away from research.

Moreover, there is an implicit assumption that having done research in chemistry qualifies a faculty member to be an expert teacher. Most faculties walk into their first class with no formal training in education.

Following up on this issue of teacher training, we as a large community of scientists often complain about the level of scientific literacy in our Country. Yet, we take little responsibility for educating the K-12 teachers, and indeed also our future political leaders, business leaders and citizens, who come through our institutions.

There is another major constraint placed on chemistry faculty. If you observe from outside the discipline, you will conclude that you need to be white male. Few institutions can claim even one African-American graduate student. At the assistant professor level, some institutions have still to hire their first woman.

And sadly, some still believe that the women and minorities who have been permitted to enter the profession are there only because they belong to underrepresented groups.

Recommendations

I strongly believe that systemic curriculum efforts are key if we are to reform chemistry education specifically and science education generally. In this regard, the National Science Foundation deserves to be applauded for its efforts and should continue these efforts. Although there have been many notable small programs in recent years, these programs do not have wide impact, and are not easy to disseminate effectively. One reason is that there is no widespread discussion and buy-in that comes with participating in the project. The systemic curriculum reform efforts that are underway have engaged many in a major rethinking. This is having a huge impact because of the publicity, and the acknowledgments that come with having received a major grant. I believe that it is fair to say that the National Science Foundation has nearly single-handedly raised the status of scholarship in chemistry education.

There has been less success regarding diversity. Large segments of the population continue to be excluded. Curricular changes may help to increase diversity when course materials are more suitable for students from diverse cultural and ethnic backgrounds. But if the most significant changes are to occur, the culture in our institutions must change. Those presently on the inside need to reevaluate their behavior, their prejudices, and their perceptions, and find effective ways to welcome excluded groups.

In Conclusion

Reform efforts will be successful if the value system and reward structure at our institutions are changed. Definitions of scholarship that emphasize the central importance of teaching must be embraced. Diversity must become more than a slogan. Promoting issues of diversity and the scholarship of teaching will require a rapid evolution of institutional and cultural changes championed by enlightened leadership. The National Science Foundation's leadership in these efforts is essential if cultural change is to become a reality at our nation's institutions.

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Disciplinary Perspectives in Science, Mathematics, Engineering and Technology Undergraduate Education: Physics

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There is an old Chinese curse: "May you live in interesting times." For undergraduate science education, these are indeed interesting times. With the passing of the Cold War and the arrival of a newly-elected majority in Congress, we are all part of a massive re-examination (sometimes explicit, but more often implicit) of the role of science and technology in our society and the mechanisms by which society supports research and development in science and technology. No one has easy answers to the questions of how many scientists and engineers we need as we enter the 21st century and what level of support the nation ought to provide for research, development and science education and how should that support be apportioned between the public and private sectors. I certainly will not pretend to be able to provide answers to those questions here, but I will focus on how these issues bear on undergraduate science education and undergraduate physics education in particular. In fact, I will argue that these "interesting times" are more a blessing than a curse for all of undergraduate education. They force use to address fundamental problems, some of which have been with us for decades.

For all of those concerned with the health of physics, both as the foundation science for the education of scientists, engineers, and a scientifically-literate citizenry, and as a key link in the development of the entire scientific and technological enterprise, the dilemmas we face have many horns. I have grouped my remarks into six categories. After discussing these categories I will address the issue of how the National Science Foundation can best help the scientific community grapple with these problems. We face several qualitatively new challenges:

1. The lessons of physics education research.
2. The lessons of research in physics education.
3. The crisis of careers.
4. The dilemma of diversity.
5. Preparation of the future professoriate.
6. Implementing what works.

In addressing each of these challenges, I shall focus on physics because that is the field I know best, but I believe that what I have to say applies equally well to all undergraduate science education.

Physics Education Research

Thanks to the widespread efforts of many physicists working in physics education research (the study of how real students learn and how real teachers teach, and the relationship, if any, between the two). We now have overwhelming evidence that the standard introductory physics courses dominated by lectures and cookbook-type laboratory exercises, succeed only with the most highly motivated and best-prepared students, and even with those students the gaps in their conceptual understanding rivals the budget gaps of Washington. Our standard approaches to teaching, like our standard approaches to budget making in

Washington, just seem to widen the gap between what we want to achieve and what the outcome actually is to exacerbate the problem. Introductory physics instructors suffer a kind of pedagogical schizophrenia; they want to provide students with a solid and broad grounding in fundamental principles and techniques, but they also want to let students know about contemporary issues and excitement in physics. No one claims to know how to do both in the standard two-semester introductory course.

Research in Physics Education

Within the last ten years the science teaching community has developed a remarkable consensus of "what works," the theme song of Project Kaleidoscope. We know beyond any reasonable doubt that engaging undergraduate students in active learning and active research, in close contact with faculty and other students encourages students of all kinds to continue toward a career in science. This engagement takes several forms:

- Instruction that keeps students active in the classroom working on problems and questions and laboratory exercises with each other aids conceptual understanding, problem solving abilities, and students' attitudes towards science.
- Early participation in scientific research in close association with faculty members and other students is a strong motivator for those who stay on in a scientific career. NSF has clearly played a major role in this area with its support of URE and RUI programs, but the Pew Charitable Trusts, Research Corporation, and the Howard Hughes Medical Institute have been important players as well.
- The appropriate use of technology can enhance active learning even in large "lecture" classes. Interconnected small computers provide a focus for small group discussions with immediate feedback to the students and to the instructor about the range of answers. The use of spreadsheets has provided a means for numerical computation with almost no programming and permits even introductory students to produce sophisticated graphs and curve-fitting. Digital video-processing provides means to study realistic applications of Newtonian mechanics. We also know that some kinds of technology are not very effective: computer simulations of experiments easily done in the lab are the work of the devil. Science is about understanding the natural world, not a computer simulation of the world. Computer-aided instruction, at least in its traditional implementation, both isolates students from one another, and is also extremely time-consuming to develop.

The Dilemma of Diversity

The face of science is changing. The number of women and minorities in science has increased dramatically in the last 10-20 years. This is a very positive sign for physics and all the other sciences. But we have a long way to go. The science professions are still not making use of the full spectrum of the nation's talent. This is bad for the science professions and bad for society as a whole. Most professional career decisions are made at the undergraduate level, so we must all focus our attention here.

But there is also another kind of diversity – a diversity that cuts across the lines drawn by gender and ethnic background – a that is much more important for our concerns in undergraduate science education: this is the growing diversity in the backgrounds and experiences students bring to their college-level courses. If we could afford to teach all introductory science courses in sections of 20-25 students, we could handle the problem. But we don't and, at least during our teaching lives, we probably never will. Therefore, any introductory physics course that fails to acknowledge that diversity and the design of teaching strategies to deal with that diversity is bound to miss the mark.

A related diversity issue is the future impact of the National Science Standards and related projects, such as the National Science Teachers Association's *Scope, Sequence and Coordination* and the AAAS *Project 2061*, on the science preparation of secondary school students. All of these standards efforts are still in a period of gestation, and it is too soon to tell what impact, if any, these programs will have on what students bring to their college-level courses. The past ten years have shown signs that high school science and math is progressing. The percentage of students taking chemistry has risen; the increase for physics is smaller, but still evident.

Crisis of Careers

Job prospects for doctorates in academe and basic research range from poor to miserable. The shortage of scientists and engineers predicted in the Neal report never materialized for a host of reasons, most of which could not have been foreseen at the time the report was written. As a consequence, the physics community is beginning to re-examine the structure of Ph.D. and Masters programs to make physics graduates more employable. Similar efforts are beginning to emerge at the undergraduate level for example in numerous physics and cross-disciplinary programs (physics and engineering, physics and business, physics and computer science, for example). Although I applaud these programs, I believe that to some extent they miss the crucial issue. Physics programs already prepare physicists for a wide variety of careers. For example the October 1994 issue of *Physics Today* provides an impressive list of the diverse careers of physics majors graduating from Haverford College. The crucial points are ones of career counseling – letting students see the wide range of career possibilities and reducing the strong bias toward graduate education, aiming only for a career in basic science. NSF plays a role here. For example, as part of a grant application, I filled out some NSF forms that asked how many of our undergraduate majors went on to graduate school in physics? With the clear implication that the more, the better. We also need to change our language. For example, the physics community traditionally talks about "traditional" (academic jobs and basic research jobs in industry and the national labs) and "nontraditional" employment. In fact, it has never been the case that more than approximately 40 percent of physics doctorates have taken academic and basic research positions.

Preparation of the Future Professoriate

Graduate education in science has traditionally focused solely on research. Undergraduate programs focus on preparation for graduate school. Neither has provided much in the way of professional training for those who aim to teach. As a consequence we teach as we were taught without much recognition of what has been learned about science pedagogy. This feedback system then tends to reward those who can learn best with traditional lecture instruction, thereby contributing perhaps unintentionally to the dichotomy between the scientific haves and have nots. Support and training for new faculty members and teaching assistants (the forgotten teaching force in undergraduate education) informing them of the results of science education research and new pedagogical methods must come at all levels: individual departments, colleges and universities, professional societies, and federal agencies.

Special attention needs to be paid to two-year college faculty, who, for example, teaches almost half of the nation's students who take calculus-based introductory physics. These faculty work often in very small departments with very little professional contact with other faculty members in their discipline. Programs such as the *AAPT TYC21* program supported by NSF are needed to help develop both the sense and the reality of professionalism for this important group of science educators.

Undergraduate science education is also crucial for prospective K-12 teachers, with special needs and problems for K-8 teachers who must be prepared to teach a wide range of disciplinary materials.

Developing curricular materials such as NSF supported *Powerful Ideas in Physical* Science, which allow the teachers to learn science as they will teach it, with an emphasis on hands-on projects that cut across the traditional disciplines, is of crucial importance.

Implementing What Works

There is a two-fold problem here: First, the new pedagogy is at odds with the standard "fire hose" pace of what passes for teaching in most introductory courses. The demands for "coverage" outweigh the demands for conceptual understanding and true learning. To complicate matters, many of the innovative pedagogical strategies still focus on the standard topics of introductory physics, particularly mechanics and electromagnetism. There are only a few brave efforts to apply the new pedagogy to twentieth century physics, though we are beginning to see some efforts in this direction. Indeed we will soon need to think about the physics of the 21st century.

The second problem is what I might call Newt's First Law: The Law of Institutional Inertia. Research universities see graduate science education and research as a source of both prestige and cash. For them undergraduate science education is an unruly and sometimes aggravating stepchild. Even comprehensive universities and four-year colleges are not immune to the "glamour" of research over education. We still talk about teaching "loads" and research "opportunities." I urge NSF to use its bully pulpit for renewed focus on undergraduate education. We need to remind (or convince) researchers and university administrators that their efforts in undergraduate education will in the long run help graduate education by providing them with better prepared students and more thoughtful support for research with a well-informed citizenry.

But reforming undergraduate education is often expensive at least in terms of one-time capital costs. Setting up a *Workshop Physics* program to service several hundred introductory physics students would cost several hundred thousand dollars. What we need is a way of recognizing the fact that the equipment will be used by those students and succeeding classes of students for hundreds of hours. The cost per student-hour is then quite modest. Is there a way that NSF can assist financially in this endeavor?

How are reforms to be promulgated and made effective? I argue that most science faculty members feel more loyalty to their profession than to their home institution - and are more responsive to "pressure" from the profession than the home institution. (If the Dean says so, we do it reluctantly - if the profession moves in a certain direction, we join in enthusiastically). Thus I believe that NSF and other groups seeking to implement effective reforms in undergraduate science education will need to work closely (as they have already in some cases) with professional societies such as the American Association of Physics Teachers, the American Physical Society, and the American Chemical Society.

NSF and Undergraduate Science Education

NSF's role should, I believe, focus on providing catalysts and leverage. The classic example of leverage is the ILI program. But we also need to leverage people as well as equipment. We need at the undergraduate level a program like the highly successful Physics Teacher Resource Agents (PTRA) program that has now reached hundreds of high school teachers with workshops and programs that bring them up-to-date on physics content and pedagogical issues. Of course, the culture of college faculty is different from that of high school teachers, but the notion of faculty working with faculty to disseminate what works seems to be the best way to leverage limited NSF funds.

NSF ought to encourage the development of central repositories, for example on the Worldwide Web, where science educators can find information on everything from the latest curricular innovation and pedagogical research to lists of textbooks available for various courses.

Major curricular development and reform is time-consuming and expensive. Producing a complete set of text materials, assessment materials, software and so on requires many person-years of effort and considerable field-testing and evaluation if the curriculum is to have widespread acceptance. NSF already has played a major role in physics by supporting programs such as the *Introductory University Physics Press* project, which has made radical change in introductory physics possible and in fact intellectually respectable. At the high school level NSF's support for Active Physics, designed to reach 80 percent of the high school students who have not taken the traditional physics courses.

Major efforts are needed to develop science courses aimed at non-science majors. In most cases, these students bring to their college-level science courses different levels of motivation and preparation compared to science majors. Putting them all into the same introductory courses serves neither audience well and makes large courses even larger. NSF support would aid in providing a ready repertoire of such courses.

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Scientific Elite or Outcast?

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There is no doubt that since the beginning of this century the United States ranks first in generating outstanding scientists. It is therefore ironic that as a whole, the population of the United States does not rank first in Science and Mathematics. One only need turn to the media to see that society does not value science and science education as it did just a few decades ago. In spite of all the advances in science and the many contributions of related technological developments to society, science illiteracy is rampant. The average person has little faith in scientists and there are more pressing problems than science education on the agenda of most people. These are worrisome developments because it is in the interest of society that everyone understands at least what science is about. No one can deny the formidable advances that have been achieved in science and their impact on the quality of life – advances that would not have been made without the outstanding quality of American scientists. What happens now in the classrooms across the United States will directly affect the health and well being of this country in the next century. We must act now to prevent losing our edge in science and technology.

At the college level, the introductory science course often is one of the biggest hurdles in the academic career of a student. For a sizable number of students the course leaves a permanent sense of frustration. I only have to tell people I am a physicist to hear grumblings about high school or college physics – almost to the point of making me feel embarrassed about being a physicist. This general sense of frustration with introductory science is widespread among non-science majors required to take science courses. Even science majors are frequently dissatisfied with their introductory courses, and a large fraction of students initially interested in science end up majoring in a different field. What have we done to make it that way, and can we do something about it?

I believe science education has been focused much too long on competitively generating a steady supply of future scientists. We must direct our science education not just at students going on to a scientific career but also at those majoring in other fields. It is time to realize that the demand for scientists is determined to a large extent by people for whom the introductory science course is the only direct exposure to science and who remember science only by the frustration it has caused them. It is time to realize that those who become successful scientists do so in spite of the current educational system, not because of it. It is time to realize that better science education for all will ultimately lead to a higher standard of living.

Broadening and improving science education will require a major change in attitude. The current mode of instruction is self-perpetuating: post-secondary faculty educates both their own successors and future secondary teachers; secondary teachers, in turn, prepare the next generation for a new cycle. At all levels one can find excellent teachers, but for the most part instruction in science is geared at the scientist, not the general public.

Recommendations

- *Teacher enhancement:* To restore public opinion of and support for science I suggest making an all-out and systematic effort to place the nation's best, most innovative, and most dedicated instructors at all levels of education. This will require a new reward structure – currently successful research is rewarded much more highly than successful teaching. A new role model – that of the "teacher-scholar" – must replace the current role model of the hard-core researcher in a white coat who prefers not to deal with students.

- *Innovating Pedagogy:* The science education literature abounds with innovative ideas, but unlike innovations in science and technology, few of these ideas are adopted by anyone besides the innovator. Even techniques that have been demonstrated to work have not found widespread acceptance. Overcoming this inertia is becoming an urgent problem. I therefore recommend rewarding not just the developers of successful innovations, but also those who adopt these innovations.

- *Using Technology:* New advances in information technology must be used to increase and accelerate dissemination of new ideas and materials in education. Widespread availability of materials will lower the threshold for adopting innovative ideas in science education.

I firmly believe science has done more for society than it is generally credited for—a view that unfortunately is not widely held outside the science community. It is therefore more important than ever that we direct some of our energy at educating the public about science—energy that has been directed almost exclusively at research and at educating and training future scientists. It is time for science educators and researchers to become more pragmatic, to step down from their ivory towers, and to reach out to society not only through scientific accomplishments, but also through better education and information.

Eric Mazur *is Gordon McKay Professor of Applied Physics and Professor of Physics at Harvard University. He obtained his doctorate in experimental physics at the University of Leiden in the Netherlands in 1981. In 1982 he came to Harvard and in 1984 he joined the faculty. He currently divides his time between research in laser physics and teaching, and is interested in educational innovations and applications of instructional technology. In 1988 he was awarded a Presidential Young Investigator Award. He is a Fellow of the American Physical Society and a member of the Society's Committee on Education and of the Physics Programs Policy Committee of the American Institute of Physics.*

The State of Undergraduate Education in the Earth Sciences

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Thank you for this opportunity to speak to the [EHR Advisory Committee]. I speak as a professor from the university trenches, and I draw upon the thoughtful written letters and comments of about ten colleagues, the results of several meetings and workshops, and informal discussions with many dozens of colleagues from many diverse undergraduate and K-12 venues.

I speak for the Earth Sciences and I speak with great conviction and urgency, for I believe that the generation of students that we are presently educating are going to be increasingly forced to make profound decisions concerning the fate of planet Earth, our home. The outcome of our human experiment called "civilization" will be highly dependent upon their coming to understand and incorporate Earth systems into their thinking and planning. They will need a host of well-trained Earth Science professionals and, just as important, a citizenry that is Earth cognoscente and Earth caring.

I shall address four topics; two are issues that apply quite generally to SME&T educational goals: 1) computer literacy; 2) undergraduate research opportunities, and two aspects that more specific to Earth Sciences; 3) the modernization and refocusing of Earth Science curricula; and 4) the need for major systemic changes in the teaching of Earth Science to non-scientists, especially to in-service and pre-service K-12 teachers. The latter two subjects concern a major turmoil in our field, one that may be particularly amenable to help from a NSF Earth Science initiative.

Computer Literacy

The last decade has seen a revolution in computer accessibility, usefulness, and user-friendliness and NSF has played a major role in the spread and use of this powerful technology. Basic computer literacy is now a must for all science professionals for computing/modeling/data processing and for communication at all levels. It is fast becoming a mandatory aspect for success in most professions. The impact of the Worldwide Web is only beginning to be felt but will surely be enormous. NSF should continue to urge and support projects that provide computer training and accessibility for all faculties and all students. Basic computer training should be particularly provided and stressed for future K-12 teachers, as they will in turn reach the vast pool of non-college bound students.

While the spread of computer access and training and of access to the Web has been tremendous, it is far from complete. There is a legitimate concern that this revolution may only exacerbate the gap between "haves" and "have nots" in our society. NSF would do well look into the distribution of this technology across the educational spectrum.

Many Earth Science databases are particularly amenable for use in combined computer and science education projects of great intrinsic interest. For example, the study of events such as storms, earthquakes, volcanoes, floods, and meteor showers, and of observable phenomena such as moon cycles and tides, can be made much more immediate with real-time data from the Web. Projects that create user-friendly educational pathways through the Web should be particularly encouraged.

Undergraduate Research Opportunities and Other "Hands On" Activities

One of the most important aspects in the education of a future scientist is the actual experience of “hands on” scientific investigation. NSF has long had a strong role in urging and supporting opportunities for undergraduates to be involved in ongoing research projects, and it should not slacken its efforts in this activity. Furthermore, related hands-on scientific experiences such as lab projects and field studies, all situations in which students collect data and draw their own conclusions are crucial at all levels of scientific education and should continue to be supported. In the earth sciences, these experiences often occur in the field, with students observing and interpreting natural objects and processes in their natural "habitats". This real, experiential component must never be lost (no matter how many computer models we make). The student exhilaration after a day in the field speaks for itself.

Modernization and Refocusing of Earth Science Curricula

There is presently a widespread turmoil within the nation's Earth Science departments, an identity crisis of sorts. The traditional, classical Geology Department was deeply tied to the solid earth with, perhaps, a recognition of fluids, but only as they occur within the pore spaces of rocks. In recent decades, other earth science fields such as oceanography, meteorology, climatology, environmental science, marine geochemistry, modern hydrology, and satellite geodesy, to name a few, have blossomed and taken center stage. Some of these subjects have been accepted and integrated into existing departments and curricula, but more often they are appended to geology departments like uneasy stepchildren. Often they are scattered across related departments (such as geography, environmental science) or simply ignored. Most recently, there has emerged a new, much more encompassing view, known as "Earth Systems Science", which considers the Earth and all its spheres (lithosphere, hydrosphere, cryosphere, biosphere, atmosphere) as an intricately interacting system (which, of course it is!). Some geology departments have changed their names and broadened their visions; others are making half-hearted attempts or have simply hunkered down. There is a lot of confusion.

The curriculum for undergraduate geoscience majors is, for the same reasons, in great flux. Many different experiments are being tried to trim traditional subjects to make room for others and many would-be reformers report great resistance to these changes. Furthermore, many attempts to reorganize are hampered by the complicated need for cross-departmental integration. The result is that, at present, there is very little consensus as to what constitutes a good geology or earth science education. It is clear that some changes are needed. It is equally clear that there is not one “correct” solution for all institutions or for all students. None-the-less, the earth science community could sorely use a careful introspective review of our subject and of the likely directions and needs of our majors, our future earth science professionals. An Earth Science Initiative from NSF, examining this subject, would be greatly welcomed and would lend needed credence and weight to any recommended changes that might emanate from such a review.

Needed Systemic Changes in the Teaching of Basic Earth Science to Non-Scientists and, especially, to In-service and Preservice K-12 Teachers

Earth Science can be a great subject for general science education. It can be an excellent vehicle for introducing basic physics and chemistry using familiar examples in the locally observable world. Furthermore, it lies at the core of many environmental, hazard reduction, and public policy issues and therefore is a central subject for an educated democratic citizenry. In fact, introductory courses in geology, oceanography, meteorology, and environmental science are very commonly taught as large “general education” type classes, for many of these reasons.

Unfortunately, professors (and their textbooks) tend to teach the same way that they were taught. The traditional approach – highly content driven, lecture/lab/exam format – is not usually fatal for science majors (it succeeded with them, after all) but it is often inaccessible, alienating, and highly irrelevant to others. Whole generations of former students, including many of our present K-12 teachers were turned off to science by this approach. These courses are presently commonly organized as an "introductory" overview of the field for potential majors, even though a very few percent of the students fit this category. The rest are very poorly served. There is a need for a profound reevaluation of the goals in these courses and of the pedagogical means to get to those goals. In many respects, this is another face of the curriculum confusion described above, and could very productively be addressed within the same proposed Earth Science Initiative.

If an Earth Science initiative were constructed, it would do well to include a separate consideration of the needs of future teachers, particularly the K-6 group. This group is highly likely to find themselves teaching many basic aspects of Earth Science and having to invent activities to illustrate these subjects. These teachers are responsible for the most fundamental science teaching and, perhaps, for the establishment of society's attitudes toward science, as well.

In recent years, NSF and other funding agencies have supported many excellent individual experiments toward more effective science pedagogy. These range from slight variants on the lecture-exam format to quite radical alternate approaches, incorporating elements of constructivism and of group learning strategies. The reports from educators who have taken these leaps are generally full of enthusiasm, but so far seem scattered and anecdotal and often lack clear ways to prove their efficacy to the busy skeptic. It may be time to put some energy into a systematic collection, sifting, and dissemination of these results. We need good, practical, concise descriptions of a wide variety of changes, large and small that have been shown to make a difference. I believe the science education community is ready to change our ways if we can see how to do it with relative efficiency. (We know we are not doing very well.)

We are ready to listen and to try new approaches.

Tanya Atwater *is a Professor of Tectonics at the University of California, Santa Barbara. She received her schooling at the Massachusetts Institute of Technology, the University of California at Berkeley, and Scripps Institute of Oceanography, completing her Ph.D. in 1972. She was a professor at the Massachusetts Institute of Technology before joining the faculty at UCSB in 1980. Dr. Atwater's research has concerned various aspects of tectonics, ranging from the fine details of sea floor spreading processes to global aspects of plate tectonics. She is very well known for her works on the plate tectonic history of the San Andreas fault system in particular and of western North America in general. Atwater is devoted to education, both in the University setting and for the broader public. She is deeply involved in the undergraduate program, working to revitalize teaching techniques, especially in large general education classes, and to modernize science curricula. She works at many levels (with the media, with museums, in teacher workshops) to spread Earth information and Earth passion across the wider citizenry. Tanya serves on numerous national and international committees and panels. She is a fellow of the AGU and the GSA and a co-winner of the AAAS Newcomb Cleveland Prize.*