Shaping the Future

Volume II: Perspectives on Undergraduate Education in Science, Mathematics, Engineering, and Technology

Contributions to the

Review of Undergraduate Education

by the

Advisory Committee

to the

National Science Foundation
Directorate for Education and Human Resources

NOTICES OF DISCLAIMER

1. This publication is a companion volume to the report *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139) and its stand-alone Executive Summary (NSF 96-141), published by the National Science Foundation in 1996. The views, opinions, and recommendations expressed in this report are those of participants in the Review of Undergraduate Education, the "National Year of Dialogue" and the Advisory Committee to NSF's Directorate for Education and Human Resources; they do not necessarily represent the official views, opinions, or policy of the Foundation.

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REVIEW OF UNDERGRADUATE EDUCATION

by the

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NATIONAL SCIENCE FOUNDATION
OFFICE OF THE ASSISTANT DIRECTOR FOR EDUCATION AND HUMAN RESOURCES

Review of Undergraduate Education in Science, Mathematics, Engineering and Technology
June 1995

CHARGE TO THE SUBCOMMITTEE

I appoint a Subcommittee of the Advisory Committee to the Directorate for Education and Human Resources (ACEHR) to conduct a Review of the state of undergraduate education in science, mathematics, engineering, and technology (SME&T); to identify its recent successes and to point out both its needs and opportunities for its improvement. Members of the Subcommittee will be: Drs. Melvin George (chair), Sadie Bragg, Frederick Brooks, James Rosser, David Sanchez, and Carolyn Meyers (consultant). [Drs. Alfredo de los Santos, Jr., Denice Denton, Mary Lindquist, and Mr. Peter Gerber were later added to the membership of the Subcommittee.]

The Subcommittee should consider the needs of *all* undergraduates attending *all* types of U.S. two- and four-year colleges and universities that provide undergraduate education in science, mathematics, engineering, and technology. In particular, the review should address issues of preparation of K-12 teachers in these fields, the needs of persons going into the technical work force, the preparation of majors in these areas, and the issue of science literacy for all. The review should cover the full range of general issues in undergraduate education—curriculum, educational technology, pedagogy (including the degree to which student learning is infused with research), institutional practices and the need for comprehensive reform, and key student transitions between levels of education (*from* high school, *between* undergraduate institutions, and *to* graduate school) and from undergraduate studies to employment. The review should draw upon a full range of constituent groups having a stake in undergraduate education—students, parents, faculty, administrators, scientific societies, accrediting groups, employers, and state and local education officials. The Subcommittee is requested to develop a schedule of draft reports and activities leading to a Final Report.

The Final Report should be action oriented, recommending ways to improve undergraduate education in science, mathematics, engineering, and technology for all students in all types of colleges and universities. Recommendations should be directed not just to NSF but, as appropriate, to mission-oriented Federal agencies, business and industry, academic institutions and their faculties and administrations, professional societies, private sector organizations, state and local government, and to other stakeholders in undergraduate education. The recommendations should reflect an assessment of accomplishments during the recent past [i.e., those following completion of the National Science Board study *Undergraduate Science, Mathematics and Engineering Education* (NSB 86-100, 1986)] and be based on the comments and ideas submitted by individuals and groups during the course of the Review and on findings and analysis by the Subcommittee. The Report should consider carefully future roles for sponsors of educational improvements and the nature of their efforts to improve undergraduate education. In particular, guidance is sought for the National Science Foundation regarding its support of innovation in educational practice through a portfolio of programs ranging from sponsorship of individual investigator-led efforts to catalysis of institutional programs of comprehensive change and covering the full range of educational settings.

I ask that the Subcommittee complete and transmit its Report to me by March 1996. Thereafter, the Report will be submitted to the full ACEHR for its comment and approval and, when that is obtained, will be submitted to the NSF Director and to the Director's Policy Group for approval as a NSF Report.

Luther S. Williams
Assistant Director

Introduction to the Second Volume

This is a companion volume to *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139), the 1996 report of the Advisory Committee on Undergraduate Education to the National Science Foundation's Directorate for Education and Human Resources. For this supplement, we have selected the materials that helped to initiate the discussion and debate of the review, and provided the framework for the Recommendations presented in the first volume of *Shaping the Future.*

No single document could purport to fully represent the breadth and depth of the expansive and complicated endeavor of higher education and its reform. While the EHR Advisory Committee did a formidable job of soliciting broad-based community opinion, synthesizing the issues facing contemporary undergraduate education, and summarizing this process in its report to NSF, the material presented in this second volume provides an essential resource for anyone wishing to explore these issues more completely, without the benefit of interpretation or distillation. To this end, we have made every effort to allow these authors to express their views in their own words and present references and data without undue editorial revision or comment.

The review of undergraduate education and the *Shaping the Future* report have already generated much discussion and activity in the U.S. education community. In recognition of this, the National Science Foundation has initiated its "NextSteps in Shaping the Future" campaign to capitalize upon this enthusiasm, coordinate regional efforts, and help guide discussion towards a national movement to achieve even greater excellence in higher education. We begin this volume with a summary of these ongoing, follow-up activities.

Section II of this volume presents a detailed account of NSF programs in undergraduate education since NSB 86-100, *Undergraduate Science, Mathematics and Engineering Education: Role for the National Science Foundation and Recommendations for Action by Other Sectors to Strengthen Collegiate Education and Pursue Excellence in the Next Generation of U.S. Leadership in Science and Technology* the last substantive review of undergraduate education in this nation. Section III presents the written remarks contributed as part of the public hearings on undergraduate education held in October and November, 1995, as well as an overview of the Social Sciences workshop held in February, 1996. Section IV summarizes the series of national focus groups conducted by NSF in 1995 and 1996, while Section V presents data from a variety of sources that contributed many—but certainly not all—essential facets to the overall analysis.

Finally, no accounting of this remarkable, cooperative achievement would be complete without proper acknowledgment of the participants and contributors to this process (Section VI) and the benchmark publications upon which the current appraisal was founded (the References of Section VII).

The National Science Foundation
Division of Undergraduate Education
Arlington, VA
August, 1998

Section I:

Activities in the Reform of Undergraduate Education Since Volume I of *Shaping the Future*

Introduction

During the review of undergraduate education by NSF Advisory Committee for Education and Human Resources, the deliberate process of acquiring information from a broad cross-section of the undergraduate community ensured a broad level of participation by many educators, administrators, employers, and students. This process occurred during April 1995 to June 1996, and culminated in three milestones in the summer of 1996:

(1) the publication of the Committee's report *Shaping the Future: New Expectations for Undergraduate Education in Science Mathematics, Engineering, and Technology* (NSF 96-139):
(2) the publication of the National Research Council's report *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Academy Press, 1996): and
(3) a major conference in Washington DC to air key findings and recommendations in these reports, and to continue discussions about how to implement their recommendations. ("Shaping the Future: Strategies for Revitalizing Undergraduate Education," held during July 11-13, 1996). The proceedings of this Conference are available at NSF Division of Undergraduate Education Web site (http://www.ehr.nsf.gov/EHR/DUE/start.htm).

It was the intent of the Committee from its inception to write a living report, stimulating an active and vigorous process of reviewing, debating, and improving undergraduate education in science, mathematics, engineering, and technology (SME&T) in all types of post-secondary institutions across our nation. This chapter reviews the types of activities the Division of Undergraduate Education (DUE) has undertaken with the undergraduate SME&T community following the July 1996, national conference on *Shaping the Future*. Additionally it provides a bibliography of studies, reports, and recommendations that have been published during the past several years on the same theme. Because these activities had been underway even before the summer of 1996, this overview extends from March 1996 through July 1997.

Shaping the Future NextSteps

The activities have the underlying similarity of engaging educators, academic administrators, and employers in discussions of methods to improve undergraduate education in SME&T. Generally, the efforts sponsored by DUE have identified and disseminated information about needs and opportunities to improve undergraduate student learning—particularly opportunities for developing effective teaching practices—and overcoming barriers to the widespread adoption of these practices.

The basic thrusts of these activities are:

- promoting greater understanding, and identifying ways to improve student learning;
- designing further improvements in courses and learning experiences to improve learning by all students;
- supporting interdisciplinary course and curricula development work by faculty from different SME&T disciplines working collaboratively;
- strengthening internal connections across departments (within all types of academic institutions) in support of improved undergraduate education for future teachers, and students

majoring in non-SME&T disciplines, and students preparing to enter technical fields and the professions; and

- expanding links with SME&T "communities" (government agencies at all levels, schools, scientific societies, professional associations, policy makers, public interest groups, and employers):

The Division of Undergraduate Education (DUE), assisted by members of the Advisory Committee for NSF Directorate for Education and Human Resources (EHR), has addressed the need for such improvements in a variety of ways. Some of these are:

- Providing the full-time support of the Division Director (on assignment from the Division of Undergraduate Education) Dr. Robert Watson, to the task of disseminating important information to the national undergraduate SME&T community from November 1996, through November 1998. During this period he has been leading and participating in workshops at regional events and scientific and professional meetings.
- Leveraging professional staff attendance at scientific and professional society meetings as occasions to disseminate findings and recommendations in *Shaping the Future*.
- Inviting academic institutions to host regional or local workshops in order to discuss and actively encourage faculty to participate in reform of undergraduate education in SME&T, with some logistical and financial support from NSF.
- Encouraging scientific and professional societies to continue to address the issues raised in *Shaping the Future*.
- Suggesting that NSF grantees participate in these same types of outreach efforts on their own or jointly with NSF program directors.
- Incorporating principles enunciated in *Shaping the Future* in the DUE Program Announcement, and seeking to evolve our programs in directions considered to be most fruitful to further the recommendations of *Shaping the Future*.
- Forming an alliance with major corporations and foundations through a Memorandum of Understanding, with the purpose of seeking their advice, counsel, and support.
- Continuing to fund the Institution-wide Reform initiative through FY 98.
- Emphasizing in all DUE programs the need to educate *all* students, especially those preparing to be teachers or to join the technical workforce armed with greater flexibility and enhanced skills.

External Assignment of Dr. Robert Watson

A key feature of the past several years is that these objectives are being pursued not only programmatically through NSF's competitive grant process, but also through extensive outreach activities by NSF/DUE program officers and principal investigators. The external assignment of Dr. Robert Watson, Division Director (on assignment) from the NSF Division of Undergraduate Education, has provided many professional groups assistance in accomplishing the objectives of encouraging improvements and reform in undergraduate SME&T education at the national level.

Dr. Watson accepted a two-year special assignment during the period November 1996, to November 1998: as visiting scholar at The American University in Washington, DC (where he is serving as Scientist-in-Residence) and at the National Research Council, where he is working with the leadership of colleges, universities, education associations, scientific and professional organizations, and with groups representing employers of college graduates (business, industry, school systems, and governments).

The primary purpose of this assignment has been to inform, encourage, and assist colleges and universities to implement key national improvements that have been developed, and to engage them actively and comprehensively in the reform of undergraduate SME&T education. The principal blueprint for these goals is the report of the EHR Advisory Committee, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139), however other reports—notably the National Research Council's *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology*—and materials from NSF-supported projects and programs also are providing valuable examples and information about ways to achieve successful reform.

A key strategy has been to engage scientific societies, professional associations, and educational associations in order to take advantage of their wisdom, and the great leverage and access that they have to many sectors concerned with undergraduate education. Dr. Watson has been engaged in doing this both directly and collaboratively with the assistance of NSF professional staff and members of the advisory committee to NSF's Directorate for Education and Human Resources responsible for writing the *Shaping the Future* report.

The recommendations of both *Shaping the Future* and *From Analysis to Action* have been discussed and presented in large national and regional meetings sponsored by these associations and societies, and also in planning sessions with their leadership. Increasingly, these societies are themselves publicizing *Shaping the Future* and sending copies of the report to their membership and to others with a stake in improving undergraduate education. Members of the societies and associations are expressing interest in hosting regional workshops at their campuses.

Campus-based regional workshops utilizing the report to directly promote reform serve as a second emerging mechanism. These workshops typically involve teams from institutions coming together to learn of national trends, of the work that others are doing, to share such information, and to develop their own plans.

As word of these activities has spread, individuals have requested advice and assistance at an increasing rate in their own efforts to improve SME&T undergraduate education. In most cases these are not inquiries about potential NSF support, but rather, requests for help in identifying best practices, invitations to on-campus or in-state promotion of education reform, and nomination of others to provide this type of assistance. As one example of this, a university leader called to ask for advice and assistance on the proposal that they are preparing for submission to the legislature.

Regional Workshops for "Shaping the Future"

The regional versions of NSF's July 1996 "Shaping the Future" conference are particularly noteworthy. The purpose of these regional workshops is to:

- facilitate specific regional and institutional plans to achieve widespread improvements in undergraduate education; and

- provide information to faculty and administrators on NSF programs and national activities to support undergraduate education reform.

The design of these workshops is determined by what is considered most effective by the host institutions with respect to their unique circumstances. The planning of these workshops generally embraces the following features:

- participation of institutional teams, representing faculty, administration, students, and business partners;
- significant involvement of employers of undergraduates;
- participation of public policy makers to engender public support for undergraduate education;
- development of institutional plans for reform of undergraduate education;
- exhibits of innovations in undergraduate education; and
- sessions to assist participants in developing projects and proposals.

Institutions have been encouraged to seek other academic hosts to share in the planning and design of regional workshops. Follow-up activities for the participants are also expected to be an important part of the workshop planning.

Strengthening Participation by Corporations and Foundations

During the last several years, NSF has strengthened efforts to increase participation by members of the business and foundation community in undergraduate education reform. A Memorandum of Understanding, representing commitment to cooperation for revitalization of the nation's undergraduate education has been crafted for this purpose. It reads:

> *In these rapidly changing times, the demands placed on the educational infrastructure of the nation, at all levels, are enormous and growing. This pace of change will continue to encourage cooperative relationships between all of those involved in, and all those who provide support for, the undergraduate education enterprise in the nation.*
>
> *We, the undersigned, are committed to nurturing the evolution of the highest quality undergraduate science, mathematics, engineering, and technology (SME&T) education, and to catalyzing working relationships between all parties involved in its delivery, and its support. Towards this goal we intend to cooperate with our colleagues in other private, government or industry oriented funding organizations that support undergraduate education in the nation. We intend to share information about our funding plans and funding profiles, to work towards common and complete assessment of our funded projects, to encourage the widest possible dissemination of project results, and, when appropriate, to support these projects through cost sharing partnerships. We intend to meet as a group periodically to share successes and to cooperate in developing national strategies in education. Through cooperation, we intend to amplify the impact of our individual efforts.*

As of August 1997, the following signatories have joined this alliance:

AirTouch Communications
Bayer Corporation
Bellcore
Boeing
Business-Higher Education Forum
The Camille & Henry Dreyfus Foundation, Inc.
DuPont
Exxon Education Foundation
General Electric Fund
Global Wireless Education Consortium
Hewlett-Packard Company
Howard Hughes Medical Institute
International Business Machines
Lockheed Martin
Lucent Technologies
Microsoft Corporation
Motorola
Pew Science Program
Shodor Education Foundation
Society of Manufacturing Engineers Education Foundation
Stratagene Cloning Systems
Technology Assessment and Transfer, Inc.
Texas Instruments
Toyota
Wolfram Research

Working Through Scientific Societies and Professional Associations

Scientific societies, professional associations, and associations of colleges and universities are key to effective dissemination of the recommendations of *Shaping the Future*. Consequently, one of the key focal points of the "Shaping the Future NextSteps" campaign has been to reach these organizations through the active assistance of Dr. Robert Watson and members of the Advisory Committee for Education and Human Resources at NSF.

The following organizations have participated in or otherwise sponsored activities in the reform of undergraduate education through the NextSteps campaign:

Accreditation Board for Engineering & Technology Inc. (ABET)
Affiliated Colleges & Universities Office (ACUO)
American Association for the Advancement of Science (AAAS)
American Association of Community Colleges (AACC)
American Association for Higher Education (AAHE)
American Association of Physics Teachers (AAPT)
American Association of State Colleges & Universities (AASCU)
American Chemical Society (ACS)
American Council on Education (ACE)
American Geophysical Union (AGU)
American Institute of Physics (AIP)
American Mathematical Society (AMS)
American Physical Society (APS)
American Society for Biochemistry and Molecular Biology (ASBMB)
American Society for Engineering Education (ASEE)
Association of Community College Trustees
Association for Women in Science (AWS)
Consortium of Social Science Associations (COSSA)
Council of Colleges of Arts & Sciences (CCAS)
Council on Competitiveness
Council of Scientific Society Presidents
Council on Undergraduate Research (CUR)
Education Commission of the States (ECS)

Institute of Electrical & Electronics Engineers (IEEE)
Mathematical Association of America (MAA)
National Academy of Sciences (NAS)
National Research Council (NRC)
National Association of State Universities and Land Grant Colleges (NASULGC)
National Council for Accreditation of Teacher Education (NCATE)
National Council for Resource Development (NCRD)
National Science Teachers Association (NSTA)
National Society of Black Engineers (NSBE)
SEMATECH
State Higher Education Executive Officers
Sigma Xi
Society for the Advancement of Chicanos and Native Americans in Science (SACNAS)

Chronological List of Conferences Sponsoring Workshops & Presentations in Support of "Shaping the Future NextSteps"

The following chronological list indicates many of the meetings, conferences, and workshops that have been employed by DUE staff to facilitate widening awareness and increased momentum towards improved undergraduate education in SME&T. Members of the Advisory Committee have often joined the DUE staff in these activities for Education and Human Resources. This list is not complete, but is representative of the breadth of activities undertaken. It extends back to March 1996, because by then many of the findings and recommendations of *Shaping the Future* were being discussed in draft form, in advance of the report's official release in July 1996.

March, 1996

- 1-3: Meeting of the Education Committee of the Geological Society of America (GSA), Boulder, CO
- 21-23: "The Genetics Revolution: A Catalyst for Education and Public Policy," a meeting for community college faculty sponsored by American Association of Community Colleges (AACC), local colleges, and Exxon Education Foundation, Dallas, TX
- 24-26: 211th annual meeting of the American Chemical Society (ACS), New Orleans, LA

April, 1996

- 13-15: Annual meeting American Association of Community Colleges (AACC), Atlanta, GA
- 16-18: Meeting of the Government-University-Industry Roundtable, Seattle, WA
- 26: Special meeting (invited address) with a number of private firms, Phoenix, AZ

May, 1996

- 2-5: Annual Washington, DC joint meeting of the American Physical Society (APS) and the American Association of Physics Teachers (AAPT)
- 7-10: International conference on Acoustics, Speech, & Signal Processing sponsored by the Institute for Electrical and Electronic Engineers (IEEE), and the Signal Processing Society, Atlanta, GA
- 20-22: Spring meeting of the Geological Society of American (GSA), Baltimore, MD

June, 1996

- 1-6: Annual meeting of the American Society of Biochemistry and Molecular Biology (ASBMB), New Orleans, LA

- 13: Introductory Physics Reform Conference: An Undergraduate Faculty Enhancement (UFE) Project, Joliet, IL
- 16-18: Conference on publishing strategies sponsored by DUE, Hampshire College, and Saunders Publishing Co., Amherst, MA
- 27-28: The 6th biennial national conference of the Council for Undergraduate Research (CUR), North Carolina Central University, Durham, NC
- 30-July 5: Gordon Research Conference - Innovations in College Chemistry Teaching, Plymouth State College, NH

July, 1996

- 11-13: National conference, Shaping the Future: Strategies for Revitalizing Undergraduate Education, Washington, DC
- 13-15: EHR annual Partnership Conference, Washington, DC
- 27-30: Annual meeting of the American Society of Plant Physiologists (ASPP) and site visit to Trinity College, San Antonio, TX
- 31- August 3: International Conference on Undergraduate Physics Education (ICUPE), College Park, MD

August, 1996

- 4-7: 14th Biennial Conference on Chemical Education, Clemson University, SC
- 4-8: 47th Annual meeting of the American Institute of Biological Sciences (AIBS), Seattle, WA
- 5-10: Summer meeting of the American Association of Physics Teachers (AAPT), College Park, MD

September, 1996

- 25: Meeting of the Texas Association of Schools of Engineering Technology (TASET), Austin, TX
- 28-29: Meeting of the American Society of Biochemistry and Molecular Biology (Human Resources Committee), Washington, DC

October, 1996

- 4: American Society for Engineering Education (ASEE) regional meeting, Fargo, ND
- 7-8: Meeting of the National Visiting Committee for the University of Cincinnati - American Chemical Society (ACS) project "Advanced Technological Education in Chemical Technology," Silver Bay, NY
- 11-12: Annual meeting of Mathematical Sciences Department Chairs, Rosslyn, VA
- 16-19: National Association of Biology Teachers (NABT), Charlotte, NC
- 25-27: Project Kaleidoscope (PKAL) Workshop on Interdisciplinary Approaches to Teaching Science and Mathematics, Colby College, Waterville, ME
- 30: American Association of Community Colleges (AACC) Task Force on Academic and Student Affairs, Arlington, VA
- 31-November 1: Annual meeting of the Accreditation Board for Engineering Technology, Inc. (ABET), San Diego, CA

November, 1996

- 2: Mathematical Association of America (MAA), DelMarVa section, Frederick, MD
- 3-5: Regional meeting of the American Society for Engineering Education (ASEE), Fargo, ND
- 5-8: Institute of Electrical & Electronic Engineers (IEEE) meeting, Denver, CO

- 6-9: 26th Annual meeting of "Frontiers in Education," Salt Lake City, UT
- 7: Annual joint meeting of the Alabama College Chemistry Teachers Association, Columbia, AL
- 7-10: Mathematicians and Education Reform (MER) workshop on "Teacher Education and Mathematics Departments," University of Illinois at Chicago, IL
- 8: Regional meeting, Issues in Gateway Chemistry Courses, University of Maryland, Baltimore County, Baltimore, MD
- 8-10: Project Kaleidoscope (PKAL) workshop, "Revitalizing Undergraduate Biology," Morehouse College, Atlanta, GA
- 12: NSF Forum on Distance Learning, Washington, DC
- 12-17: Meeting of the American Mathematical Association of Two-Year Colleges (AMATYC), Long Beach, CA
- 13: Industry-University-Government Roundtable, Bethesda, MD
- 14: American Chemical Society (ACS) meeting, University of Maryland, College Park, MD
- 14: Annual meeting of the Council of Colleges of Arts and Sciences (CCAS) - Deans, Philadelphia, PA
- 14-17: NSF sponsored Task Force on "Educating the Next Generation of Information Specialists," Omaha, NE
- 15-17: "Spheres of Influence: Shaping the Future of Earth Systems Sciences Education" Meeting, American Geophysical Union (AGU) headquarters, Washington, DC
- 21-22: Meeting of the Institute of Electrical & Electronic Engineers (IEEE) Computer Society Education Board, Pittsburgh, PA
- 22-23: Workshop on the programs of DUE and key aspects of proposal preparation, Inter-American University, San Juan, PR

December, 1996

- 10: "Results of NSF Review of Undergraduate Science, Mathematics, Engineering and Technology (SME&T) Education," National Technological University (NTU) Faculty Forum (via live national satellite broadcast)
- 15: Meeting with American Council on Education (ACE), Washington, DC
- 28-30: Annual meeting of the Society for Integrative and Comparative Biology
- American Association of Community Colleges (AACC) Presidents' workshop, Washington, DC
- Annual meeting of the American Society of Cell Biology (ASCB), San Francisco, CA
- National Council for Resource Development national conference, Washington, DC

January, 1997

- 4-10: Annual meeting of the American Association of Physics Teachers (AAPT), Phoenix, AZ
- 7: SUMMA (Strengthening Undergraduate Minority Mathematics Achievement) meeting, San Diego, CA
- 9-11: *NextSteps* presentation at the 6th annual meeting of the American Mathematical Association (AMA) and the Mathematical Association of America (MAA), San Diego, CA
- 15-19: *NextSteps* presentation at the meetings of the American Association for Higher Education (AAHE), San Diego, CA
- 28: Regional *Shaping the Future* workshop sponsored by the University of Washington and Bellevue Community College, Seattle, WA

- 30-February 2: Louisiana Collaborative for Excellence in Teacher Education regional workshop on *Shaping the Future*, Baton Rouge, LA
- 31-February 1: Oakton Community College workshop on *Shaping the Future*, Oakton, CA
- Joint annual meeting of Mathematics Societies, San Diego, CA

February, 1997

- 1-3: SEMATECH annual conference, Austin, TX
- 9-15: American Society of Limnology and Oceanography (ASLO), Santa Fe, NM
- 25: Annual meeting of the American Council on Education (ACE), Washington, DC
- 26: Meeting with the executive officers of the American Physical Society (APS) and the American Association of Physics Teachers (AAPT), with the staff from the American Institute of Physics (AIP), College Park, MD
- 28: Meeting of the American Psychological Association (APA), Washington, DC
- 27-28: Annual meeting of the ACM Special Interest Group in Computer Science Education (SIGCSE) and the ACM 50th Anniversary, San Jose, CA
- 27-28: Annual meeting of the National Visiting Committee of NSF Los Angeles Collaborative for Excellence in Teacher Preparation (LACTE), Los Angeles, CA

March, 1997

- 4: Meeting of the Federal Interagency Chemistry Representatives (FICR), Washington, DC
- 6: National meeting of the Association for Practical and Professional Ethics, Alexandria, VA
- 6-8: Annual conference of Sigma Xi, New Orleans, LA
- 10-11: North Louisiana Research Conference, Louisiana Tech University, Ruston, LA
- 13-19: Symposium, New Developments in Education in Analytical Chemistry, held at the 'Pittsburgh Conference' on Analytical Chemistry and Applied Spectroscopy, Atlanta, GA
- 14: Workshop II of Curriculum Development in Analytical Sciences, Atlanta, GA
- 14-16: Regional workshop on *Shaping the Future*, hosted by California State University at Los Angeles, Los Angeles, CA
- 14-16: Alliances for Minority Participation (AMP) - Teacher Preparation meeting, Puerto Rico
- 16-17: Meeting of the national conference steering committee for A National Urban Summit: Creating a Techno-Literate Workforce Through Major Policy Change - Forging Communication Among Business, Education, and Government for Strengthening Technical Skills Among Urban Students, Chicago, IL
- 16-19: The Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Atlanta, GA
- 23: Meeting with the Consortium for Social Science Associations (COSSA), Washington, DC
- 27: Meeting with the Delaware Community College System, Dover, DE
- 27-30: National Society of Black Engineers national conference, Washington, DC

April, 1997

- 7: *Shaping the Future* presentation at Washington & Lee University, Lexington, VA
- 10: *Shaping the Future* presentation at University of California, Davis, CA
- 11-12: The Council on Undergraduate Research (CUR) April Dialogue meeting: The Teaching-Research Connection, National Institutes of Health, Bethesda, MD
- 11-12: The Modular CHEM and ChemLinks consortia pedagogy meeting, Berkeley, CA
- 13-17: 213th National meeting of the American Chemical Society (ACS), San Francisco, CA

- 17-18: Meeting of principal investigators and evaluators, Systemic Change in Chemistry Curriculum project, Menlo Park, CA
- 18-19: *Shaping the Future* regional workshop, co-hosted by University of Missouri, Columbia, and St. Louis Community College, St. Louis, MO
- 18-19: Spring meeting of the MD/DC/VA Section of the Mathematical Association of America (MAA), College of William and Mary, Williamsburg, VA
- 18-21: Joint annual meeting of the American Physical Society (APS) and the American Association of Physics Teachers (AAPT), Washington, DC
- 20: Arizona State University faculty retreat, Tempe, AZ
- 24-26: National Council for Resource Development (NCRD) Regional IV Conference, Savannah, GA
- 24-27: Phi Theta Kappa International convention, Dallas, TX

May, 1997

- 8: Sigma Xi/A*DEC Town Meeting video conference on *Shaping the Future*, "Undergraduate Education to Meet Societal Needs in the 21st Century," Research Triangle Park, NC
- 8-9: Regional workshop on *Shaping the Future*, "Revitalizing Undergraduate Mathematics and Science Education: A National Dialogue," Michigan State University, East Lansing, MI
- 8-9: Edu.Tech@Work97 Conference and Expo, Bellevue, WA
- Meeting of the education board of the Association of Computing Machinery (ACM), Atlanta, GA
- 10-11: Regional workshop on *Shaping the Future*, "Revitalizing Undergraduate Mathematics and Science Education: A National Dialogue," The University of Michigan, Ann Arbor, MI
- 16: Presentation to the North Carolina Community College System, "Leading the Nation: Opportunities for Two-Year Colleges," Smithfield, NC
- 16-17: National Institute for Science Education (NISE) Workshop on Collaborative Learning, Madison, WI
- 19-23: 96th Annual meeting of the American Society for Microbiology (ASM), New Orleans, LA
- 24-25: 11th International *C. Elegans* research conference, Madison, WI

June, 1997

- 5-7: Program workshop, NSF Collaborative for Excellence in Teacher Preparation (CETP) program, attended by 10 Collaboratives, California State University, Dominguez Hills, CA
- 11-13: Meeting of Mathematics Across the Curriculum (MATC), Villanova University, Philadelphia, PA
- 15-17: Annual meeting of the American Society for Engineering Education (ASEE), Milwaukee, WI
- 18: Regional workshop on *Shaping the Future,* Central Washington University, Ellensburg, WA
- 20-21: 6th Conference on the Teaching of Mathematics, Milwaukee, WI
- 22-27: Unidata Workshop, Using Instructional Technologies and Satellite Data for College Level Education in the Atmospheric and Earth Sciences, sponsored by the University Corporation for Atmospheric Research (UCAR) and the National Center for Atmospheric Research (NCAR), University of Colorado, Boulder, CO
- 30-July 2: McNU 97, Northwestern University, Evanston, IL

July, 1997

- 10-12: 1997 Reunion of Research Opportunity Award (ROA) participants
- 14-17: Annual meeting of the Society for Industrial and Applied Mathematics (SIAM), Stanford University, Palo Alto, CA
- 19-20: Project Kaleidoscope (PKAL) workshop, Research-Rich Environments for Undergraduate Education, Washington, DC
- Annual meeting of the American Association of Medical Colleges, Washington, DC
- 22: Presentation of *Shaping the Future* recommendations to reviewers at the annual NSF DUE panel reviews of proposals submitted to its Course and Curriculum Design (CCD) and Undergraduate Faculty Enhancement (UFE) programs, Arlington, VA
- 24-26: 2nd Association of Computing Machinery (ACM) International Conference on Digital Libraries, Philadelphia, PA
- 29: *Shaping the Future* Workshop at Chautauqua Institute, Chautauqua, NY

August, 1997

- 23-28: ASBMB (American Society for Biochemistry and Molecular Biology) satellite meeting "2001: Biochemistry Education for the Millennium," organized by the Human Resources Committee of the ASBMB, University of California at San Francisco, San Francisco, CA.

September, 1997

- 16: Symposium on "Shaping the Future of Undergraduate Education and The Role of University, Industry and Government in the Development of Human Resources," The Inter-American University of Puerto Rico - Metropolitan Campus (IAU-M).

October, 1997

- 4-5: Project Kaleidoscope's annual workshop, "Reforming Earth and Planetary Science Curricula: What Works," Whitman College, Walla Walla, WA.
- 8-11: The 1997 Convention of the NABT (National Association of Biology Teachers) overview of Shaping the Future, Minneapolis, MN.
- 17: Workshop on "Shaping the Future: The Role of Two-Year Colleges" at the ACCT (Association of Community College Trustees) annual conference, Washington, DC.
- 24 - 25: Regional Shaping the Future workshop hosted by Drexel University, Philadelphia, PA.
- 25-27: Geological Society of America, GSA's Shaping the Future, Salt Lake City, UT.

November, 1997

- October 31-Nov 2: Project Kaleidoscope Workshop on "Enhancing Learning-Centered Environments: The Biology of the Future," University of Wisconsin, Madison, WI.
- 14: State of Maine Regional Follow-Up to Shaping the Future, Bates College, Lewiston, ME.

December, 1997

- 4: District of Columbia Section of the American Society of Mechanical Engineers, "Shaping the Future" and its implications for the mechanical engineering profession, Washington, DC.

January, 1998

- 4-8: Gordon Research Conference on Innovations in College Chemistry Teaching, Ventura, CA.

- 6-10: The annual joint meetings of the American Mathematical Society (AMS) & Mathematical Association of America (MAA), Baltimore, MD.
- 16 - 17: Workshop on the New Traditions Chemistry Initiative, Madison, WI
- 22: Maryland Collaborative for Excellence in Teacher Preparation Workshop on "Shaping the Future of Mathematics and Science in Maryland," College Park, MD.

February, 1998

- 14-15: Shaping the Future Follow-Up Conference, hosted by Birmingham Southern College, Birmingham, AL.
- 19-20: South Carolina Shaping the Future Conference, hosted by the University of South Carolina, Columbia, SC.

March, 1998

- 20: A Regional Conference on "Transforming Undergraduate Education in SME&T," hosted by New Jersey Institute of Technology, Newark, NJ.

April, 1998

- 3-4: A Regional Shaping Conference, hosted by Northeastern University, Boston, MA.

May, 1998

- 1: Meeting of the Governing Board of the Hispanic Asssociation of Colleges and Universities, Washington, DC.
- 1-2: A Regional Conference "Shaping the Future with Core Curriculum Reform: Guiding Undergraduate Education in SME&T," Colorado State University, Fort Collins, CO.
- 6: Meeting of the Education and Human Resources Committee of the Semiconductor Industry Association (SIA), Washington, DC.
- 8 - 9: A Shaping the Future Regional Conference, "From Dialogue to Action: Improving Instruction, Collaborations, and Partnerships in Mathematics and Science for All Students, A Workshop for Stakeholders in the Future of P-16 Education," hosted by at Clark Atlanta University, Atlanta, GA.
- 8 - 9: Regional New York Shaping the Future Conference, New York City, NY.
- 11 - 13: The North Dakota planning conference, "Reforming Undergraduate Science and Mathematics Education," Bismark, ND.

Bibliography of New Publications in Support of Shaping the Future of Undergraduate Education in Science, Mathematics, Engineering, and Technology

A much longer bibliography of material that influenced the preparation of Volume 1 of *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139) is available at the end of Volume 2. The following bibliography is provided as a separate listing of those published books and articles that appeared after the conclusions and recommendations of Volume 1 had been prepared.

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James Cooper and Pamela Robinson, *Annotated Bibliography of Science, Mathematics, Engineering, and Technology (SMET) Resources in Higher Education* (Working Draft, California State University - Dominguez Hills, 1997).

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S. C. Ehrmann, "Asking the Right Questions," *Change*, Vol. 27, No. 2 (1995), pp. 20-27.

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J.D. Herron, *The Chemistry Classroom: Formulas for Successful Teaching* (Washington, DC: American Chemical Society, 1996).

P. Hutchings, *Making Teaching Community Property: A Menu for Peer Collaboration and Peer Review*, American Association for Higher Education (AAHE), (Washington, DC: AAHE, 1996).

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Section II:

Program History of Undergraduate Activities at NSF
Since the Neal Report (86-100)

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Program History of Undergraduate Activities at NSF
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As was noted in *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139), the report of the 1985-1986 Task Committee of the National Science Board (86-100) has been the principal guide for the restoration and evolution of NSF undergraduate education activities since its acceptance by the Board in March, 1986. Presented in this section is more detailed analysis of some aspects of the Foundation's efforts to implement the 1986 report in the decade since. Small portions of text from Volume 1 of *Shaping the Future* are repeated here to aid the reader in recalling the framework.

The numerous recommendations in the Board Report fell into two categories: *Leadership* and *Leveraged Program Support*.

Leadership

The *central leadership recommendation* of the National Science Board Task Committee was that the Foundation

> *"Develop quickly an appropriate administrative structure and mechanisms for the implementation of these recommendations. The focal point should be the [Education Directorate]; it should foster collaboration among all parts of the Foundation to achieve excellence in science, mathematics, and engineering education."*

The Foundation established such a unit later in 1986. It has evolved into the present Division of Undergraduate Education (DUE) in the Directorate for Education and Human Resources (EHR). DUE staff of program officers is drawn from across the disciplines of science, mathematics, engineering, and technology. Many come from leadership positions in national organizations and from university faculties and administrations. Its programmatic offerings devote attention to the development and dissemination of innovative courses, curricula, and laboratories, as well as to the preparation and development of faculty, future preK-12 teachers, and technicians. Particular emphasis is placed on the translation of innovations among and between disciplines.

The Board Task Committee made 11 other leadership recommendations to the Foundation. It urged NSF to:

"(1) *Take bold steps to establish itself in a position of leadership to advance and maintain the quality of undergraduate education in engineering, mathematics, and the sciences*."

> NSF has clearly established the desired leadership position of the Foundation. Allocations of resources have been smaller than envisioned originally by the Board in some areas, but a little larger in others.

"(2) *Stimulate the states and the components of the private sector to increase their investments in the improvement of undergraduate science, engineering, and mathematics education*."

Beginning in 1980 with the *Experimental Program to Stimulate Competitive Research* (EPSCoR) and culminating with the establishment of the *Rural Systemic Initiatives* (RSI) program in 1997, the Foundation has fostered the creation of vigorous partnerships involving itself, individual states, and various private sector entities in substantial projects to improve research and education in mathematics, engineering, science, and technology. The emphasis has been on graduate and K-12 education, but articulation of school and college-level programming has been addressed by many of these projects. The partnership mode of project operation ranges in scope from adherence to matching funds requirements to the basing of projects in consortia and collaboratives. Examples of current undergraduate programs are the *Alliances for Minority Participation* and *Advanced Technological Education*.

"(3) *Provide a forum for consideration of current issues related to such efforts*."

NSF has gone far beyond this directive by sponsoring workshops, symposia, and conferences on disciplinary, cross-disciplinary, and institutional aspects of undergraduate education. The reports of these gatherings circulate widely and are highly regarded resource documents.

"(4) *Implement new programs and expand existing ones for the ultimate benefit of students in all types of institutions.*"

It was apparent to NSF from the start that the emphasis in this recommendation lay in the words *all types of institutions*. Doctoral universities submitted the great majority of successful education proposals in 1985-1986; but by 1994, special efforts by NSF resulted in their number being at least matched by proposals from two-year colleges, four-year colleges, and comprehensive universities. NSF supports the development of a broad spectrum of educational products (from innovative texts and software to new courses and curricula) has helped expand and improve student learning nationwide.

"(5) *Actuate cooperative projects among two-year and four-year colleges and universities to improve their educational efficiency and effectiveness*."

The principal concern in this area in 1986 was particularly the Advanced Technological Education program, for improved articulation between two-year and four-year institutions. While NSF programs have recently fostered the establishment of consortia and other types of cooperative projects, they have long addressed broader objectives by including two-year college faculty and institutions in the full range of undergraduate programs.

"(6) *Stimulate and support a variety of efforts to improve public understanding of science and technology*."

NSF has strong commitments to K-12 and informal science education evidence direct concern for public understanding. It is hoped that activities following upon the recommendations of this report will enhance efforts to address similar needs at the undergraduate level.

"(7) *Stimulate creative and productive activity in teaching and learning* (*and (8) conduct research on them*), *just as it does in basic disciplinary research. New funding will be required, but intrinsic cost differences are such that this result can be obtained with a smaller investment than is presently being made in basic research*."

The next section examines in detail the funding history of undergraduate activities at NSF. However, it is the case that the Division of Undergraduate Education allocates most of its resources quite directly to activities designed to improve teaching and learning. The Division of Engineering Education and Centers in the Directorate for Engineering and the Division of Experimental and Integrative Activities within the Directorate for Computer and Information Science and Engineering devote substantial portions of their budgets to undergraduate engineering education. Across the Foundation it is the scale rather than the scope which needs expanding. Although EHR Division of Research, Evaluation, and Communication vigorously supports research on teaching and learning, a special effort within this division, as well as those previously mentioned, should be made to stimulate proposals for research on teaching and learning at the collegiate level.

"(9) *Bring its programming in the undergraduate education area into balance with its activities in the pre-college and graduate areas as quickly as possible*."

The *balance* sought by the Board Task Group was dual—programmatic *and* fiscal. Between FY 1983 (when K-12 education was re-established at NSF) and FY 1986 (when the Board Committee made its recommendations), the main themes of NSF K-12 programs had become firmly established. While urging the restoration of a vigorous undergraduate program, the Committee wanted to ensure that it would be coordinated well with the Foundation's activities at the K-12 level (which produced undergraduate students and employed graduated teachers) and at the graduate level (where the products of undergraduate institutions are further educated).

NSF undergraduate programming in the Education Directorate was brought into that balance by three events: transfer of responsibility for Teacher Preparation from the Division of Elementary, Secondary, and Informal Education (ESIE) to DUE in 1993; establishment of the program in Advanced Technological Education in 1994; and start-up of the Institution-Wide Reform initiative, begun in 1995.

"(10) *Expand its efforts to increase the participation of women, minorities, and the physically handicapped in professional science, mathematics, and engineering*."

The Foundation as a whole has a good record of such efforts, and the record of the Directorate for Education and Human Resources (EHR) is especially good. In FY 1995, NSF allocated more than 3 percent of its budget to programs, in both the education and research directorates, designed to address underrepresentation. While all divisions of EHR share responsibility for addressing NSF educational objectives in this area, the Division of Human Resource Development (HRD) has the programmatic lead and has mounted a variety of programs designed to increase participation of women, minorities and persons with disabilities.

"(11) *Design and implement an appropriate database activity concerning the qualitative and quantitative aspects of undergraduate education in mathematics, engineering, and the sciences to ensure flexibility in its response to changing national and disciplinary needs*."

NSF Division of Science Resources Studies has principal responsibility for such database activity. At the present time, some of the Undergraduate Science, Mathematics, Engineering, and Technology (SME&T) Education Database content envisioned by the Board Committee is being built into the *Impact Database* of EHR's Division of Research, Evaluation, and Communication.

Leveraged Program Support

The FY 1995 NSF budget provided a very substantial sum for support of all but one (Information for Long-Range Planning) of the program categories detailed in the Neal Report. The total was actually in excess of the amount recommended for FY 1989 by the Report of the NSB Task Committee. In addition, NSF undergraduate support in FY1995 included programs in categories not mentioned in the Neal Report (*Teacher Preparation and Advanced Technological Education*). How well NSF has done by the Neal recommendations is a judgement that should reflect ten years of experience and hindsight; and it should be informed by comparison with the intent of the recommendations.

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
Arlington, VA

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

Dean, Graduate Studies & Vice Provost, Academic Outreach
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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 the U.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"

Eleanor Baum

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Winfred Phillips

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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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***Winfred M. Phillips** is currently Dean of the College of Engineering at the University of Florida and Associate Vice President for the Engineering & Industrial Experiment Station. He is currently President of the American Society for Engineering Education; President of the American Institute for Medical and Biological Engineering; Past President of the Accreditation Board for Engineering & Technology; Governor of the American Society for Mechanical Engineers; Vice Chair of the Board of Directors of the Southeastern Consortium for Minorities in Engineering; and serves as corporate director and member of a number of industrial, state and national scientific advisory boards. He was Professor and Head of the School of Mechanical Engineering at Purdue University from 1980-88. Prior to this, he was a Professor of Aerospace Engineering; Associate Dean for Research in the College of Engineering, 1979-80; and Acting Chair for the Intercollegiate Bioengineering program, 1978-79 at Pennsylvania State University. Dr. Phillips received a Bachelor of Science in Mechanical Engineering in 1963 from Virginia Polytechnic Institute; a Master of Engineering in Aerospace Engineering in 1966 from the University of Virginia; and a Doctor of Science in Aerospace Engineering in 1968 from the*

University of Virginia. Dr. Phillips was granted a National Institutes of Health Career Development Award in 1975-80, named Distinguished Hoosier by the Governor of Indiana in 1987, and serves as a Governor appointee to the Enterprise Florida Technology Development Board and the Southern Technology Council. He is Chairman of the Board of the North Florida Technology Innovation Corporation, Inc. of Gainesville and Vice Chair of the Council for Economic Outreach, Inc. Dr. Phillips is author of over 140 research publications, and his personal research and teaching interests include mechanical engineering, fluid mechanics and biomedical engineering.

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 21st 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:

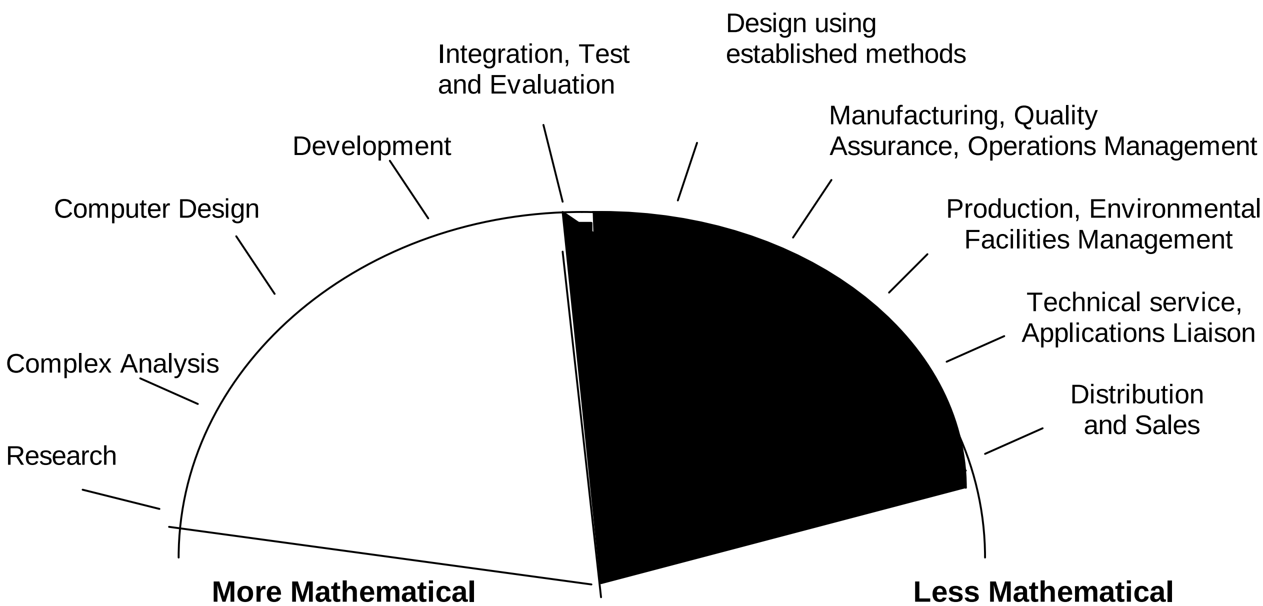
> "Engineering technology is that part of the technological field that requires the application of scientific and engineering knowledge and methods combined with technical skills in support of engineering activities; it lies in the occupational spectrum between the craftsman and the engineer at the end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

***Angelica M. Stacy** joined the Department of Chemistry at Berkeley as an Assistant Professor in 1983 and has been a Professor since 1994. Her educational interests include the development of environmental and biologically-relevant chemistry laboratory experiments for freshman chemistry; development of curriculum materials using a modular approach to lecture and laboratory, where each module is motivated by an overarching question of interest to the students; this serves as a springboard to teach chemical concepts; and implementation of teaching methods which emphasize active learning and metacognition and incorporate mutimedia tools. Additionally, Dr. Stacy's research interests include the synthesis and characterization of new solid state materials with novel electronic and magnetic properties; development of new synthetic methods, including the use of molten salts for the synthesis of oxide materials; discovery of new layered niobium oxide superconductors; synthesis of polymeric transition metal chalcogenides; and studies of cooperative phenomena in rare earth transition metal phosphides.*

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 - andare 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.

***Robert C. Hilborn** received a B.A. in physics from Lehigh University in 1966 and his Ph.D. in physics from Harvard University in 1971. Following a two-year postdoctoral position at the State University of New York at Stony Brook, he taught physics for 13 years at Oberlin College. In 1986 he moved to Amherst College as Professor of Physics, where, in 1993, he was named Amanda and Lisa Cross Professor. He has been a visiting faculty member at the University of California at Santa Barbara, Taiwan Technical University in the People's Republic of China, and at Georgia Institute of Technology. During 1996 he served as President of the American Association of Physics Teachers. He is also a member of the American Institute of Physics Governing Board and the Council of the American Physical Society. In 1994 Oxford University Press published his book* Chaos and *Nonlinear Dynamics: An Introduction for Scientists and Engineers.*

Scientific Elite or Outcast?

Eric Mazur

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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

Tanya Atwater

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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.*

Written Contributions to the EHR Advisory Committee Public Hearing on Institutional Perspectives

Convened October 25, 1995
At the National Science Foundation
Arlington, VA

Invited Speakers:
"Institutional Perspectives on SME&T Undergraduate Education"

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

Grinnell College *Grinnell, Iowa*	**Pamela A. Ferguson** *President*
Emory & Henry College *Emory, Virginia*	**Thomas Morris** *President*
Onondaga Community College *Syracuse, New York*	**Bruce H. Leslie** *President*
St. Louis Community College *St. Louis, Missouri*	**Gwendolyn W. Stephenson** *Chancellor*
American Association of Community Colleges *Washington, District of Columbia*	**David R. Pierce** *President*
Florida A&M University *Tallahassee, Florida*	**Frederick S. Humphries** *President*
University of Maryland, College Park *College Park, Maryland*	**William E. Kirwan** *President*
American Association of Colleges & Universities *Washington, District of Columbia*	**Paula P. Brownlee** *President*
New Jersey Institute of Technology *Edison, New Jersey*	**Saul K. Fenster** *President*
Portland State University *Portland, Oregon*	**Judith A. Ramaley** *President*
University of Wisconsin - Madison *Madison, Wisconsin*	**David Ward** *Chancellor*
University of Michigan - Ann Arbor *Ann Arbor, Michigan*	**Homer Neal** *Vice President for Research*

Institutional Perspectives of College and University Leaders on Undergraduate Education and the National Science Foundation

Pamela A. Ferguson

President, Grinnell College
Grinnell, Iowa

We must ask three questions as we reckon with the worth of existing programs and entertain the addition or expansion of others:

1). What does the nation need in its workforce and its scientists?

2). What does NSF have to do with filling this need?; and

3). How does undergraduate education relate to the nation's needs and NSF?

I will try to paint the picture as most of my colleagues and I see it. A vital workforce for the 21st Century is peopled with the technically literate, inquisitive, and entrepreneurial in spirit. It is this workforce that will discover new technologies, use these technologies, and keep us as a major contributor to the betterment of this nation and the global community. Undergraduate education is not an auxiliary enterprise– it is a conduit and the birthplace for most scientists and a significant portion of the workforce.

NSF has successfully created a research infrastructure in which people are stimulated to have new ideas, with the confidence that, if their peers find an idea meritorious, funding will be provided to explore the idea. This is consistent with NSF's mission to provide the nation with both scientific knowledge and scientists– it is consistent with the nation's need to be a competitive force in an ever-changing, technologically sophisticated world.

This same infrastructure which enables and promotes people to take risks to do interesting things must be further developed for the undergraduate sector. We need to improve undergraduate science education so that our workforce is technically literate as well as to train the small percent who will be future scientists – including those few who will join the likes of Tom Cech (a Grinnell alumnus who recently received the National Medal of Science) or the late Robert Noyce (a Grinnell alumnus who co-invented the integrated circuit). Science education should be an embodiment of the entrepreneurial spirit because staid teaching begets staid students.

NSF can make a difference with funding and programs that are responsive to innovative ideas coming from the teaching community. It needs to support faculty and students the way it supports researchers because the undergraduate sector is the source for the researchers as well as educational citizens and multitudes of workers. One example of an extremely successful program is the Instrumentation and Laboratory Improvement (ILI) program, which provides modest support for instrumentation for teaching. In effect, however, it catalyzes major curricular renovation. The ILI program has been evaluated several times and has received glowing reviews.

In the ILI program, dollars are highly leveraged. A minimum of 50 percent of the funding must come from non-federal sources. Furthermore, no funds are provided to support personnel to actually develop experiments making use of the new instrument. There are other leveraged aspects to the program. Other faculty at the institution will notice the instrument, learn to use it, and devise unforeseen curricular changes. Furthermore, students and faculty involved in research projects will undoubtedly use the instrument. Faculty (either formally through publication or informally) tell their colleaguesat other institutions of their successes and encourage them to mount similar efforts.

DUE has done a remarkable job, especially considering that funding was cut to zero dollars in the early 1980s. Since then, they have developed several programs that serve the community well. To address the issue of teaching and learning science at the undergraduate level, three areas need attention.

First, research and teaching still remain divorced at NSF. The programs, which support undergraduate research, are not cognizant that among the most important products of research at undergraduate institutions are the students. At an undergraduate institution, research not only contributes to the scholarship in a field, but it is a tremendous learning ground for students. Students learn, by doing science, what it is to be a scientist, how to ask questions, how to deal with the many obstacles that inquiry presents and the exhilaration of discovery.

Currently, NSF REU and RUI support is targeted only at the most elite institutions. It effectively discourages most faculty at undergraduate institutions from pursuing research projects because they know that their research can not be as grand as that at large research institutions, because their research will have multiple roles and thus may take longer to complete. Cognizance, during review and funding, of the additional and essential role of research as a teaching tool at the undergraduate level has the potential for institutional change. As is, undergraduate faculty finds it difficult to compete for research support – the effect – fewer students get to learn what science is really about and there is no mechanism by which an institution can improve its programs.

Why is integrating education and research, providing hands-on learning opportunities for students – at all levels and with different career aspirations – in the national interest? The answer is clear and I reiterate: we need a workforce for the future with the kind of skills learned through a rigorous encounter with science and mathematics; we need a citizenry prepared to make decisions about issues with scientific and technological dimensions. Research experiences provide these skills. The corporate leaders on my Board of Trustees regularly describe the kind of people they seek to hire: persons who can ask questions, solve problems and work collaboratively; persons who know how to communicate the results of their work; and persons who know how to use computers and other sophisticated equipment.

Such skills are developed when students have the opportunity to “do science” as scientists do science. More and more, what is happening on campuses across the country is that students are being taught how to ask questions, question evidence, and use computers and other sophisticated instrumentation in seeking answers. Many of the innovative courses now being developed for beginning students provide “research training” opportunities. These courses challenge students to take an active (rather than passive) role in shaping their understanding and to work collaboratively in teams – sharing ideas freely and taking collective responsibility for the results of their work.

We recommend that DUE establish a program of support for undergraduate research which is cognizant of the impact research has on increasing the number of scientifically literate students and potential scientists, as well as the impact that research at undergraduate institutions can have on the quality of the instructional program and faculty of the institution.

The second point I would like to make is that attention must be placed on undergraduate faculty development. A program that truly supports faculty development in teaching/research is needed. I make research and teaching a singular noun because at the undergraduate level, research informs teaching, the two go hand in hand. A program is needed to provide time for faculty to explore bold initiatives to reach more students or teach in a new way. Faculty at two and four-year colleges often teach in an atmosphere where there is not much research occurring. These faculties need to periodically step back into a research-rich environment to replenish research skills and their awareness of current science. Faculties at research universities often are not in an atmosphere, which is conducive for curricular and pedagogical development.

We recommend that a program should support summer or academic year leaves for faculty to work on research or curricular projects that will have an impact on the vitality of the faculty as well as the academic program.

The third issue we must address is that the undergraduate sector is comprised of a great variety of institutions. If we are really attending to the future workforce, we must be conscious of their educational origins, which include two-year colleges, four-year public and private colleges, night schools, and large comprehensive universities. NSF has had a laser approach to a spectral issue. Funding and programs need to reach into where the students are. Scientific literacy is not going to be attained by focusing most support on one, narrow sector of the populace.

The Neal Report targeted a program of comprehensive institutional reform, but DUE has not had the resources to implement such a program. We recommend that such a program be established which would support promising institutions. This program would recognize that real improvement would involve instrumentation, curriculum, and student-faculty research opportunities.

Grinnell has played a leading role in a consortium that has been funded by NSF to reform calculus and a current project to improve chemistry education. We can see that these projects have a tremendous local impact as well as changing the national sense of undergraduate education. It is unfortunate that DUE can only support programs in mathematics and chemistry. We recommend that these highly successful systemic reform efforts be expanded to other science disciplines.

I will conclude with the following observation. We have all talked about the need for improved educational experiences for our children. We have publicly acknowledged that our future leadership, tomorrow's workforce, is today's children. Yet, we do not adequately support the one profession in whose hands these children are. I am talking about teachers from kindergarten through college. NSF, with its dual mission of promoting the human resources as well as the discoveries, has the unique opportunity to make a difference. Through programs which fund teaching and learning science, that barrier between research and teaching dissolves, and the perception of teaching as a lesser endeavor diminishes.

NSF has the power not only approve of innovations in teaching but raise the value of the activity. Such legitimacy will have a direct impact on this future workforce. NSF grants to the undergraduate community set the standards for our work in research, research-training, and education; they provide further incentive to colleges by helping to set parameters for effective planning for curriculum; they leverage critical dollars from other donors, and they enable us to make a significant contribution to the community. To double the budget currently allocated for DUE programs would support our nation's focus on the future workforce. Such an increase [would equate to] doubling a very small fraction (about 3 percent) of NSF budget.

In summary, we have four recommendations:

1) We recommend the creation of program to support research at undergraduate institutions, cognizant of the teaching role research plays at undergraduate institutions.

2) We recommend a faculty development programto support summer or academic-year leaves to support research in curricular development at the undergraduate level.

3) We recommend a program to encourage comprehensive institutional reform.

4) We recommend a program to support systemic educational reform initiatives in the SME&T disciplines.

Pamela A. Ferguson *is currently president and professor of mathematics at Grinnell College. Previously she was associate provost and dean of the Graduate School at the University of Miami where she was responsible for approximately 45 doctoral and 100 masters programs and an undergraduate honors program for 1,600 students. Early in her career she was also an assistant professor of mathematics at Northwestern University. A graduate of Wellesley College, Dr. Ferguson received M.S. and Ph.D. degrees in mathematics from the University of Chicago with National Science Foundation Fellowship support. A member of Phi Beta Kappa, Omicron Delta Kappa, and Sigma Xi, she has received numerous teaching awards. She is a member of the Mathematics and Education Reform Network, the Mathematical Society of America, the American Mathematical Society, and the Association for Women in Mathematics. She served on the Florida Advisory Council for Math, Science, and Computer Education and currently serves on the board of the Iowa Research Council. Her professional activities have included lectures or participation in conferences in the USSR, West Germany, Scotland, England, Hungary, Italy, and many universities in the United States. She is the author of more than 45 articles in leading American and foreign mathematical journals on topics on finite group theory and combinatorics.*

Testimony on the Views of Institutions Toward Undergraduate Education in Science, Mathematics, Engineering, and Technology[1]

Thomas R. Morris

President, Emory & Henry College
Emory, Virginia

I appreciate the opportunity to be here. I am a humble social scientist. I taught political science at the University of Richmond for 21 years before going to Emory & Henry College, where I am in my fourth year as president.

As a political scientist at the University of Richmond, an outstanding small university, I had virtually no contact with natural scientists. They were on the other side of the lake. But one of the things that I found to be very different when I went to Emory & Henry College was the interaction among faculty from different departments. Perhaps it was in part because I had become an administrator and was more aware of the contact. However, I also think it was due in part to the smaller size of the college as measured by faculty size. I moved from an institution with 160 to 175 faculties to one where the faculty totals only 60 to 62. I can report to you that the natural scientists *do* talk with people in the other areas in my institution; there is a great deal of interaction. Because of this interaction, I think there is an opportunity for integrating curricula that you might not have even in small universities, not to mention large universities.

I don't go anywhere without at least saying a word about Emory & Henry College. I believe it is in my contract somewhere. We will be 160 years old next year. The "Emory" was a Methodist bishop, and the "Henry" was Patrick Henry. We consider ourselves to be a premier Appalachian Region, church-related, small liberal arts institution. And for a good number of those 160 years in the Appalachian Region of southwest Virginia and northeastern Tennessee, Emory & Henry have held up the flag of liberal arts education. We have also had a good tradition over the years of turning out science graduates who have gone on to graduate and professional schools and to employment in scientific and technical occupations. There was a period of time when we had a faculty member with strong connections with NASA, and NASA employed many of our graduates. A good number have also ended up in medical professions.

We are associated with the Virginia Foundation of Independent Colleges, one of 15 institutions in that fundraising organization. We are one of 32 institutions in the Appalachian College Association, and we are one of seven institutions across the country that have Bonner Scholar endowments that allow us at Emory & Henry to support 85 students who are of high financial need. In exchange for that financial aid, these scholars perform ten hours of volunteer service in the community each week, as well as participate in a summer program.

I mention those associations to just give you some idea of where we fit into the higher education environment. The University of Richmond, a member of the Virginia Foundation of Independent Colleges, for example, has an endowment of something over $450 million. Most of the institutions in the Appalachian College Association have endowments that are under $8 million.

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[1] This text is an edited version of Dr. Morris' verbal testimony to the EHR Advisory Committee on October 25, 1995.

The size of endowments has implications for the ability of small colleges to improve undergraduate science education. I believe that I am here to speak on behalf of the less well-to-do small liberal arts colleges in the country. I would like to recount a story about a small college president that rings true with me. He was walking in the woods, happened to look down, and saw a shiny object. He pushed the leaves aside and picked it up, and discovered it was a lamp. Being well-educated, he began to rub it, and, sure enough, a genie popped out. Upon learning that the person rubbing the lamp was a college president, the genie said: "I am able to grant you one wish. You may have health, you may have wealth, or you may have wisdom."

The college president reflected and said, "Well, I deal with ideas, work with faculty, and make important personnel decisions, so I certainly should choose wisdom." The genie said, "So be it" and was gone. Endowed with his new wealth of wisdom, the college president sat down on a log to reflect and, a few minutes later, stood up and said: "I should have chosen wealth."

Most of us interested in the health of small liberal arts colleges think that what we need is wealth. At Emory & Henry College, for example, we are getting ready to start another capital fundraising campaign. In my inaugural address, I singled out the arts and the sciences as two areas where I thought we needed to reinvigorate our programs. One of our goals is to raise approximately $8 million to build a new science classroom building. The building we have now is 40 years old, inadequate for the kind of program that we would like to have. In addition, we need at least $1 million to purchase modern laboratory instrumentation for use by our students and faculty, and we also have a campaign goal of accumulating a $3 million endowment to support the updating of technology and instrumentation on an ongoing basis.

At a small institution like Emory & Henry College, we are not certain exactly how we will raise those funds, but that is what capital funds campaigns are all about. We will approach our alumni, particularly those who have gone into the sciences and into the medical professions. We will attempt to do some sight raising with regard to what they might do to contribute to support of the classroom building and the endowments that are necessary to maintain a strong science program.

In other areas, I can easily support [Grinnell College President] Dr. Pamela Ferguson's recommendations. Certainly her testimony earlier today is appropriate for all of the college and university presidents who are talking with you today.

Two major problems for us are limited faculty time and shortage of resources. These are the major obstacles to a successful undergraduate science program, at least at the small college level. In preparation for this session, being a social scientist, one of the things I did was to sit down with the natural scientists at Emory & Henry College and talk about some of the things that were important to them.

Our greatest challenge is to generate the resources to purchase, support, and maintain the instrumentation necessary for our laboratories. We do benefit from a roving repair van that NSF helped us with, which is very useful to the small colleges of the Appalachian College Association, it makes its way around the Appalachian Region and assists the Labs operated by member institutions with needed repairs. That form of collaboration and sharing of resources is very helpful in meeting our instrumentation needs.

With respect to resources, our natural science faculty suggest that colleges with small endowments and more limited resources, however that might be defined, should perhaps be offered less challenging matching requirements and/or longer periods to raise such funds. They also suggest that the application process for programs that NSF wishes to encourage with small amounts of money – up to $10,000, perhaps – be simplified, and they request a simplification of the forms for application and reporting so that they are relatively easy to fill out. Perhaps it was somewhat self-serving on the part of the natural science faculty on our campus, but they suggested that some resources be limited to persons who have not previously been supported by NSF.

We work with the private sector at Emory & Henry. The college has an association with the Eastman Company, not too far from where we are located in southwest Virginia. Recently, Eastman shared with us three important pieces of instrumentation for our Chemistry Department, which were happily received by the members of our Chemistry Department.

Now, with regard to faculty development, I would second all that Dr. Ferguson [president of Grinnell College] said about the importance of that, and particularly the idea of making teaching and research a singular noun. At Emory & Henry, for example, the Physics Department and the head of the Education Department are spending time talking about a conceptual physics course that would be required of all people who are going into teaching. There is a "Teaching of Science" course that is taught for education majors, and there is a great deal of dialogue that goes on between the education faculty and the natural science faculty with regard to what ought to be addressed in that particular course.

The second point I would make is that our greatest contributions to undergraduate science education are the collaborative and integrated teaching innovations that characterize our institutions. As we are all well aware, the excitement of the scientific technique is not generally a part of what goes on in elementary, middle school, and secondary education. Students come to undergraduate institutions like Emory & Henry without having had that experience. Someone has suggested that there is probably more vocabulary in a high school chemistry class than there is in most foreign language courses, to the extent that students have been subjected to simply memorizing and dealing with vocabulary rather than the excitement of the scientific technique at the K-12 level, that makes it more difficult for students and faculty when they advance to the higher education level.

So what I would want to leave with you is the challenge of recognizing that opportunities for creating innovations in undergraduate science teaching are present, particularly at small liberal arts colleges. These colleges do not have the institutional barriers that are more likely to be in place at the large research institutions. One of the things I would encourage the National Science Foundation to do is, support those faculty who are willing to work with innovative, integrative, and collaborative teaching possibilities; with regard to undergraduate science education, then follow up on an ongoing basis, evaluate the effectiveness of new approaches, and find ways to report methods and findings to the larger academic community, through articles, lectures, and workshops.

I would argue that at this time in our history, it is probably as important to be putting resources into how students learn science as perhaps it is into the more traditional type of science research that is going on, and the laboratories in the form of small liberal arts colleges are there to make that possible.

Thomas R. Morris *assumed office on July 1, 1992, as the 19th president of Emory & Henry College. A distinguished Constitutional scholar and political scientist, he brought to the college 21 years of higher education experience at the University of Richmond. Dr. Morris also is well known on a state and national level as an astute political commentator and writer. A native of Galax, Virginia, Dr. Morris earned a bachelor's degree in government at Virginia Military Institute, studied at Princeton University, and then completed Masters and Doctoral degrees in government at the University of Virginia. He received fellowships for additional advanced study including a year as a Liberal Arts Fellow at the Harvard Law School and a year as a fellow of the National Endowment for the Humanities at the University of Wisconsin-Madison. He has also served as a political analyst for television, radio, and print media over the past fifteen years.*

NSF Review of Enhancing Science, Mathematics, Engineering, and Technology Education

Bruce H. Leslie

President, Onondaga Community College
Syracuse, New York

Thank you for the opportunity to share my thoughts and those of my colleagues regarding science, math, engineering, and technology education (SME&T). The invitation comes at a time when our nation appears to be redefining itself in the post-Cold War era, but also at a time when new extraordinary forces are rapidly exerting their influence upon the void created by the end of superpower military competition, replacing it with complex economic competition. Science and technology are, many of us contend, more important in this new era, than ever before.

There are a number of obvious problems with the current state of science and technology. Such problems are cyclical and reflect the need for adjustments in our response to shifts in the environment. Many of us are the product of such a response by the nation to *Sputnik*, which created "accelerated" federal initiatives in our math and science education programs to correct newly perceived deficiencies. Perhaps a similar response is called for today, despite the differences in the environment of the late 1990s vis-à-vis the late 1950s. Just as opportunities presented themselves 30 years ago, today's opportunities should be capitalized upon to positively affect our national competitive and social objectives. In one sense, NSF has already initiated such a response by greatly expanding its interest in, and support of, the nation's community colleges. The other half of our undergraduate students now have the opportunity to be impacted. My colleagues and I are most grateful.

Rather than summarize perceived problems, for they are explored more effectively in numerous other venues, and are inferred in my comments, my intent here is to suggest the possibilities inherent in today's environment. Such opportunities exhibit themselves in the following themes:

1. The growing national agenda to address the needs of youngsters so they are adequately prepared for success in school. Programs such as *Head Start*, Eisenhower grants and *Success by Six* exemplify this trend.

2. Recognition that youthful excitement and discovery, brought naturally into the world, but often suppressed early in childhood, must be enhanced and nurtured, especially in a world where "life-long learning is the only job."

3. Capitalizing upon the *Nation at Risk* movement that has been, for the past decade, gradually changing our thinking about how best to foster learning.

4. The infusion of technology, especially computers, into our schools, homes and day-to-day world.

5. The growing interest by the business community to ensure a technologically sophisticated populace both to provide the needed workforce and a consumer capable

of using, and thus interested in buying, the increasingly complex products being developed. Our very economy, and the success of business, depends upon an educated citizenry. As the world becomes better educated, this will become a greater competitive challenge and opportunity for business.

6. The internationalization of the economy, a growing worldwide competitive environment, and increasingly sophisticated defense requirements created by a changing world, suggest that the nation's continued strength is dependent upon maintaining a technological edge across all sectors of public and private systems.

These opportunities describe an agenda for improvements in the SME&T aspects of our educational system. Three specific recommendations should drive NSF's considerations:

1. We know what works. NSF should help the nation's educators implement the proven principles. Although continued exploration to improve learning is important, fewer resources require us to widely apply what we already know.

2. SME&T must be infused with broader skills, which today are required in the workplace: customer orientation, quality, teamwork, problem solving and leadership.

3. Colleges must apply affective domain strategies, especially for second and third quartile students who can and must succeed. The traditional emphasis on the discipline itself excludes the larger proportion of our citizens.

In order to profit from the opportunities before us, four themes are recommended:

1. Improvements must begin with the faculty. Each of us has personally experienced or observed the positive affect a teacher can have on a student by inviting her/him into a course or discipline. Conversely, teachers too often discourage a student from pursuing a field or career, especially in math or science, by ignoring or redirecting them to "easier" studies. Faculty who must democratize the process will recruit the future generation of scientists and technicians. To achieve this, faculty must:

    - Receive better preparation in graduate school to become recruiters and nurturers of the next generation of scientists by learning how to excite students into entering these fields. Faculty should become skilled at positive reinforcement and the means by which students can be encouraged to pursue SME&T. Students of color and women must receive strong encouragement to enter these fields. So called "average" students must be nurtured since almost every future employee must be sophisticated in math and technology. Such programs as the NAACP's *Act-So*, science fairs, and kids colleges create enthusiasm that attract potential scientists of any age.

    - Diminish the "elitism" of SME&T so that fewer individuals will be intimidated by study in these fields and more will choose to enter the professions, especially at the technician level where job data suggests strong future growth. Faculty is especially important in the decisions many students make to pursue or not to pursue such studies.

- Be skilled as learning facilitators, not lecturers, and curriculum designers, not just subject matter experts, with an emphasis on application, learning outcomes, measurements, and subject integration among relevant disciplines. All current faculty must be similarly retrained.

- Be student centered rather than faculty centered. Learn how to nurture and/or reinvigorate students' excitement and positive self -concept about learning SME&T.

- Be steeped in the use of such techniques as classroom research, learner-centered instruction and team study.

- Infuse curricula design and instructional tools with the interests of the secondary schools and employers. The transition from school to work should be "seamless."

- Become sophisticated in organizational operations, to better structure disciplines within the college or university in ways, which facilitate realization of educational ends. The barriers between subjects and disciplines must be removed so that the integration of knowledge is modeled for students.

- Be competent in the use of computers, not only in the demands of the discipline, but in their use as instructional and class management tools as well.

- Commit to life long learning in order to remain current in the discipline*and* in the classroom.

- Be open to business sector professionals who often have more knowledge of learning theory and curricular design than academics. ASTD and other professional associations produce and distribute the most current research materials in learning theory. Such companies as Motorola and Nvnex are demanding outcome accountabilities from their educational venders and are teaching college faculty how to adopt new learning theories. Educators must become open to such expertise, rather than reject it because it's from outside the academy.

- Become knowledgeable about the national skills standards program and, with employer's active involvement, integrate results into the curricula.

- Make mathematics a more accessible and less threatening language to American students. It should become more applicable and less theoretical so that students understand its use and importance.

2. Post-secondary institutions are in the position to provide leadership. They must:

- Invest in faculty development as described above.

- Ensure faculty have the technology available and working, and the means to use it.

- Structure the college, organizationally and within facilities, so that curricula and disciplines are integrated. The academic department, both structurally and geographically within the college, reinforces isolation of disciplines and faculty. New structures must be explored which create an academic version of a business environment where information flow, organizational learning and technology interface. This is the developing model of the post industrial information age. Education should adjust itself, as it did in the beginnings of this century, to reinforce demands on both its management and "production."

- Provide the means to define, measure, and continuously improve learning ends. This will distinguish the college as accountable at both the management and academic levels, and build trust with employers, sponsors and, most importantly, students and their sponsors.

- Initiate tech-prep, school to work, co-op, apprenticeship and other such models to create the relationship between college, business and student, that provide the practical work skills necessary.

- Ensure the curriculum emphasizes SME&T within a framework of the humanities.

- Partner with business to explore and, where appropriate, implement the results of the national skills standards program.

- Reward faculty for applied teaching rather than research, for being risk takers, for being change agents rather than the defenders of the proud traditions of academia, for forming alliances with business and community.

3. Because of the multiple level of employers' interests in a technologically sophisticated society they should:

- Become invested in the development of our nation's students. The German approach is not the only possible model, but its integration of business into the nation's educational system provides many benefits to both. An "apprenticeship" emphasizing science, math, engineering and technology already exists through co-op programs and is being expanded through tech-prep initiatives. Business should greatly expand opportunities by utilizing such models as the Ford Asset program, which prepares automotive technicians through community colleges and co-ops with the sponsoring dealers. The faculty receives annual training and the college new technologies. But must important, the students are employed by the dealer upon graduation, and ready for a successful technological future.

- Assist secondary and post-secondary institutions by contracting with faculty. Such arrangements increase their knowledge and enhance the preparation of students. Many of the skills today's employers require, including in SME&T, such as teamwork, problem solving, leadership, quality, customer orientation, and organizational understanding (see Tony Carnavale, Workplace Basics: Skills Employers Want, *The American Society for Training and Development*, 1990), are most effectively taught through work place application.

- Partner with education to ensure the technology is adequate and remains current. The company benefits by ensuring new employees are adequately prepared and existing employees are continuously retrained without down time at the business. Ford ensures this through its*Asset* program; but smaller, local businesses reap similar benefits through modest investments. Education's ability to remain current in technology will depend to a large extent on business investment in such alliances.

- Partner with education to implement the results of the national skills standards program. Together, this effort, which is similarly occurring in many other nations, may provide important benefits to both business competitiveness and development. Jamie Houghton, president of Corning, is the chair of the board, indicating the level of business interest in the 22 projects underway.

4. The National Science Foundation and other federal programs can support the necessary changes by:

   - Establishing a national agenda, which integrates employers, educators, and students into a “seamless” system of learning from elementary through college and life-long education.

   - Nurturing the public's awareness of, and interest in, SME&T by clearly describing the need and defining understandable national objectives. Then funding programs which, on a long-term basis, will reinforce the objectives and attain desired ends.

   - Creating long range programs rather than short-term projects. This will also benefit educational efforts by reducing uncertainty of funding, allowing projects adequate time and resources to achieve high levels of impact.

   - Replicating the already excellent work achieved at less cost than developing anew. Initiate a mechanism to make the best programs available for transfer and to encourage their implementation.

- Assisting smaller institutions which make up the largest number of individual organizations, but lack the resources for professional grant writing and are, thus, absent from the benefits of grant funds, to develop the means to be included.
- Emphasizing development of faculty, including counselors and advisors, to reinforce the skills required by future and current educators, to prepare a citizenry sophisticated in SME&T. Change often happens only when money is made available, where there is a means to pursue new directions.
- Support organizational model development and implementation, which will foster the integration of knowledge and learning.
- Broaden the emphasis of science and technology education away from only those whose goal is a career in science and math, to all students. Eliminate the perception of elitism by opening SME&T to all students.

In summary, an environment exists, which if effectively mustered, holds the prospect of much opportunity for SME&T development and enhancement. The short-term prospect may appear to be negatively affected by current budget balancing. On the other hand, many forces favor a national agenda by which government, business and education collectively strengthen the means by which teaching and learning, curricula innovations, technology, organization and supplemental academic programs integrate to prepare a more scientifically sophisticated citizenry.

Today and forever, we must teach a "different" science than in the past. Knowledge is expanding exponentially and the classroom by itself can no longer remain the single place for learning. Technology, including multimedia, the Internet, and simulations hold much promise to augment the basics covered in class. But new approaches such as learner centered and team based programs, co-ops and internships all must be used collectively to provide students adequate skills to contribute to their society and employers.

By focusing on faculty development, the creation of teachers as nurturers and facilitators; the integration of learning ends into the instructional process; implementation of organizational models which enhance the achievement of academic outcomes; partnerships between business, students, faculty and colleges which fulfill the academic vision; and, with NSF and other federal programs providing national leadership, long range direction and funding and a broader base of SME&T education. This nation can maintain its competitive edge while providing a better standard of living and society for its citizens.

***Bruce Leslie** has been a Director of the American Association of Community Colleges, chairing the Association's Public Relations Commission. He is currently Chancellor of the Community-Technical Colleges of Connecticut. He is also a Director and treasurer of the American Society of Training and Development, having chaired its Technical and Skills Training Committee, served on its National Issues Committee, and served as a member of the Editorial Board of ASTD's Technical Skills Training Journal. Dr. Leslie has served on the boards of the Urban League, Salvation Army, Private Industry Council and similar organizations in Syracuse, Chicago and Seattle. He has received the Harriet Tubman award from the Urban League, CEO Recognition Award from the American Association of Community College Trustees, Distinguished Alumni Award from the University of Texas, The Paul Dunbar Community Service Award, and Outstanding Community Service Award for Excellence in Education from Phi Beta Sigma.*

National Science Foundation Review of Undergraduate Education Institutional Perspectives of College and University Leaders

Gwendolyn W. Stephenson

Chancellor, St. Louis Community College
St. Louis, Missouri

Thank you for this opportunity to speak before the National Science Foundation's [EHR Advisory Committee for the Undergraduate Review]. I am sharing my concerns and recommendations with you today as chancellor of St. Louis Community College, as a former teacher, and as a member of a very strong national network of community college leaders. My remarks are concerned primarily with instructional programs – the fundamental exchange of information between teacher and student that is at the heart of both personal developments for the student and economic development for our nation.

Community colleges pride themselves on the quality of their teaching and instructional delivery systems. As open door institutions, we must accommodate a diversity of learning styles and many levels of ability. Community colleges occupy a unique place in higher education. We are midway in the public education continuum that extends from pre-school to post-graduate programs and lifelong learning opportunities. We are in a position to understand the problems and potential of education at all levels and cooperate in programs to improve the performance of students of all ages.

Our position is pivotal as we consider:

- how to improve literacy in science and technology of students majoring in other disciplines;
- how to strengthen the knowledge base of those earning associate's and baccalaureate degrees in science, mathematics, engineering and technology; and
- how to change our institutional policies and practices to aid undergraduate education in science, mathematics, engineering and technology.

Certainly, we must continually support two overall goals: improving student achievement, and improving instruction through the development of curricula materials, faculty preparation, and instructional activities.

About one-half of all the nation's first-time freshmen are enrolled in community colleges, and community college students make up the largest sector of higher education in the U.S. – 37 percent. About 47 percent of all minorities in college attend community colleges, as well as more than half of higher education students with disabilities.

Many of these students come to us with academic deficiencies in mathematics, and community colleges offer extensive programs in developmental studies. In many States including Missouri, legislators and educational agencies have mandated that baccalaureate institutions scale down or eliminate their remedial and developmental programs, thus leaving this complex task almost totally to community colleges. I have come across a significant number of legislators who resent what they consider double payments to prepare students for college-level work in mathematics. They feel that their support of secondary-level programs should be sufficient.

We know better. In St. Louis (and we are not much different from most large urban districts) nearly 25 percent of our students who enroll for college credit – or more than 6,800 – are taking at least one developmental course. This is up from 19 percent five years ago. These numbers include those students who also exhibit deficiencies in language and the ability to read, think critically, problem-solve, observe and respond Our faculty would argue that language deficiencies contribute significantly to mathematics and science deficiencies. We also are seeing a widening gap between the upper one-third and the lower one-third of high school classes.

The problem of under-prepared students clouds our vision of full participation in the global economy and of competitive economic development at home. In addition, our academically able students must master increasingly complex concepts and applications as the SME&T curricula evolve to match technological advancements. We are deeply concerned about the widening gap between the expectations of business and industry and the inability of significant segments of the work force to meet these expectations or even to function as informed consumers of technology.

But under-prepared students – as well as the sheer numbers of able students who attend community colleges – also provide educators the challenging opportunity to experiment, to take risks, to find innovative ways to teach mathematics, science, engineering and technology. If we can be successful with our students, we can influence and improve teaching methods at the elementary-secondary level, at the undergraduate level, and in industrial training.

I would like to briefly share with you a few examples of programs at St. Louis Community College, which are moving us forward in this critical area. Many community colleges across the country currently offer similar programs.

- Our *Minority Engineering Scholarship* program is sponsored in conjunction with Emerson Electric Company and the University of Missouri-Rolla. Recipients take the first two years of their engineering studies at the college, then transfer to UM-Rolla to complete the remaining two years. Since the program started in 1988 80 students have enrolled, seven have graduated from the university and 22 are currently in the program's pipeline. The completion rate compares favorably with a national retention rate of 35 percent. Ninety percent of our regular engineering transfers graduate from UM-Rolla, and we find they do as well or better academically than those students who start as freshmen at the university. The program has been so successful that we are exploring a similar tripartite relationship with the St. Louis College of Pharmacy and Monsanto Company.

- We are entering our fourth year of leading development of the *St. Louis Area Tech Prep Consortium*. Sixteen local school districts are members of this initiative, representing more than two-thirds of the public high school-age population in the area. Our faculty members work with teachers at the junior and senior levels in local high schools to blend the curricula and ensure smooth articulation.

- The college has participated in a NSF-funded program directed at middle-school students. Partners in the project included the University of Missouri-St. Louis and Harris Stowe State College. In addition, our mathematics faculty members have been called upon to teach at all levels because of their skills and the measurable results that they have achieved.

I am sure you have noticed a strong, common thread running through these sample programs – and that thread is partnerships and collaborative efforts. I am convinced that the only way our educational systems and our nation can advance in SME&T education is to do so in tandem with other educational institutions and with business and industry. The material is too complex, the required delivery systems too costly, the technological advancements too rapid, and the economic imperatives too critical for educational systems to meet the challenges independently. Such laudable programs as Tech Prep and School to Work are only the beginning of collaborative efforts we must create to prepare our students for the demands of the next century.

When the National Science Foundation is asked to support programs in curricula development, science-mathematics literacy, faculty development, work force preparation, and laboratory instrumentation, it should do so within the context of institutional collaboration. As we all know, funding is a powerful motivation for change, and *NSF* should insist that institutions demonstrate their concern for articulation, cooperation, logical course sequencing, and resource sharing in their proposals for support. The concept of teamwork in problem solving, so critical in the work force, should be reinforced at every level in the educational process.

Community colleges are most grateful that the National Science Foundation has increased its support over the last five years from about $1 million to more than $30 million. The renewed NSF emphasis on teaching – rather than just research – and work force education has been received with much enthusiasm by community colleges who are on the front line in the battle for mathematical and scientific literacy and career preparation. The Instrumentation and Laboratory Improvement program has helped update science labs in ways that would not have been possible before the program; and other funding has helped update our curricula through acquisition of new computers, CD-ROM, and video disks.

Future NSF support should focus on the following areas:

- *Increased availability of sophisticated instrumentation in laboratory work.* There is a world of difference for students between, for example, learning how to interpret an NMR in a textbook and actually taking an unknown sample, running the actual NMR spectrum and interpreting the information to arrive at the identity of the compound. Students become very enthusiastic when they are involved in hands-on experiments that mirror what a scientist might do. Similarly, the increased use of CD-ROM and videodisks helps students visualize the concepts being studied. Science is observational, and the use of more video techniques helps students – particularly in the field of chemistry – see what cannot be seen. Computer use should be interactive and kinetic, not limited to static data acquisition and display.

- *Enhanced faculty development.* Such programs as national exchanges among colleges and business and industry would reinforce workforce expectations. Workshops on technological advancements and curricula development would encourage faculty to adapt to change and incorporate more innovative teaching methodologies.

- *Continuous integration of SME&T instruction among elementary-secondary, community colleges, and university systems.* In every community, these three levels should be linked to produce a logical sequence of instruction and an appropriate knowledge base for all students, no matter what their major course of study or career plans. Particularly in the public sector, our state legislators, educational agencies, and taxpayers are beginning to demand no less.

- *Expansion of curriculum reform.* The calculus reform movement and the development of standards, such as NCTM, are excellent steps in this continuous process. More emphasis (and funding) should be focused on interdisciplinary curricula, improved textbooks, and assessment methods.

Once again, thank you for the opportunity to outline concerns and recommendations today. Community Colleges look forward to a continued productive and mutually beneficial relationship with the National Science Foundation.

***Gwendolyn W. Stephenson** was appointed chancellor of St. Louis Community College in February 1992. She leads an institution that includes three campuses – Florissant Valley, Forest Park, and Meramec – and four education canters; serves more than 120,000 credit and non-credit students annually; employs more than 3,400 faculty and staff; and is supported by a budget of more than $100 million. From 1988 until her appointment as chancellor, Dr. Stephenson served as president of College's Meramec campus. She joined the College in 1980 as dean of student services at the Forest Park campus. She served as the College's vice chancellor for planning and academic affairs from 1982 to 1986, and as vice chancellor for educational development from 1986 to 1988. Before joining St. Louis Community College, Stephenson was employed by Washington University in St. Louis for seven years. She also has worked for Southern Illinois University-Edwardsville, the Missouri Department of Education, and St. Louis Public Schools. Dr. Stephenson earned a doctorate in education with a minor in research methodology in 1975 from St. Louis University and a management certificate in 1987 from Harvard University. She received a master's degree in counselor education in 1968 from St. Louis University and a bachelor's degree in education in 1965 from Harris Teachers College. She is a licensed psychologist in Missouri. Dr. Stephenson serves on numerous state, regional and national educational advisory groups and on the boards of directors of local organizations including St. Louis Science Center, St. Louis Children's Hospital, St. Louis College of Pharmacy, and the Urban League of Metropolitan St. Louis. She also serves on the board of directors of the American Council on Education and the Advisory Committee for the National Science Foundation's Division of Undergraduate Education.*

Testimony on the Views of Institutions on Undergraduate Education in Science, Mathematics, Engineering, and Technology[2]

David R. Pierce

President, American Association of Community Colleges
Washington, District of Columbia

My role here this morning is to be here in support of two very fine representatives of community colleges [Dr. Bruce Leslie, President of Onondaga Community College of New York, and Dr. Gwendolyn Stephenson, Chancellor of St. Louis Community College of Missouri.] These two outstanding leaders have both served on our Association's Board and have both been in leadership positions while on the Board.

I do, however, have a couple of observations to make. First, let me congratulate Dr. Melvin George, Dr. Luther Williams, and Dr. Robert Watson for their fine leadership in sponsoring these hearings. There is a tremendous change going on in our society, and much of it is being driven by science and technology developments. The important question is: how can the National Science Foundation engage its many resources and programs into helping our country and its citizens live in this world of rapid change?

I read an article on productivity two weeks ago in *Business Week*. The article stated that we now have 62 PCs for every 100 people; we are almost at the point where there is one PC out there per person. The country closest to us by that measure is Japan, with only 17 PCs per 100 people. This fact can be viewed as a statement of the impact that science, mathematics, engineering, and technology are having on our society. Consequently, these are very important hearings that you are holding and we are pleased that you have invited us to present testimony. We know you will benefit from the perspectives of these two presenters.

One other point I'd like to make is that Bruce Leslie mentioned the document *Crossroads in Mathematics: Standards for Introductory College Mathematics Before Calculus*. This was funded in substantial part by the National Science Foundation. This process that produced this document was very significant, because the National Science Foundation took leadership to engage the community college sector in a leadership capacity relative to higher education. These standards are intended to be – and in fact are they have just been out for a month – the standards for mathematics below calculus in undergraduate education, for both community colleges and universities. The community college sector considers this document as a statement from the National Science Foundation of the importance of engaging community colleges and universities together in common cause.

In closing, let me remind you that community colleges are strongly community-based. They are engaged with their communities to help thrive in this strong technology, science, mathematics, and engineering-based society that we live in. Community colleges have an important role to play.

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[2] This text is an edited version of Dr. Pierce's verbal testimony to the EHR Advisory Committee on October 25, 1995.

David Pierce *has extensive community college experience at the local, state, and national levels. During his career he has served as a community college instructor, department chair, academic dean, president, chancellor, and state director. In addition he holds an associate of arts degree from Fullerton College in California. Including his time as a student, David Pierce's experience with community colleges exceeds 35 years. His professional involvement includes service on the Board of the American Association of Community Colleges, the AACC Futures Commission, and the Joint Commission on Federal Relations for AACC and the Association of Community College Trustees; and he serves on numerous boards and councils including the Phi Theta Kappa Board, the AAWCC Leaders Foundation Board, and the Advisory Board for the Harvard Institute for the Management of Lifelong Education.*

Institutional Perspectives of College and University Leaders

Frederick S. Humphries

President, Florida A&M University
Tallahassee, Florida

Thank you Mr. Chairman, for this opportunity to share my thoughts with you on some of the most critical issues impacting undergraduate education in Science, Engineering, Mathematics and Technology. My comments, while broad in concept, speak to the rapidly changing demographic trends that are reflected in the increasing presence of members of minority groups in primary and secondary school systems today.

"This country must sustain world leadership in science, mathematics, and engineering if we are to meet the challenges of today ... and of tomorrow." These are the words of President William J. Clinton that served as the preamble in the report of the Forum on Science in the National Interest, held in January 1994. This report also states that "... science and mathematics education must provide our children with the knowledge and skills they need to prepare for the high-technology jobs of the future, to become leaders in scientific research, and to exercise the responsibilities of citizenship in the twenty-first century."

One of the major roles of the National Science Foundation is that of ensuring that the country's educational system provides to this country's citizenry a level of training that will produce the technological workforce that will be required in the twenty-first century. This system must translate new information rapidly and efficiently to students in the classroom, capitalize on new technologies that will enhance learning abilities, and afford to every student an opportunity to effective utilization of his/her creative abilities. As is implied in the words of President Clinton, public literacy in science and technology is no longer an option; it has become a national imperative.

Having made these opening observations Mr. Chairman, I must express concern that demise of Russia as a major world power has lessened this country's resolve to maintain a strong and vibrant science and engineering education enterprise at the undergraduate level that will provide sufficient training to all of its citizenry. We must remember that the strong system of secondary and higher education of the sixties and seventies produced the American Nobel Laureates of the nineties. This country has developed a cadre of science and engineering research universities that are unparalleled in their ability to provide state-of-the-art graduate education. Data shows however, that the majority of American entrants into this graduate education system are bachelor degree recipients from the smaller liberal arts colleges and comprehensive universities. Accordingly, I would argue that we must continue to maintain a strong undergraduate science and engineering training program in these institutions so as to maintain this country's scientific preeminence.

In the same vein, our education system must ensure ample opportunities for training for the increased number of minorities in SME&T fields. The stature of America into the twenty-first century will be defined by the contributions of all its citizens. We must sustain the educational intervention programs that enhance the preparation of inner city and rural youths and insure that every person has an adequate opportunity to serve as a contributing citizen.

The National Science Foundation has supported the development of partnerships of the multiple stakeholders to impact and enhance the educational continuum. These coalitions have provided manpower and resources that reinforce areas in which we, in academia, require assistance. It also serves to provide students real life experiences that make classroom learning more meaningful.

The technological revolution has bypassed the inner cities and is deficient in equalizing opportunities provided to this segment of the population with the scope of their desires. This failure can be attributed to society as a whole rather than the individual educational consumer.

Teachers who do not have access to technological equipment cannot teach the technology skills required of a competitive society in the next century. Curriculum revision cannot take place if adequate resources are not available. The technological age is a cost driven age.

Several years ago the National Science Foundation budget was about $1.7 billion. President Bush promised that he would double NSF budget to approximately $3.5 billion. The member institutions of the American Association of State Colleges and Universities through its Science and Technology Committee recommended that as the National Science Foundation budget increased, the increase would place a significant emphasis on education – two-thirds research and one-third education. This would have increased the education budget to something on the order of $1.2 billion if our recommendation had been followed.

Education today is more expensive than it has ever been but it will cost more to ignore this inequality than it would to provide the proper resources for science education at the undergraduate level.

The National Goals, which were proposed in the early 1990s, represent a framework for addressing the educational needs of all citizens.

As this nation forges ahead to become first in the world in science, mathematics, engineering and technology, the needs of minorities must be addressed. The stature America will hold in the 21st century will be defined by the contributions of all of its citizens. Education will play a major role if this mission is to be accomplished. Educational interventions that are inclusive of all citizens, that are sustained and substantial, are the only means for success.

The growing diversity of industry/education partnerships, which are coming together, enhances education. These coalitions provide manpower and resources that shore up areas in which we, in academia, have lost support. It also serves as a means of providing a needed continuum in education.

In a similar view of cooperation, collaborations are beginning to emerge between our two-year anal four-year institutions. Since the two-year institutions serve a large number of minority students, the linkages, which are developing between the institutions of higher learning, appear to be facilitating student access to the upper-division level. More effort needs to be made in this regard.

There is a crisis in graduate education. The intractable movement of African Americans into the Ph.D. ranks, particularly in mathematics, science, and engineering, is unacceptable. This nation cannot seem to surpass the progress made in the 1970s for Ph.D.s in engineering, or even secure double digits for Ph.D.s in mathematics. Barely 19 or 20 Ph.D.s are being awarded annually. It is an embarrassment to this nation that we cannot do any better than that in the production of African Americans in the Ph.D. arena.

A second significant point pertaining to graduate education is the continuing erosion of Ph.D.s in science, mathematics, and engineering given to native-born Americans. Every day that we live, more and more Ph.D.s are awarded in mathematics, science, and engineering to a greater number of international students and a lesser number to native-born Americans. This nation is failing to train its best people. This should be of serious concern to everybody who is concerned about the production and the development of the human resource in this Nation.

The federal government has recognized the value of early and sustained intervention in preparing minority youth for careers in the science, mathematics, engineering and technology areas. The last decade has seen support for the efforts being made at the university level. The level of support must be projected on a long-range basis granted that the programs demonstrate success. The system-wide approach to reform sparked by the National Science Foundation is taking hold in the various states, which are receiving support. There is more evidence of partnership and collaboration than at any time in our history. These partnerships and collaborations have generated the feeling that, it will take the efforts of an entire nation to educate our youth.

In the K-12 system there is a lack of first-rate science and mathematics education providers to the rural and urban sectors of our society. Most of the well-trained science and mathematics teachers are not teaching in the inner cities and rural areas of America. We have a modest level of success with mathematics and science teachers in the suburban areas. That is where the best education in science and mathematics is happening.

In rural and inner cities, many of the schools lack mathematics and science infrastructure. This results in inadequate mathematics and science laboratories. When many of the students graduate from these school systems, they are termed “underprepared” and need remediation in mathematics and science to be competitive in any reasonably good university or college in our Nation.

We have all kinds of circumstances where we reward and pay homage to distinction and achievement in research. There are a tremendous number of opportunities for the people who make contributions to the advancement of knowledge through research to be acknowledged for their significant and dedicated hard work. We need an organization that focuses on and requires annual professional meetings dealing with this whole issue of making scientists, engineers, and mathematicians. What works effectively in the curriculum? What is the curriculum restructuring mechanism?

The National Science Foundation needs to use its tremendous influence to make way within the National Academy of Science and Engineering so that the great teachers of science and mathematics can be afforded the privilege to belong to the academy in an educational capacity and not in a research capacity.

There are teachers who develop good scientists, mathematicians, and engineers; teachers who are inventive in finding ways of captivating the interest of young people to go into those fields; and master teachers who can solidify that interest by inspiring a student to become a Nobel Laureate. *Build a mechanism, which reinforces the notion that it is worthwhile to pay attention to these very important activities in our society.*

Programs developed in the Education and Human Resources Directorate of the National Science Foundation are tremendous and excellent starts, but they are not the end in terms of what is needed to be done to continue this role of increasing the numbers, particularly of minorities, and increasing the numbers generally of our society in mathematics, science, and engineering.

Given the political climate of the past several years, it is evident that the academic arena cannot accomplish this mission on its own. We must have the full commitment of partners who believe in a system of fair and equal opportunity for all. One of my major concerns is the fact that support for public colleges is becoming more dependent on revenues from tuition and fees owing to the decrease in funding from State and Federal sources. This situation has even greater impact on the number of minorities progressing through the system and receiving baccalaureate degrees in four to six years. Increasingly, minorities enrolled in college are required to carry reduced course loads or even delay college owing to the combination of limited financial aid, rising tuition and the limitation of course availability. Budget compression is forcing institutions to increase class size in order to maintain existing levels of enrollment.

If America is serious in its desire to maintain its lead in the world in science and technology, then America must be committed to providing the necessary resources to see that adequate SME&T training is available to all students in secondary and post-secondary education.

Listed below are my recommendations of a realistic approach to a comprehensive action-oriented revolution of our educational system:

- Promote the development of new curricula emphasizing virtual reality and simulation training in the teaching of science, mathematics, engineering, and technology subject areas at the undergraduate levels.
- Promote the development of State/Federal partnerships to fund the replacement of aging facilities and equipment utilized in teaching science, mathematics, engineering and technology subject areas.
- Increase the level of science, mathematics, engineering and technology funding designed to attract students from the inner city and rural areas.
- Promote collaborative efforts among faculty that will facilitate a multidisciplinary approach to the education of all students regardless of major.
- Promote the dissemination and utilization of science, mathematics, engineering and technology curricula that have proven successful.

- Establish an organization to focus on the professional development of scientists, engineers, and mathematicians.
- Encourage the National Academy of Science and Engineering to expand membership requirements to include science and mathematics in an educational capacity.
- Fund and promote the utilization of distance learning facilities to infuse science, mathematics, engineering and technology instruction into secondary and post-secondary curricula.
- Fund and promote partnerships between higher education and industry that will ensure relevant laboratory experiences for the next generation of the science, mathematics, engineering and technology workforce.
- Ensure the education of a sufficiently diverse science, mathematics, engineering, and technology workforce so as to afford each citizen an opportunity to contribute to the country's well being.
- Forge at both the state and national levels, communities of stakeholders – students, parents, faculty, administrators, scientific sources, accessible bodies, employers and local, state and national leaders – who demonstrate their support for education.
- Create an environment where faculty can effectively integrate their research and teaching at the undergraduate level.
- Provide a level of support, which will enable the K-12 system to effectively administer programs, which demonstrate and enhance comprehension of scientific and technological subjects.
- Introduce prospective teachers to the classroom setting early in their preparation and continue this exposure while developing their proficiency in science, mathematics, engineering, and technology.
- Promote the development of University-Community College articulation agreements that provide services to promote scientific interest and scientific literacy before students complete their associate degree programs.

Recently there has been a high level of concern about the quality of the products of our undergraduate institutions and questions regarding their preparation for diverse post-matriculation endeavors. The enhancement programs, which are emerging with Federal and State support, have demonstrated that a comprehensive and holistic approach to learning will produce students who are up to the challenges of post-graduate education.

I strongly endorse continuation of the Following National Science Foundation Initiatives:

- Instrumentation and Laboratory Improvement;
- Course and Curriculum Development;
- Undergraduate Faculty Enhancement;
- National Science Foundation Collaboratives for Excellence in Teacher Preparation;
- the Alliance for Minority Participation in Science, Engineering, and Mathematics;

- the Systemic Statewide Initiatives Programs; and
- the Advanced Technological Education program.

Furthermore, I strongly support the continuation of undergraduate programs sponsored by the National Institutes of Health, Minority Access to Undergraduate Careers Research Program, Minority Biomedical Research Support Program – and the office of Naval Research such as BIONR. All these programs have played a vital role in increasing the pool of minority scientists and engineers in our country.

I urge you to make the tough decisions and redirect funding so that all undergraduate students would have access to state-of-the-art equipment, modern facilities and innovative curricula anchored by inspiring and well prepared professors. We must rise to the challenge if we are to meet the technological demands of leadership in the 21st century.

*When **Frederick S. Humphries** was appointed President of Florida A&M University in 1985, he brought new tools and ideas designed to dramatically impact the national perception of Historically Black Colleges and Universities. He set as a major goal early in his administration to challenge Harvard University in the race for National Achievement Scholars, the most academically talented black students in the country. He accomplished his goal in 1992-93 and again in 1994-95 when FAMU led the nation in the recruitment of National Achievement Scholars. He serves on numerous boards and committees including the White House Advisory Committee on Historically Black Colleges and Universities, and as a member of the Board of Directors for the Wal-Mart Corporation. His honors include the University of Pittsburgh's Bicentennial Medal of Distinction and the 1990 Thurgood Marshall Educational Achievement Award. He received his bachelor's degree in chemistry from Florida A&M University and the Ph.D. degree in physical chemistry from the University of Pittsburgh.*

Testimony Before the Undergraduate Review Subcommittee of the National Science Foundation

William E. Kirwan

President, The University of Maryland
College Park, Maryland

Mr. Chairman, I am pleased to be able to appear before the committee created by the National Science Foundation to review undergraduate education the areas of science, mathematics, engineering, and technology (SME&T). I hope that my comments will be useful to you as you begin this important undertaking.

You have identified a number of broad issues relating to science and technology education in our nation's colleges and universities. My remarks will focus on two of your major concerns: improving the quality of the undergraduate curricula in SME&T areas, and identifying changes in institutional policies and practices that might contribute to the desired changes. I would be happy to address the remaining issues, if time permits, in response to the committee's questions.

Strengthening Curricula in SME&T Fields

Certainly one key to improving instruction in areas of science and technology will be affording our students greater access to powerful and easy-to-use computers for data analysis, simulation, and instrument interfacing. The networking of computers has opened up the processes of information gathering, analysis, and the dissemination of knowledge, and the effects are already visible in many of our classrooms. Computer linkages with federal agencies and private industry now offer invaluable opportunities for our undergraduate engineering and science students to use state-of-the-art design models. In the near future we can expect to see a dramatic increase in the number and variety of electronic texts being made available for use in undergraduate instruction. In our electronic classrooms at College Park we have observed first-hand the tremendous potential of computers to enhance learning, and there is every reason to think we are just at the beginning of this era.

There is also now widespread acceptance of the proposition that, in science areas as in other disciplines, students learn best when they work within problem-focuses formats. Where students can take an active or 'constructivist' approach to problem-solving, where they are able to take a direct role in the development of their knowledge rather than mimic behavior of the past. They can more quickly overcome their misconceptions as well as acquire a greater degree of interest in the subject matter. In the process they also gain experience in the kind of cooperative, collaborative approach to research that will be characteristic of later stages of their careers. At the moment, however, student- and problem-centered instruction is found in many institutions largely in the form of pilot projects supported by external grants, with special, sometimes Herculean efforts on the part of individual faculty and staff. These successful pilot projects must become the norm, and not the expensive, labor-intensive exceptions in our science and technology curricula.

In addition to mastering the skills and knowledge specific to the field of study, students enrolled in SME&T disciplines will increasingly need to improve their communication and problem-solving skills, to acquiring a positive attitude lifelong learning, and to be able to deal effectively with the ethical dimension of their professional lives. At present few courses in areas of science and technology offer significant opportunities for students to develop facility in oral and written expression, or to pursue broader questions relating to the nature of scientific knowledge and inquiry.

In light of what we now know about the ways in which science and technological development affect the environment, for good as well as for ill, it is also imperative that we afford our students opportunities to reflect on how their actions as individuals will contribute to the larger problem, or to its solution. As David Orr recently put it, "the kind of discipline-centric education that has enabled us to industrialize the Earth will not necessarily help us to heal the damage caused by industrialization."[1]

In thinking about improvements in the quality of education at the college and university level we should also keep in mind that many of our students are entering their programs of study with inadequate preparation and knowledge in the sciences, especially in mathematics. This lack of proficiency manifests itself even in such everyday activities as solving simple proportional equations and graphing X-Y plots. I am aware of a number of reform efforts that are underway at the elementary and secondary level, and many of these show great promise.

The point is that those of us within the higher education community must regard what goes on at the elementary and secondary level of education as our concern as well.

Needed Changes in Institutional Policies

It is my view that to a large extent upgrading the quality of the undergraduate educational experience is a matter of individuals and institutions having the determination to put into general practice the kinds of innovative approaches that have already been shown to be successful in various pilot projects. But, to a very large degree, this moans we must give considerable thought to what we expect our universities faculty to be doing in future years.

A significant number of faculty throughout the nation, and in all disciplines, have some sense of the importance of upgrading the quality of undergraduate instruction. But many others have little desire and incentive to take part. Indeed, to be perfectly frank, a significant percentage of faculty resist taking the time and effort required to incorporate new scientific and instructional technologies within their own instructional activities. And many, perhaps most instructors carry out their teaching assignments with little understanding of the nature of the learning process and which approaches to teaching might be most conducive to their students' learning. At our nations' research universities, most existing faculty performance-assessment and reward systems afford little opportunity for recognizing the effort of those faculty who are prepared to make a major commitment of time and effort to work toward improving the quality of undergraduate instruction. To some extent, then, enhancing the quality of undergraduate education will require a fundamental change in the priorities by which faculty decide how to spend their time, as well as a more learning-focused set of performance reward systems.

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[1] David Orr *Earth in Mind: On Education, Environment, and the Human Prospect.* (Washington, D.C. and Covelo California, 1994) p. 2

The magnitude of the impact of poorly prepared entering students on instruction at the college and university level highlights the importance of improving communication and forging new alliances with teachers at elementary and secondary levels. In my view, improvement in SME&T instruction at the college and university level requires that K-12 teachers participate in the process of setting the reform agenda and that colleges and universities undertake to provide teachers with the kind of preparation and in-service training they will need in order to introduce new materials, concepts, and teaching styles into the classroom. It is essential that we work to increase understanding of the ways in which our nation's educational system is a unified whole. The various levels depend on one another in many ways, but we rarely plan and execute programs accordingly. So here also universities must find ways to support the efforts of teachers at the elementary and high school levels, and to reward the members of the university community who are prepared to build stronger school-university relationships. Thank you very much, Mr. Chairman.

***William English Kirwan** has served as President of the University of Maryland at College Park since 1989. A member of the College Park mathematics faculty since 1964, Dr. Kirwan has played a pivotal role in shaping the destiny of the state of Maryland's flagship campus. In 1981, after serving as Chair of the Mathematics Department for three years, he was appointed to University's chief academic post. As Provost and Vice Chancellor, he raised admission standards, increased the number of merit scholarships and fellowships, and established an academic planning process. When he became President, the University undertook a major restructuring of its academic organization, and a renewed emphasis on undergraduate education. One of the nation's most respected educators, Dr. Kirwan has served as Chair of the Mathematical Sciences in the Year 2000 Committee, a task force created by the National Research Council to improve mathematics education at the nation's colleges and universities during the next decade, and as charter member of the NRC's committee on Undergraduate Science Education.*

Testimony Before the Undergraduate Review Subcommittee of the National Science Foundation

Paula P. Brownlee

President, Association of American Colleges and Universities
Washington, District of Columbia

Mr. Chairman, thank you for the opportunity to speak before this committee. I am very appreciative of the chance to share some of Dr. William (Brit) Kirwan's time here. He serves as a member of our Association's Board and provides important leadership to the work of AAC&U. The review that you are undertaking of undergraduate education in science and technology is timely and important, and it is a privilege to join so many fine colleagues in trying to contribute to your efforts.

You are receiving excellent testimony from colleagues representing the disciplines and colleges and universities, whose experiences with advances in science and engineering education are current and in depth. The perspective I bring is that of an association whose activities involve working with academic administrators and faculty leaders across hundreds of universities and colleges.

The AAC&U mission is to strengthen and promote liberal education. We interpret contemporary liberal education as an education that prepares students to best understand, analyze and contribute their developed knowledge to the world they can come to know. Such an education includes the study of the arts and sciences, implies the understanding of interdisciplinary connections and anticipates integration of theory into their lives, lived in a changing world. The study of science and mathematics, engineering and technology all have absolutely essential places in such a liberal education–and for students who major outside these fields as importantly as for those of us who majored within them. My own background includes a number of years as an organic chemist, briefly in industry then in a university, before I moved into campus administration.

AAC&U has long been involved in projects, a number of which have been funded by NSF, which address the improvement of curricula and teaching practices in the scientific disciplines–for undergraduate majors and in general education courses.

Brit Kirwan, in his testimony spoke of "upgrading the quality of the undergraduate educational experience" as being to a large extent "a matter of individuals and institutions having the determination to put into general practice the kinds of innovative approaches that have already been shown to be successful in various pilot projects." He talks of the need for "determination" in order to translate successful pilots into general practice. I think that his "engendering the 'determination' to translate successful pilots into generalpractice" is a central issue for us. This is the only way we shall ever see widespread improvement in undergraduate science education for all students.

AAC&U works with many hundreds of individuals and campus science and engineering departments, and we are impressed with the range of effective innovations being made. At the same time, too often it appears that the faculty members have thought up their own ideas in relative isolation. A chemistry faculty friend recently said to me: "NSF knows that it is getting good value for its dollar investment in research. But teaching is not the result of training comparable to research, and the reform of teaching often seems to me driven by uninformed bright ideas." Maybe each innovation is too much a separated pilot project. Much of others' testimony will speak well to many of the best practices, and will be important for the review.

We do all lack knowledge of how to spread the best practices for others to access. Once disseminated, how is interested faculty inspired to transmute them into their *own* laboratories, classrooms or technology-aided instruction? I think that complex understanding of this process is needed to successfully propagate multiple improvements.

At AAC&U it is said that we try "to enable our member institutions or departments to do together what they cannot do alone." In earlier decades, our projects aimed to bring together faculty to spark each other's initial ideas around a particular reform. This is probably still the underlying premise of content-filled educational meetings. Sometimes we can return to our own campus ready to adapt the new ideas to our own setting. Very often, however, on our return the initial idea with its attendant energy just dies.

In more recent years, our association has strongly encouraged campus *teams* to participate in our annual meeting; almost all our funded projects now involve teams also. A group of colleagues sharing an off-campus experience can better enable the work to be sustained back on campus. The group brings back a tiny encouraging community.

A continuing use of this practice is in the AAC&U "Asheville Institutes." Two of these, in which interdisciplinary science with humanities general education courses were designed, NSF helped fund. Over the past five summers, 105 colleges and universities have sent five-member teams of faculty and an academic administrator for 6 days. Administrative commitment from the beginning enhances the likelihood of the innovations being adopted and supported on campus. For particular projects, the involvement of a trustee or the president of the institution is required. I cite these examples to illustrate the complexity of the process by which the initial bright idea for the improvement of some aspect of undergraduate science teaching will finally be spread (and often changed en route) to lastingly improve quality.

Wherever dramatic transformation is planned, efforts must be sustained by multiple means. The pairing of institution teams, with occasional trips to each other's campuses, enables exchange of experience at much deeper levels. We are beginning to utilize listserves and other electronic communications; these hold great promise for the future. When a team can stay connected with a project for a year, much more opportunity for help with economic and political issues surrounding the introduction of reforms can occur. In such cases, nationally respected consultants can offer informed assistance. As an example, the lack of faculty rewards for teaching and the lack of recognition for innovative developments are widely cited as a disincentive to reform. Consultant help might offer outside credibility and cite other positive experience.

Sometimes projects falter along the way. A planned final gathering of project leaders can spur sustained effort. The goal is always to achieve students studying well in the reformed curriculum and assuming that good assessment tools are in place. In just one AAC&U project (not one in science education alas!), funding was provided so that we could, several years later, send an outside evaluator to each campus involved. I have the written report now, and I think this is an extraordinarily good means for a funding agency, and others, to know how deeply a reform is rooted. Such evaluations would also inform the design of later funded projects. I believe that this Review Subcommittee might consider this idea further.

I have asked here for you to consider how best to multiply the impact of fine examples of undergraduate curriculum reform. Simple dissemination is not enough, whether by print, electronic or face-to-face means. We are rapidly learning that students learn best when they are enabled to actively construct their own understanding. It is scarcely surprising then, that faculty, too, learn to teach best when they can use others' ideas – out of which they are enabled to construct their own teaching. *Enabled* means having others to talk and debate with, having support to experiment and being recognized for the intellectual effort demanded.

I cannot finish my testimony without adding a word on the continuing needs of women and minority faculty to be supported and "enabled" as creative reformers in the world of science and engineering education. This world is still a more difficult one for a variety of reasons; the past support of NSF is deeply appreciated. Many of us hope it can be sustained.

A final word on the role of graduate education as a preparation for the role of future professor. AAC&U is undertaking, with the Council of Graduate Schools, a project on "Preparing Future Faculty." Under it, Ph.D. students (many of whom are science and mathematics students) at 17 research universities are having a planned "field exposure" to the life of professors at the neighbor college, these graduate students are receiving unprecedented introductions to the professoriate. We are particularly pleased to have minority students in these programs, which we hope will be encouraged to seek faculty positions on graduation. I hope that NSF and other government and private agencies will help us plan ahead for the kind of informed young faculty members we want to design and teach our undergraduate science, mathematics, engineering and technology courses of tomorrow. Thank you.

As president of the Association of American Colleges and Universities (AAC&U), ***Paula P. Brownlee*** *heads the only higher education organization of member institutions that focuses on strengthening liberal education on our nation's campuses. AAC&U was founded in 1915 and is now composed of more than 660 public and private colleges and universities, whose presidents, deans, and faculty members are the active participants. The goals of AAC&U are carried out through its research and publications, projects, national meetings, and specialized workshops. Before becoming president of AAC&U in September 1990, Dr. Brownlee was president and professor of chemistry at Hollins College for nine years. Previously, she was dean of the faculty and professor of chemistry at Union College for five years and a dean and tenured faculty member in chemistry at Rutgers, the State University of New Jersey. She received her bachelor's and doctoral degrees in chemistry from Oxford University and held a post-doctoral fellowship at the University of Rochester before working briefly in chemical industry. She was recently elected Honorary Fellow of her college, Somerville College, Oxford.*

Testimony to the National Science Foundation Hearings on Undergraduate Education

Saul K. Fenster

President, New Jersey Institute of Technology
Edison, New Jersey

I appreciate the opportunity to testify on the subject of undergraduate education in the fields of science, mathematics, engineering, and technology (SME&T). This subject lies at the heart of what we do at New Jersey Institute of Technology. The leadership of the National Science Foundation is exceedingly important to us, and I am delighted to participate in this dialogue.

In 1986, a National Science Board task committee under the leadership of Homer Neal, issued a report that has contributed to significant change in undergraduate education in science, mathematics, engineering, and technology.

That report – an analysis of the weaknesses and findings of traditional attitudes and approaches to SME&T instruction, followed by specific recommendations for reform – set the tone for a decade of rethinking and retooling. Although much remains to be done, I think it is fair to say that the stimulus provided by the National Science Board, and the advice and support subsequently provided by the National Science Foundation, have helped transform the way faculty approach the mission of undergraduate instruction in SME&T fields.

Today I would like to share with you my assessment of the impact those efforts have had at one institution, New Jersey Institute of Technology. I will describe our philosophy of undergraduate education. Cite some of the specific steps we have taken, and offer some comments on what is working best.

A recurrent theme in what I have to say will be*the importance of context.*

Let me begin, therefore, with a bit of context for my remarks. The central purpose of undergraduate education at NJIT is to prepare students for careers as "complete professionals" with the potential for leadership in their chosen fields of endeavor. Let us review for a moment the specific characteristics of such a person. It goes without saying that "professional" conduct implies honesty and integrity. In addition, a "complete professional":

- embraces responsibility
- is technologically proficient
- communicates effectively
- comprehends the interdisciplinary nature of innovative thinking
- can see the totality of an enterprise and the inter-relatedness of its goals
- understands the competitive nature of the marketplace
- is entrepreneurial
- respects the environment

- adapts to change with flexibility
- is a productive and cooperative team member
- appreciates and respects diversity; and
- continues to learn throughout life.

I believe that our success as a nation will depend upon such people. People who can lead in a global economy, keep our corporations at the cutting edge, design and produce goods, employ natural resources in an environmentally benign wayand do all these things with respect and appreciation for diversity.

The key, of course, is to provide a comprehensive, well-rounded education that maximizes *all* of the values listed above. The package is incomplete if scientific and technical excellence is sacrificed; but it is also inadequate if the pursuit of scientific and technical expertise precludes attention to the external context within which the science and technology enterprise functions. The old saw about the value of a broadening general education at the undergraduate level holds true today, perhaps more than ever.

How is all this to be accomplished?

There is no simple formula for success. But it is certainly possible to point out a number of contributing factors that have demonstrated effectiveness. Reforms of curricular design and course content, the introduction of improved pedagogical methods and new technologies, the integration of research into undergraduate teaching, and institutional recognition of faculty efforts in undergraduate education are among them.

In each case, NSF has served as a powerful catalyst for change. NJIT and many other institutions have benefited from its guidance and support.

In the balance of my remarks I will try to demonstrate why I make that assertion.

We know that one objective of SME&T education must be to captivate students: we must literally *capture their imagination*, and then we must *hold their interest*. The key, I believe is to teach in context and to give students a realistic preview of the roles played by the engineer, the architect, the scientist, and the manager. With NSF support through the Gateway Coalition and two major grants under the Technology Reinvestment program, we are reconfiguring the shape and content of the undergraduate curriculum at NJIT.

There are a few specific features of the new curriculum

- A new required full-year course, *Fundamentals of Engineering Design*, involves all freshmen in complex, open-ended design problems from the very beginning of the curriculum.
- Traditional freshman humanities and social science courses are coupled to the *Fundamentals of Engineering* course to create a cohesive sequence that emphasizes connections among the fields of human knowledge.

- Multi-lifecycle and pollution prevention concepts will be introduced throughout the curriculum to show students that economic viability and environmental responsibility are essential considerations in developing design solutions.
- We are developing computer-assisted decision-making tools that introduce environmental concern in the form of "clean" manufacturing considerations at every stage of the design process for use in freshman chemistry classes as well as for direct use by industry.
- Our factory floor, summer internships, and cooperative education programs offer immediate hands-on experience.
- A required seminar series will bring to the campus speakers from industry to discuss manufacturing topics from the perspective of their direct experience.
- In chemical engineering, required courses link communication and critical thinking to the analysis of chemical processes, unit operations, and plant design.
- Required courses in economics and management have been combined into a single, year-long course that leads students through the critical financial considerations that must be taken into account in producing goods and services.
- A course for seniors gives them the opportunity to carry out projects from product conceptualization through commercialization as a capstone experience.

Thus, throughout the curriculum, we will provide integrating learning experiences that provide a foretaste of the complexities of the workplace. Students will realize *before* they graduate that professional success depends upon the ability to organize a variety of human resources as well as apply science and mathematics. This is truly science, mathematics, and technology*in context.*

Other new modes of undergraduate education supplement these curricular developments. For example, we now offer undergraduate students the opportunity to work directly with a faculty mentor, thereby experiencing the kind of thinking and experimental activity that goes on in the world of basic or applied research.

The use of computer technology in delivering the undergraduate curriculum also takes the form of distance learning. With the support of the Sloan Foundation, NJIT now offers an entire undergraduate degree program (the Bachelor of Arts in Information Systems) through computer-mediated instruction supplemented by videotapes.

The curricular improvements we have undertaken appear to be having beneficial effects on our students. One indication of this is last year's 85 percent retention rate from the freshman to the sophomore year. Another is the enthusiasm reported by many of our faculty members.

Yet the curriculum as a whole might best be characterized as a "work in progress." It is surely not perfect, nor has it been developed to our full satisfaction. The individual strands I have described have yet to be woven together as a coherent a fabric as we would like to see, with a pattern that commands immediate recognition when viewed from a distance.

The ultimate goal is to educate professionals with a better understanding of their calling, thereby rendering them better prepared to lead others. The means is a curriculum bound together not only by a traditional set of academic objectives that are related to the notion of preparing students for professional practice, but also by a broad thematic expression that represents the profession directly. Real curricular integration demands explicit linkage between and among sources.

A desirable consequence will be higher retention and graduation rates. If the broad thematic motif is sufficiently compelling, it will arouse curiosity and stimulate interest. We can then hope to spur better teaching on the part of faculty and better learning on the part of students.

The challenge to university leaders is to nurture a unity of purpose within the campus community. It is no trivial matter to do this with individuals, both faculty and administrators, who tend to view the world from a discipline-oriented perspective. Moreover, the academic enterprise rightly values individual creativity. Curricular unity must be achieved without compromising the "free market" of ideas, without sacrificing open-ended debate and intellectual controversy.

Clearly, the university community will need more time to internalize the conceptual framework embodied in the new curriculum, and to capitalize more fully on its pedagogical possibilities.

Two additional points arise from the notion of a broad reform of the undergraduate curriculum based on integrating themes.

First, undergraduate education does not take place in a vacuum. The next generation of faculty is emerging from Ph.D. programs across the nation. They will be expected to teach a new undergraduate curriculum. It follows that the nature and content of Ph.D. programs themselves deserve reconsideration, especially in the SME&T fields. If we need faculty attuned to new approaches in undergraduate education, we should deliberately build the necessary components into our doctoral programs.

Some of the necessary components are obvious. More emphasis on making interdisciplinary connections and on filling the lacunae in the matrix between the disciplines. More opportunities to teach. More emphasis on preparing for non-academic careers by working in teams and learning leadership skills. More emphasis on the roles of quality and cost in an era of global economics. More emphasis on the need to realize the commercial value of research.

Second, I cannot leave the matter of undergraduate curriculum without reference to the training of schoolteachers. Since so much more can be accomplished when the interest and motivation start at an early age, the teaching of "SME&T in context" should begin in the elementary and secondary schools. It therefore stands to reason that colleges and universities, and – more importantly – those individual faculty members who know how to teach SME&T in context, should be playing a central role in the education of future K-12 teachers of math and science, rather than institutions and faculty whose primary focus is on pedagogical methods. And there should be far more interactions between elementary/secondary schools and universities that teach the sciences, engineering, and technology.

The faculty reward system is another powerful tool.

As I see it, the distinction between a Ph.D.-granting institution and other colleges and universities is *not* based on a difference in the importance attached to undergraduate education. NJIT's academic culture is defined by the presence of a faculty engaged in undergraduate instruction as well as graduate education, research, continuing professional education, and professional practice. The faculty's experience of research and professional practice adds freshness and excitement to the classroom and the laboratory. They integrate what they have learned from their own work into the material they teach. The unity of teaching and research is becoming a way of life at NJIT precisely because it contributes powerfully to excellence in professorial education.

Once again, NSF support has encouraged us in the right direction. With two grants under the CRCD (Combined Research-Curriculum Development) program, new graduate courses will incorporate current faculty research in the fields of particle technology and optoelectronics, and the fundamentals can be integrated into undergraduate courses long before they appear in textbooks.

That said, it remains necessary to remind faculty that the university values undergraduate instruction.

NJIT’s promotion and tenure processes emphasize good teaching as well as research productivity. In the review of each candidate for promotion and/or tenure we examine the record of teaching – including curriculum and course design, advisement, and very importantly the results of student evaluations. No one who is rated less than “good" as a teacher is recommended for advancement, regardless of the individual’s intellectual research record.

Recognition can take other forms as well. NJIT has a program of annual awards for excellence in teaching. I can report that faculty take great satisfaction from the recognition they receive from their peers and from students. Some have been heard to say with pride that they devote themselves primarily to teaching undergraduates.

The transition from school to college can be particularly difficult for students interested in the SME&T fields. Most of them come with no prior experience of what to expect, or what will be expected of them. The high national rates of attrition from collegiate SME&T programs can be attributed in part to this discontinuity.

At NJIT we approach the problem in two ways.

First, we think some prior experience provides a useful bridge to college. In 1970, we started a pre-college program in urban engineering with 30 high school students from the Newark area. Today, with support from a large number of foundations and corporations, our pre-college programs have expanded to include 3000 students per year from elementary school through high school and several hundred teachers. One program, funded by NSF since 1990, introduces rising 8th and 9th graders to research in the fields of environmental science and civil and environmental engineering. All of these programs provide a foretaste of college and are designed to plant the seed of interest in the fields of science, engineering, math, technology, and architecture as potential careers. Again, teaching in context.

To assure greater continuity for students who begin their college careers at community colleges, a consortium of New Jersey colleges and universities that includes NJIT, together with local industries, high schools, and professional societies, has been awarded another NSF grant to create a national center of excellence in engineering technology education. The center will develop a model associate degree program in Mecomtronics Technology* and work toward the restructuring of existing engineering technology programs.

The second approach, one that has become standard at many colleges and universities, is to provide far more extensive orientation and adjustment programming than was traditionally the case. At NJIT this takes the form of a pre-freshman year summer orientation experience we call "miniversity," a first semester freshman seminar designed to develop early awareness of the attitudes and behaviors that contribute to long-term success in college; an "early warning" system designed to call attention to students who may need special advice, tutoring, or counseling; and an academic advisement system that operates from the first semester through the senior year.

It is also important to emphasize fuller participation by members of groups underrepresented in the SME&T fields, especially women and minorities. I say this for two fundamental reasons: First, fuller participation is a simple matter of equity. In light of the long history of social inequities, attempts to deal with the effects of economic and educational disadvantage are desirable on purely moral grounds. Beyond that, however, America's future depends to a large extent on our ability to assure an adequate supply of well-prepared professionals, people who can keep our corporations at the cutting edge and provide leadership in a global economy. The nation needs more such people, and will find them *only* if previously under-represented populations participate.

The confluence of a compelling moral imperative with the human resource needs of the twenty-first century constitutes a powerful mandate to higher education.

Institutions such as NJIT have a special role to play. We believe that this university's complementary and mutually reinforcing goals of excellence and access clearly reflect the responsibilities of a public institution with a public mission.

In this area, too, the National Science Foundation is providing leadership and support.

I would like to close with a sobering thought. It is the realization that our agenda is incomplete. Colleges and universities understand that they occupy a unique position in-service to the Nation. We think we have fulfilled this role well in the past, and we want to do so in the future. What we need from Washington, from our state capitals, and from our many other partners, is some assurance that the value of higher education will be recognized in the form of continuity in our sources of support. With tangible support from the National Science Foundation and others, higher education will continue to enrich our future and that of generations to come.

* "Mecomtronics" is the engineering technology discipline that combines the areas of mechanical and electronics technology, and computer hardware and software systems linked through telecommunications.

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Needed Improvements in Science, Mathematics, Engineering and Technology (SME&T) Education, and Institutional Policies that Would Aid Undergraduate SME&T Education

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What our nation's colleges and universities face today

Colleges and Universities are facing a number of external pressures that create tensions among the competing values of affordability (cost), quality of programs, and access. These pressures include: 1) financial constraints brought about by the redistribution of state funding from higher education to other purposes such as corrections and school equity funding; 2) demands for increased accountability and enhanced productivity; 3) expectations that higher education will make student learning its central purpose and introduce values and social responsibility into the curriculum; and 4) concerns about the employability of new graduates.

In response to these pressures, ten percent of this nation's colleges and universities sharpened their missions in the past year and 70 percent began to examine the contributions and productivity of their academic departments. This climate of renewed concern for responsibility and accountability and the growing emphasis on the importance of student learning provides an ideal opportunity for institutional leaders to reassert the importance of the preparation of teachers, for K-12 and for higher education. To emphasize the need for the introduction of significant reforms at both K-12 level and in higher education in SME&T for both students who plan to major in these fields and for students who do not.

Undertaking radical change

At the same time, institutional pressures affect the ability of our colleges and universities to undertake the major transformation of their science, mathematics, engineering and technology curricula, which are needed if we are to enhance the capacity of this nation in these disciplines. Also, to advance the ability of our citizens to make informed decisions utilizing information from these fields.

Radical rethinking of academic programs entails genuine rethinking of the entire educational enterprise, including the design and content of the curriculum, the creation of a new institutional environment through the design of many aspects of campus infrastructure, a new approach to faculty and student roles and responsibilities, and the use of unusual and creative inter-institutional and interdisciplinary partnerships. Observers of academic reform have observed that reform this sweeping is rare. More commonly change is sporadic and occasional, progresses in fits and starts, and is characterized by bouts of housecleaning followed by years of inertia (after J.B. Lon Hefferlin, *Dynamics of Academic Reform* Jossey-Bass, 1969).

What creates a supportive environment for reform?

To succeed in such an ambitious undertaking, an institution or a cluster of institutions, must have adequate time and financial resources, access to knowledgeable advocates who are committed to transformational change, and a campus and academic environment that is receptive to outside influences. In our experience, institutions that are at the edge of the academic mainstream because of their youth or the recent emergence of their institutional type (e.g. regional colleges, urban universities), or because they enjoy unusual and creative leadership, are more likely to undertake a genuine, rather than a piecemeal change process. These kinds of institutions are not likely, however, to be sought out by policy-makers seeking to identify promising and productive models for educational reform.

Once an institution embraces the importance of transformational change, it helps to have: 1) continuity of leadership; 2) a supportive governing body; 3) partners in the community who offer ideas and shared resources, as well as alternate learning environments; 4) outside resources from foundations, mission-related agencies such as NSF, and consultants who promote change through offering financial resources, political support, and the validation needed to affirm and support both the necessity and the value of change; and 5) a number of venues for discussing curricular reform, exchanging ideas, and participating in peer-reviewed and invitational meetings and workshops.

The role of institutional leaders in supporting improvements in SME&T education

Many colleges and universities, whatever their mission, have experienced "mission creep" toward the values and expectations of research institutions as faculty have sought to develop individual scholarly careers using the strategies that they learned in graduate school. To link what faculty do more effectively to the particular mission of the institution; academic leaders are turning to the redefinition of faculty roles and rewards and are focusing on the academic department as the primary focus of support both for individual faculty development and for the collective responsibilities of the faculty in organizing and offering the curriculum. During these discussions, there is an opportunity to introduce curricular reform as priority areas of faculty activity that will be supported by the institution.

In addition, some new approaches to interdisciplinary programs have been introduced across the country in recent years. These efforts can provide additional opportunities for students to integrate what they are learning and apply what they know to community issues that require multi-disciplinary approaches.

Presidents, Provosts, and Deans can encourage the trend toward a broader mission-related definition of faculty scholarship and faculty roles by providing incentives at the institutional level and the departmental level for both individual faculty excellence and for collaborative teaching and research that crosses departmental lines. Effective curricular reform that reflects recent changes in K-12 education as well as changing needs of employers who will hire our graduates requires close collaboration between faculty in education programs, engineering and business and arts and sciences as well as cooperation with local public schools and other post-secondary institutions. Often campus policies, campus support structures and campus rewards do not assist faculty who work on curricular reform or K-16 reform and who must spend significant time in the field or in collaborative activities with colleagues on campus in other disciplines.

To increase the importance attached to the improvement of SME&T education and to provide a supportive environment for curricular reform, administrators can do a number of things:

1. Utilize a clear campus mission statement as a framework for defining the goals and aspirations of the institution. Make clear to everyone, including trustees, faculty, staff and students, that constant curricular advancement is an important campus priority and that every graduate of the institution should be able to use scientific and mathematical problem-solving techniques and information competently and confidently.
2. Personally acquire a thorough knowledge of educational reform efforts in public schools and in higher education and speak consistently and knowledgeably about the importance of the reform of graduate education to incorporate both the acquisition of research and teaching skills and a familiarity with contemporary issues in curricular reform, and K-16 curricular reform itself by articulating the importance of designing the goals and outcomes of a college education upon the foundation provided by the reform movement in K-12. Talk with faculty about these issues regularly.
3. Encourage the reinterpretation of faculty roles and rewards to make them compatible with the demands of educational reform, teacher preparation in SME&T, interdisciplinary and collaborative research and teaching, and community-based work.
4. With faculty guidance, create a campus infrastructure and policies that support the activities needed to support curricular reform on campus, to reflect changes occurring in the public schools as well as employer expectations, and to promote the exploration and the reform of graduate education in SME&T. This will require, introducing new assessment strategies that evaluate student learning and that document the outcomes of curricular reform as well as providing technical assistance for faculty who engage in curricular innovation at both the undergraduate and graduate level.
5. Provide opportunities for faculty to discuss educational reform with their colleagues in workshops and campus-wide seminars.
6. Support faculty who are interested in educational innovation and in graduate education by providing campus resources such as mini-grants and release time for such work.
7. Participate in national discussions of faculty roles and rewards as well as K-16 and graduate educational reform and encourage faculty and staff to do so as well. Where appropriate, subsidize the cost of travel to such conferences and meeting in the same way that the campus encourages faculty to participate in discipline-based professional meetings and workshops.
8. Be prepared to invest in educational reform and in new faculty roles and responsibilities, drawing resources from a restructuring of campus administrative operations or redistributing resources from academic programs that are no longer in high demand.
9. Encourage institutional partnerships with other organizations to encourage innovations in education and to provide a supportive environment for faculty involvement in the local community.
10. Encourage a greater local understanding of the importance of SME&T education and K-12 reform by participating in community efforts to improve the local schools. The

local Chamber of Commerce or other local business associations often sponsor such activities.

11. Activities of this kind offer occasions for colleges and universities to introduce discussions of how high school must prepare for post-secondary education as our nation's post-secondary institutions continue to improve SME&T education. While there has been a lot of talk about the need for a high skills workforce, many employers still want only reliability, basic skills, and good attitudes towards customers and fellow workers, and are not yet introducing the elements of a "high performance" environment into their business practices. As a result, universities and colleges must work simultaneously to promote higher standards of performance for their students and for the organizations that will employ their graduates.

Graduate education has to change, too

There is a growing demand for universities to become concerned with the issues of society in the hopes that our involvement will help to clarify the competing values that are at stake, frame clear and critical questions, and build a wider repertoire of responses that will rebuild the workings of civic life in this country and the core of democracy itself. If colleges and universities become properly engaged with our communities, we can become the source of social capital for a new era. A critical component of this capacity-building must be provided by SME&T education. We must prepare the next generation of college and university faculty to offer the kind of undergraduate education that our students really need.

We must take a long hard look at how we prepare graduate students now. What are we really doing in our graduate curriculum and in our research programs? In higher education today, are we really building social capital, which sociologist Robert Putnam describes as "features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit," and are we preparing people who can create and work within such networks? Are we preparing a generation of faculty who can design a curriculum that can accomplish these goals and, themselves, model for their students a more interactive and collaborative form of learning and discovery? Will our graduate education put teaching and research on an equal footing by introducing values, skills, and professional goals that encourage a balanced career?

The process, rooted in the 19th century, that has led to greater and greater differentiation of academic life into definable disciplines, each with its own world view and culture and objects of discourse, has drawn our process of socialization of new scholars into the academy further and further away from the influence of the questions and concerns of the citizens who support us.

Do we really know whom we are preparing in our masters and doctoral programs and how they will use their education? What principles should we adopt to guide the design of our graduate studies as we think about what responsibilities our graduates will undertake after they complete their formal education?

One problem we have in higher education is that we are trapped in our own, still successful, model of graduate education. We are proud of saying that graduate education in this country is the envy of the world. We still continue to attract talented students from around the world to study in our nation's universities. Our model of a research-based doctorate has served as a *world* model for preparing scientists and engineers as well as scholars for other fields.

So, why should we question a clearly successful enterprise? The problem is that this model works effectively for a smaller and smaller percentage of the students who enter doctoral study and then take positions at our nation's research universities. The others, who will find employment elsewhere, are less well prepared.

According to a recent study completed by the National Academy of Sciences Committee on Science, Engineering, and Public Policy, we are producing students who are prepared for traditional research roles while employers are calling for doctoral graduates who have expertise in more than one discipline, who can collaborate across fields and in various settings, who can adapt quickly to changing conditions and learn in new fields and who work well with other people. Furthermore, we are preparing our graduates to join us in the academy, while more and more of them will find employment elsewhere in business and in government.

How can we promote more versatility? Faculty today needs both disciplinary strength and the ability to interpret and apply disciplinary perspectives in collaborative settings. The faculty we are hiring now and will hire in the future will need to be able to work effectively together to create opportunities for meaningful involvement of students, community members, and local practitioners in SME&T education. They will require: a) *communication skills* including the ability to listen well; b) *collaboration skills* which include the building of mutual trust and respect, ability to problem-solve in complex groups with different experiences, goals, and definitions of success; c*) time management skills* - the need to spend time creating a common set of goals, a common vocabulary, shared definitions of success with partners from other organizations; and d) *team-building skills* - the ability to work with many different kinds of people with different expertise and motivations.

If we really need faculty with these skills, we will need to recognize these competencies and achievements as significant factors for promotion and tenure and during the distribution of discretionary salary increases and other faculty rewards.

Genuine teamwork and partnership are difficult modes for faculty to adopt who have only operated within disciplinary-based frameworks, where in most cases, the questions, the assumptions and the methods of inquiry are agreed upon and understood by everyone involved. Partnerships require time, trust and patience, and a different repertoire of skills, skills that can be incorporated into our graduate and professional programs.

Few institutions are actively addressing graduate education as yet, but the time is rapidly approaching when we must do so. In *Campus Trends 1995*,[1] Elaine El-Khawas reviews the results of a survey sent to an array of 506 colleges and universities. Of our peers, only 10 percent report extensive change going on at the graduate level, 70 percent report some, and an alarming 21 percent report no activity at all. If we approach this new challenge in a way similar to our commitment to active/service learning for undergraduates, we will again find ourselves in the forefront of a concern that many people are talking about, acknowledge must be addressed, but are reluctant to approach.

There is no doubt in my mind that we must reshape graduate education in SME&T, both at the Masters and at the Doctoral level. In preparation for this, we must take time to retrace the same steps that the faculties who are redesigning our undergraduate curriculum are taking. We must ask: Who are our students? What are they experiencing and why do so many students fail to achieve their educational objectives or take so long to do so? What do our students plan to do with their education? What is happening to the marketplace for people with an advanced education?

Let us bring this challenge close to home. With respect to our own colleges and universities, what attributes and skills will we seek as we hire a new generation of faculty? Are our doctoral programs likely to produce the kinds of versatile faculty we would want on our own campus? Will our new faculty be prepared to undertake the collective responsibilities that are required to deliver a curriculum of the kind we have recently introduced? One that requires teamwork and cross-disciplinary perspectives? Will they know how to conduct effective community-based research with partners from other programs, institutions, and community organizations?

Might we define a kind of "general education" for graduate students, similar to the goals we have for our undergraduate students - a set of goals or principles that will guide us to design opportunities for our graduate students to develop advanced problem-solving skills, communication skills, collaborative skills, an appreciation for diverse viewpoints, an ability to continue to learn, and an ethical and socially responsible basis for their research and practice?

Can we design a different form of professional development for teaching and research assistants that provides mentoring and school and business and industry based experiences?

What can NSF do to reinforce and support the changes that will be necessary to create a genuine K-16 SME&T reform movement and to assist institutions that wish to redesign the study of SME&T at the college levels for both majors and non-majors?

1. Provide individual investigator awards for research on the-impact and sustainability of instructional innovation. We need research on fundamental questions concerning teaching, learning and assessment in undergraduate SME&T education.
2. Provide support for summer workshops that bring students, parents, community participants, and faculty and public school teachers together to work on community problems and to engage in curricular reform. Provide summer stipends for the faculty who design and participate in these summer programs. Faculty who do research during the summer can often obtain two full months' pay to support their time spent doing research. Faculty who engages in curricular innovation or in summer workshops and K-16 initiatives do not have access to such funds. This sends a signal that basic research is valued more than K-16 initiatives or curricular innovation. In addition, although it is understandable that NSF would want to stretch its resources as far as possible, these programs are often under-funded and the financial condition of most of our colleges and universities precludes any significant local supplements to the project budget.
3. Make provision in undergraduate research awards for introducing new faculty into the process and for supporting faculty teams. The current funding levels for REU

grants do not allow for variations in the faculty configuration or encourage the mentoring of graduate students or new faculty by more experienced faculty.

4. Provide opportunities for faculty who are engaged in curricular reform to present their work and to publish their findings in invitational and peer-reviewed publications and conference proceedings.
5. Take a leadership role through both advocacy and financial sponsorship in persuading more professional societies and professional journals to provide exposure for exemplary work in undergraduate and graduate curricular reform.
6. Recognize that curricular advancement is an on-going process and requires sustained faculty support. While workshops and conferences can stimulate an interest in reform and promote the exchange of ideas, continuing assistance will be necessary for faculty who plan to apply the ideas generated in these workshops and summer projects to their on-going courses and curricula. This support can be provided in the form of release time, graduate assistants, and periodic gatherings to review and interpret the results of work to date. It is becoming increasingly difficult for universities to offer this support. Most NSF-sponsored projects can only launch a change process. In the normal 2-3 year time span of a grant, work can barely get underway. Requirements to demonstrate actual changes in student achievement in such short time frames can actually interfere with the change process by forcing the participants to focus on very short-term goals. It is better to evaluate very concrete outcomes such as the development of new curricular materials and courses, effective involvement of faculty in the exploration of new techniques in teaching and learning, and the like. If possible, projects should be funded for 3-5 years to provide the sustained support needed to move from design to introduction of a new curriculum to accurate and effective assessment of the impact of the new approaches on student learning, competence, and confidence. In addition, the current grant process often results in a succession of faculty being involved, when in some cases, it may be important to keep at least a core of participating faculty together for a longer period of time, introducing new participants according to the nature and development of the project.
7. Graduate programs must require participation in work on curricular reform as well as offer significant teaching opportunities. NSF fellowships and training programs can promote this by emphasizing the importance of teaching, curricular reform, and interdisciplinary work. Annual and end-of-grant reports should include a request for information about the nature and impact of activities of this kind conducted under the sponsorship of the grants.
8. We must find ways for all undergraduates, both majors and non-majors, to have an opportunity to do “real” research, and to do so throughout the undergraduate experience, not just in a limited number of distribution courses that satisfy a science or math requirement. At Portland State University, we involve undergraduates who enroll in our *Science and the Liberal Arts* curriculum in active research projects over the full four years of their undergraduate curriculum because of our belief that the habits, values, and ethics of the SME&T disciplines must be practiced and learned over a long period of time. This is true for both non-majors as well as majors. SME&T taught in conventional ways using standard textbook and laboratory exercises is about as interesting as reading an instruction manual. Furthermore, this

approach addresses only one type of learning style and disadvantages students who learn best in other ways. Taught as a liberal art, however, SME&T courses for both majors and non-majors call human curiosity to attention and make such inquiry and learning a deeply satisfying and imagination-expanding experience. The liberal art of mathematical, scientific, and technical inquiry allows our faculty and students to try out – to test – their imaginations for accuracy, precision, credibility and acceptance by a community of knowledgeable peers. NSF can offer sponsorship for such experiments at any institution willing to undertake the significant and radical reform necessary to introduce this kind of curriculum.

9. After years of under-funding, our nation's instructional facilities and equipment are badly out of date and there is a enormous need simply to provide better laboratory and classroom environments. We must upgrade our equipment remodel our classroom and laboratory spaces to accommodate new approaches to learning and we must make significant investments in technology such as computers and telecommunications. The accumulated need for retrofitting and new equipment would vastly exceed the ability of any Federal source to support, but NSF could develop ways to encourage additional support for these needs by its use of equipment funds. The emphasis recently has been on the need for curricular reform. This is frustrating to many faculty, including many at Portland State University, who have already made radical changes in the curriculum, introduced new pedagogical approaches, established new areas of emphasis–including the use of interdisciplinary and cross-disciplinary options to tailor the educational experience of individual students to reflect their educational goals more directly, and used community interactions and partnerships to create richer learning environments for our students. What these faculty need now is the equipment to support the curriculum, the encouragement to solidify the reforms that the have already begun, and the resources to assess the results of what they have done.

10. It is unclear whether the goal of the investments made by NSF in undergraduate education are designed to identify and support innovative work or to promote an overall systemic improvement in the level and impact of SME&T education and research capacity in this country. Often the process of preparing a proposal and doing the necessary work to show the feasibility of a project are extremely worthwhile for an institution undertaking significant reform for the first time. But if the ideas are not new to the community-at-large, even though they are innovative at the applicant institution, will NSF decide to fund the project? This poses a significant policy question for NSF. Is it better to generate and facilitate the distribution of new ideas and positive results or is it better to build the nation's core capacity to provide effective SME&T undergraduate education by providing incentives to encourage institutions willing to undertake major curricular reform. This key policy question deserves serious attention.

11. NSF support programs for new faculty should include attention to teaching, general education, and the reform of SME&T curricula. In general, so should regular research grants. Whenever possible, a research program can effectively include undergraduates, and, in some cases, serious high school students. This should be encouraged where feasible and the grant review process should include a knowledgeable review of the potential benefits for undergraduate education and K-16

articulation. NSF can powerfully shape the focus and emphases of grants for research and education in science and engineering by calling for a thorough discussion of the human resource implications of the work to be done and requiring a thoughtful analysis of the outcomes. The Application Guide published in October 1992 (NSF 92-49) had an extensive section on this (p.4), which appears to have been omitted from later application guides.

12. Wherever possible, projects should be funded that connect reforms in SME&T undergraduate education to the rest of the liberal arts. Reform undertaken in conversation and in collaboration with faculty in the humanities, social sciences and fine arts can stimulate fresh thinking throughout the university and reinforce the efforts being made by SME&T faculty. This practice can direct more faculty attention to undergraduate education and advising, the dissemination of improved practice, and the effective integration of reform efforts across the curriculum. NSF can play a truly catalytic role in promoting changes in the entire undergraduate experience through encouraging effective linkages of SME&T reform with both the rest of the liberal arts curriculum and to professional education in engineering and technology.

***Judith Ramaley** is President and Professor of Biology at Portland State University. Portland State University has received national recognition for its innovative curriculum, campus management, leadership in interpreting service learning, and commitment to an urban mission. Dr. Rarnaley received her undergraduate education at Swarthmore College and Ph.D. at UCLA. She is Chair, Commission on the Urban Agenda of NASULGC; member, Kellogg Commission on the Future of State and Land-Grant Universities; members Board of Directors of AACU; past Chair, Biological Sciences Advisory Committee of NSF; and member of many local civic organizations in the Portland metropolitan area.*

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Institutional Perspectives of College and University Leaders

David Ward

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Madison, Wisconsin

Introduction - University of Wisconsin-Madison Programs

Thank you for the opportunity to be here today. The issue of science and math competency at the undergraduate level is one of obvious importance to us and to society. As an institution of higher learning, the University of Wisconsin-Madison has labored much in recent years to come to grips with a problem that threatens our quality of life and our ability as a nation to compete in the world market. The absence of broad science literacy poses significant dilemmas for society and for higher education itself.

Over the past 10 years, the community of scholars at Wisconsin and elsewhere has pursued broad and far-reaching initiatives to attack the problem of science competency. To its credit, the National Science Foundation has also strongly encouraged change at research universities through its own programmatic initiatives. These joint efforts are laudable and they merit continued support and experimentation. The research university must play a critical role in the improvement of science education. That role must include new and stronger relationships among different kinds of educational institutions, and better connections between our primary and secondary schools and higher education.

At Wisconsin alone, there are many examples of programs that seek to alter, reform or redirect the way science, math, and engineering are taught. The teaching and learning infrastructure is being rebuilt, and it is being connected in new ways with schools, students, teachers and the other critical components o£ the educational system.

Through entities such as the Institute for Chemical Education and the Center for Biology Education, universities like Wisconsin are creating new tools for learning. Thousands of students across the country and at all educational levels now have the opportunity to track genetic change through generations of plants in a single semester, thanks to the Wisconsin Fast Plants Program. Memory metal and other materials science innovations are becoming integrated into freshmen chemistry courses around the country, refreshing a dated curriculum. These are two examples from Wisconsin of research university-based innovations that are having broad impact.

This year at Wisconsin, with the support of NSF, faculty is embarking on an ambitious program to revamp the way chemistry is taught nationally at the college level. Employing the latest instructional technology, offering new contexts for learning and incorporating the most effective cooperative learning techniques, these researchers will attempt to make the first sweeping instructional changes in decades.

Wisconsin has established a teaching academy for faculty as a mechanism through which to identify, through evaluation, exemplary teaching practices, and to support widespread application of the best techniques across disciplines and curricula. Superimposed on these and other activities is a state-of-the-art means of evaluation through our LEAD Center. It is crucial to acknowledge the need to measure steps taken and to hold claims to improvement to a critical standard.

Thanks in large measure to the track record of educational innovation of some of Wisconsin's most distinguished researchers, the university has now been given the opportunity to enter into an interdisciplinary partnership with NSF known as the *National Institute for Science Education*. This unique partnership is expected to yield new strategic and tactical means of building the nation's science and math education infrastructure.

There seems to be no shortage of creativity among the faculties of research universities. However, tradition-laden institutions like universities must find more effective ways to sustain innovation.

Issues

Science for All. There is a critical need now for colleges and universities to more broadly and effectively integrate science, math and technology into the general education curriculum. Science is a significant and pervasive influence in the lives of all Americans, and universities need to do a much better job of preparing all of our students – not just science and engineering majors, to think more analytically and to live in a world increasingly shaped by the forces *of* science and technology. The earlier we can do that in the course of a student's education the better. Of critical importance is providing a seamless but flexible connection between high school science and the very first science experiences of higher education.

Changes in Higher Education. We need to envision the classroom of the future and not simply improve the traditional classroom approach to learning. Faculty who invest time, energy and creative power to enhance the learning environment or develop new learning tools should be encouraged to apply for educational grants with the same conviction brought to bear in the quest for research grants. In addition the reward system for faculty must evolve to recognize the importance of work by those who break new instructional ground.

Empowering Teachers and Future Teachers. Moreover, we need to do much more to develop our faculty and future faculty, to empower them to be effective innovators in science education. The academy needs to look beyond its own borders, expanding the involvement of staff and teaching assistants in the development and application of innovative teaching techniques and styles. The research university can play an important role by providing our graduate students with more exposure to innovation in the learning process and especially to cross-fertilize the research interest with the general dialogues about science.

Evaluation. It is also very important that universities begin to evaluate seriously novel learning approaches. Critical evaluation and assessment must be integrated into a system through which we can identify, develop and disseminate the most effective approaches to learning. Given all the resources that have been provided for education reform over the last decade, there are relatively few devoted to measurement of success or failure. It is essential that we incorporate some kind of outcome assessment into our education reform efforts. In addition, we must strive to communicate these results, make them accessible, and then act on them. This is a daunting task. At many of our institutions, obtaining the quantitative data – grades, retention rates, demographics – requires effort on the part of the investigator. The data are simplynot available in most places. Rigorous qualitative analysis is even rarer.

Fortunately, instructional technology is providing us with a wealth of new feedback opportunities, such as electronic mail. At research universities electronic mail is greatly enhancing access to faculty and staff and is providing timely information on the successful comprehension of course material. A spate of questions on a particular lecture topic – delivered by electronic mail – provides a compelling signal to the lecturer that he or she missed the mark. A student too shy to sign up for a face-to-face appointment may find the courage to send an e-mail with a pressing question. Faculty and staff ought to be strongly encouraged to make greater use of these now almost-commonplace technologies.

A Changing Infrastructure. Another set of related and pervasive issues lie in our infrastructure and the evolution of new technologies and instructional materials. Will the formal classroom exist a decade from now? This is an area of rapid development that outstrips the ability of any single institution to manage and guide it. Who will take leadership in identifying effective approaches? Will the academy recognize and reward contributions by faculty members in this arena? If not, how will we move forward?

We also must recognize that technology costs money. Who will pay? While the information superhighway is changing the way many of us function, we must be aware that very large numbers of students – from kindergarten to college – do not have access to this technology. To help remedy these inequities, we must begin to explore new partnerships with the private sector and others that have a stake in a technologically literate workforce.

Equity and Diversity. Equity and diversity within our institutions are critical and related issues as well. The demographics of the twenty-first century demand that we renew our commitments to access and opportunity for all. Human resources are our greatest asset and the needs of the twenty-first century will require the inclusion of the full diversity of our population in order to avoid squandering valuable intellectual resources.

Making Better Connections. Universities must also become catalysts for the development of new networks between different types of institutions. Research universities do not exist in an institutional vacuum, nor do they have a monopoly on education. We must use existing programs such as our summer programs, integrated general education for non-scientists, and distance learning to help us weave a web of learning between different educational systems.

The Value of Existing NSF and Other Programs

Clearly, research universities can change creatively in partnership with NSF and other funders. NSF and other federal and private granting organizations have already made serious investments in innovative and effective improvements in science education. These investments now need to be better connected to a rapidly changing learning environment and the possibilities of a new networked educational system. Continued and expanded support of these developments is needed to drive change.

NSF and other granting entities can begin to require some kind of relationship between research proposals and their broad impact on science education. This strategy has been discussed at a number of national meetings on science, math and engineering education, and is likely to provide the kind of motivation needed to encourage pilots and experiments.

In closing, I would like to thank you again for the opportunity to express some views and ideas of how research universities can and should change to foster change in the science education landscape. We are committed to addressing this problem and we look forward to continuing our partnerships with NSF to attain a common goal.

***David Ward** was named chancellor of the University of Wisconsin-Madison in June 1993, becoming the 25th individual to serve as the university's chief executive. Ward had served as interim chancellor since January 1993. Ward became vice chancellor for academic affairs at UW-Madison in 1989, and in 1991, he was also named provost, chief deputy to the chancellor. His UW-Madison faculty career spans 30 years, and he holds the Andrew Hill Clark Professorship of Geography. For the past eight years, Ward has provided strong leadership for efforts to improve the quality of undergraduate education. The next step, says Ward, is to redefine undergraduate education, not simply through improvements of existing programs and processes, but by developing new ways for learning to occur on college campuses. To that end, he recently published a comprehensive strategic planning document, outlining priorities for the next decade as the university attempts to balance its teaching, research and outreach missions. Ward has given new expression to The Wisconsin Idea, the venerable philosophical framework for the university's public service role. The Wisconsin Idea is embodied by a vast array of partnerships between the university and both the public and private sectors, says Ward, from economic development activity and sharing of faculty expertise to educational collaborations with K-12 schools.*

Presentation Before the National Science Foundation Undergraduate Review Subcommittee

Homer A. Neal

Vice President for Research, University of Michigan, Ann Arbor
Ann Arbor, Michigan

Thank you, Mr. Chairman, for inviting me to participate in today's hearings on undergraduate education in engineering, science and mathematics. I have chosen to depart somewhat from the suggested format of comments in order to provide the subcommittee with a brief overview of the work of the task force I chaired in 1985 which resulted in the issuance of NSB Report 100-86, which has served to guide NSF development in undergraduate science, engineering and mathematics education over the past decade. I will also share with you a current initiative in which I am involved, that bears on undergraduate science education at our nation's research universities, as well as some of my own thoughts about the important changes that we must consider with respect to undergraduate education in the future.

Charge to the NSB-100 Task Committee

At the start of the work of our committee in 1985, the charge we were given was as follows:

> . . . to consider the role of the National Science Foundation in
>
> "undergraduate science and engineering education . . .to determine what is an appropriate NSF role in undergraduate science and engineering education . . . and to examine what are possible mechanisms for carrying out that role. Should NSF move to establish undergraduate science, engineering and mathematics programs, apart for support for undergraduates provided in some research grants? Should NSF have a role in shaping undergraduate curricula?..."

We set about the task of collecting data in just about every imaginable way. We reviewed extensive literature on the subject, consulted with higher education organizations and held several hearings in Washington at which faculty, university administrators, federal agency officials, and industrial leaders testified, in much the same way as the current hearings are planned.

What we learned was not very reassuring. Among the key problems we uncovered were:

- deteriorating quality of the college-level science-educational infrastructure
- laboratory instruction that was typically, "uninspired, tedious, and dull."
- lack of opportunity for faculty to update either their disciplinary or their pedagogical skills
- outdated curricula that failed to convey the essence or excitement of contemporary science
- declining student interest in careers in science, engineering, or mathematics, or in education in these disciplines

In looking back over the years since our report was completed one can sense that real progress has been made at NSF in undergraduate science and engineering education:

- A new Office of Undergraduate Science, Engineering and Mathematics Education has been established and now administers or monitors over $100 million dollars for undergraduate programs.
- A new program to provide research experiences for undergraduates has been established, the REU program. Indeed, Director Bloch initiated the REU program while our committee was still in the midst of its hearings, being immediately convinced that this was an activity much needed and very much in keeping with the mission of NSF.
- A new program for undergraduate faculty enhancement has been established.
- A new curriculum development program has been established.
- A special undergraduate curriculum development program in calculus has been developed and, from all indications, the results are very positive.
- A new instrumentation and laboratory improvement program has been developed.

There can be no doubt that NSF has taken the recommendations of our committee very seriously, and that the leadership actions of NSF have had an impact on other agencies and foundations. For example, the Howard Hughes Foundation initiated its own program for support of undergraduate education shortly after our report was completed and has already committed many millions of dollars in this area. Leadership was, and still is, an extremely important element of NSF actions.

Changes Over the Decade

Indeed, the leadership that NSF shows in the years ahead will be critical. Since the issuance of NSB Report 100-86, there have been an enormous number of developments that will potentially influence the nation's commitment to undergraduate science education and which must certainly be taken into account as plans are made for advancing undergraduate education. As unlikely as it may have seemed in 1986, we have seen the end of the Cold War. This single event raised the hope that, by unleashing resources that might be more productively directed toward the overall improvement of life for our citizens, education needs could be more adequately addressed. But it also raised the question as to what extent a large technically educated workforce would be needed, given the apparent diminished national security requirements. Coincident with the change in the balance of world power has been the realization that the U.S. federal budget deficit must be reduced and that federal outlay will be made with a heightened degree of scrutiny. Though many voices caution against neglecting investments with long term benefits, there will be an increased tendency to focus federal and state resources on major issues of immediate urgency – a recipe that often neglects the needs of higher education.

There are further developments that serve to shape the environment within which policies and practices in undergraduate science and engineering education must exist. As a result of a few highly publicized incidents in recent years, there has been some erosion in the public's confidence in its higher education system. Compounding the effects of these events are the ever-present debates about indirect costs, high tuition, and stories of the difficulty some students claim in gaining access to faculty, who are characterized as only being interested in their research.

While we note the growth in the total number of baccalaureate degrees over the past decade – rising by almost 20 percent – it is also of interest to note that the number of degrees in the natural sciences and engineering has fallen by almost 20 percent. We note that undergraduate enrollments in laboratory courses continue to fall. Furthermore, though there has been significant growth in NSF budget for education and human resource activities, we note that most of this growth has been primarily in the K-12 programs.

These are issues that it will be critical for NSF to address in the years ahead, as we try to craft undergraduate education in science, engineering, and mathematics for a rapidly changing world. I also believe that, while NSF has a key leadership role to play, it is also incumbent upon universities themselves to think more creatively than ever in trying to deal with*these* same issues.

In Search of a New Compact

Over the past year, several research vice presidents at Midwestern universities have been engaged in a cooperative effort to construct what might be the principles that would guide the partnership between research universities and the federal government in the decades ahead. I might note that, given the end of the Cold War, many of the original guideposts in the Vanovar Bush era are no longer viewed as being sufficient to fully determine what the relationship should be between universities and the federal government.

In the quest for developing these principles, we have had numerous discussions with officials in the Executive Branch, with several leaders in Congress, and with industrial leaders. It is our hope and expectation that these consultations will continue in the months ahead and will culminate in one or more symposia where these items will be discussed in more detail.

What I can report to you today, however, is strong support for universities participating with the government to ensure a strong program of research and education in the sciences, engineering and mathematics.

In the set of draft principles we have developed to date is the following reference in the section on education for the next century:

- Education for productive life in an age that is information intensive, technologically demanding, culturally complex, and globally competitive.
- Education that will continue to assist our citizens in adjusting to the rapid changes in the modern world.
- Public understanding of the key technological, economic, cultural and social issues that we face."

Our draft report continues:

> ". . . education of the nation's citizens for productive life and work is one of the primary function of the research universities, and a function to which they can bring unique assets. One of the greatest strengths of the research university has traditionally been

> graduate education – the training of new generations of scientists and scholars. The same assets of the university that have made our doctoral programs the envy of the world can be turned, and are being turned, to improvements in other areas of education as well. Universities, in addition to training the next generation of researchers, seek to instill in their undergraduate students the culture of rational inquiry, and the skills to be effective workers and knowledgeable citizens. In our rapidly developing world, education is more than ever a life-long process; this implies that one of the most important outcomes of undergraduate education is the ability to think clearly and to learn effectively. It also implies that universities have a larger role to play in ongoing education and in serving as a resource that the broader public can draw upon in trying to understand new issues and problems that arise."

Our report also notes that,

> "universities should seek, review, and implement ways to further utilize their research competency to enhance undergraduate education, by expanding opportunities for undergraduates to participate directly in research and scholarship; and by endeavoring that all students who graduate have attained the necessary levels of scientific and cultural literacy . . . universities should explore creative ways to make their resources for knowledge and understanding available and accessible to the public; they should explore and implement ways to facilitate timely public understanding of important scientific and technological issues; they should be increasingly receptive and responsive to public interests and concerns and should seek to facilitate meaningful dialogue between the public and academic communities."

I must note again that these statements are taken from a document that is still in draft form – and that not even all of those vice presidents who have been involved in their development are necessarily in complete agreement with every phrase as it currently stands. Nonetheless, I also note that this document has gone through a number of iterations and extensive discussion. I believe that, in its current form, it already represents a well-founded distillation of considered thinking about the issues, from a number of sources.

Two things have become abundantly clear from these discussions: since 1986, universities have made a great deal of progress in enhancing undergraduate science and mathematics education, utilizing the resources available from NSF that I mentioned above, as well as from other sources, including internal sources. At my own university, for example, direct participation by first- and second-year undergraduate students in research projects has been growing at a substantial rate for the past several years. The Chemistry, Mathematics, Geology, and Physics departments have all undertaken major successful reform of their introductory science curricula. Such experiences are, I am sure, increasingly widespread among institutions of higher education.

It has become clear that universities must think even more broadly comprehensively, and creatively about undergraduate education. The pace of change in the world that our undergraduates enter upon graduation appears to be accelerating. In addition, with enhanced technology, the typical means and methods of education have the potential to change dramatically. These changes place the traditional obligation of undergraduate education – to provide a well-rounded education – in a new light. It will be incumbent upon us to employ the new technologies wisely and to be innovative in our mapping of a liberal education onto the demands of the current world. In this regard, the recently announced NSF program on Comprehensive Undergraduate Science Education Reform is a welcome addition to NSF portfolio.

I would like to set forth just two ideas, by way of example, of the kinds of discussion in which I would like to see major research universities engage internally, as we confront the need to enhance undergraduate education.

First is an idea that I have proposed for discussion at my own institution: namely, that the university consider requiring that all undergraduate students at some point in their undergraduate career have some direct participation in research. Whether such a university-wide requirement is feasible for the University of Michigan; whether one should focus instead on providing opportunities for all students to engage in research; or whether, indeed, one should focus on building research experiences more directly into courses. These are all issues that have been discussed as alternatives to the original proposal. The underlying point of them all, however, is the one that I think universities must take very seriously: with all of the research taking place at a major university. There must be some way to harness it, to utilize it in inculcating in students the sort of appreciation and understanding for science and rational inquiry that comes best as a result of relatively direct experience.

The second idea has to do with the rapid changes in information technology, and the impact that these changes will have upon undergraduate education. What should we think, for instance, about the importance of the classroom and the laboratory to science education, when technology will soon make possible more dispersed, distributed, and virtual means for learning the basic facts? How do we ensure that new educational technologies do not simply contribute to an information glut but instead are used to help our students genuinely learn how to use information effectively, i.e., how to get it, evaluate it, and convert it into knowledge? One can imagine education proceeding without any classrooms as we understand them today, but it is hard to imagine education proceeding without some direct guidance from those who are truly skilled in the development and use of knowledge. Can we imagine, then, a university without classrooms, where "courses" are available electronically, and every undergraduate student is engaged in a research team?

In the above comments I have focused on the role of research universities, because that is the setting for the current initiative in which I am involved. But, as in our findings in 1986, I must note the seamless link of the contributions to undergraduate science education issues by the entire spectrum of institutions, including community colleges, four-year colleges, research universities, and museums.

Concluding Remarks

I would like to take this opportunity to congratulate the National Science Foundation and the National Science Board for convening this current set of hearings. Clearly, there have been sufficient changes in our world to fully justify taking a fresh look at where we now stand in undergraduate science and engineering education, and to chart a course that will guide us through the next decade, which will be one far from what any of us could have envisioned in 1986.

Undergraduate science and engineering education, and the partnership required between universities and the federal government to ensure that the highest quality experiences are provided to our students, is as important now as ever. The work done by the Board and Foundation over the past decade has clearly laid the groundwork for increasing the appreciation of the importance of undergraduate science and engineering education to our nation. Now what is needed is a refinement in the strategies and goals to make sure that progress continues.

Written Contributions to the EHR Advisory Committee Public Hearing on Employers' Views

Convened November 1, 1995
At the National Science Foundation
Arlington, VA

Invited Speakers:
"Employers' Views on the Preparation of SME&T Undergraduates"

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

Baltimore Public Schools *Baltimore, Maryland*	**Walter G. Amprey** *Superintendent*
Columbia University *New York, New York*	**Eugene Galanter** *Professor of Psychology*
New York Hall of Science *New York, New York*	**Peggy Ruth Cole** *Director of Program Planning and Development*
GHG Corporation *Houston, Texas*	**Israel J. Galvan** *President*
Hewlett Packard Company *Palo Alto, California*	**Alfred Moyé** *Manager, University Relations* **Robert W. Ritchie*** *Director, University Affairs*
Boeing Commercial Airplane Group *Seattle, Washington*	**John H. McMasters** *Senior Principal Engineer, Aerodynamics Engineering* **James D. Lang*** *Director, Technology Division, New Aircraft and Missile Products, McDonnell Douglas Aerospace, St. Louis, Missouri.*
National Alliance of Business *Washington, District of Columbia*	**Robert Jones** *Executive Vice President*
Shell Oil Company *Houston, Texas*	**John J. Sisler** *Manager of Exploration & Production Training*
Bell Atlantic Corporation *Arlington, Virginia*	**Patrick E. White** *Vice President, Strategy*

* *Additional author of contributed remarks.*

Employers' Views on Desired Capabilities of Undergraduate Students Entering the Workforce

Walter G. Amprey

Superintendent of Public Instruction, Baltimore City Public Schools
Baltimore, Maryland

I thank the National Science Foundation for this opportunity to testify on behalf of public education concerning the undergraduate preparation of students entering the workforce. Our "industry," public education, develops a "product" that ultimately must support a regional and national economy and must be the source of problem-solving ingenuity and innovation to meet the challenges of change. The university undergraduate product we depend upon to mold this "product" is the new teacher: either a science, mathematics, engineering, or technology (SME&T) major who often enters secondary education or a non-SME&T major. Even though these teachers receive formal instruction in content and methodology, they are not fully prepared to teach effectively as soon as they graduate.

Many new teachers arrive at their first assignments lacking sophisticated skills in writing, speaking, and computing. These are essential skills for success in any workplace. In addition to these "basic" skills, all graduates should be able to think logically and be able to show their students how to use higher level thinking skills.

Technological literacy is another basic requirement for successful citizens of the Information Age. All new teachers should be able to use technology and adapt to its roles and applications. They also should be able to appreciate the power of science, mathematics, engineering, and technology in everyday living and should understand how mathematics and science support, undergraduate, or clarify concepts in other disciplines such as art, music, and social studies and in diverse career fields.

Along with these "basic" skills, new teachers should understand organizational "culture" and the need for continuous improvement. When entering the workforce, all new teachers should be able to contribute to team efforts that focus on an organization's goals and respect their co-workers' abilities. New teachers should also enter the workforce seeking more education. They must understand that continuous study and research, both formal and informal, are essential, and that preparation for teaching does not end at college graduation or with a master's degree.

SME&T content are also essential for all new teachers. Non-SME&T majors, especially those, who will become elementary teachers, need broad-based knowledge of SME&T content, so they can integrate material into any subject area. They also need to be aware of career opportunities for their students and be able to direct students to appropriate course work for their career goals.

While all teachers should be technologically literate, those who become SME&T teachers should be able to use technology as a pedagogical tool in their classrooms on a regular basis. SME&T teachers also should be well grounded in modern pedagogy and be able to apply modern pedagogical techniques to their content areas.

In their content areas, SME&T teachers should know more about the subject materials than they are required to teach. For example, a pre-college mathematics teacher for senior high school should be able to teach freshman and sophomore courses at the college level. Similarly, a chemistry teacher should be able to handle undergraduate skills and concepts in addition to knowing the state-of-the-art equipment.

New SME&T teachers should have the benefit of sufficient practicum/internship experience before they graduate. After they graduate, these new teachers should have mentors who are experienced teachers as well as mentors who are based in business and industry. SME&T teachers cannot lose focus on the world of SME&T beyond the classroom.

In general, all SME&T majors must be able to adjust to the changing demands of the workplace and use the higher level skills of thinking in mathematics and science to be productive workers. As requirements of business and industry change and as corporate downsizing becomes a reality, graduates must have the transferable skills and flexibility that will provide them with successful livelihoods.

Undergraduate SME&T education for majors and non-majors is influenced by several trends. First, the increased requirements in mathematics and science in precollege education will require colleges to introduce more rigors in college-level courses. Second, the increased number of students in the pipeline for SME&T at the precollege level will increase the number SME&T majors at the college level. This will require more college SME&T faculty. Finally, the increased number of SME&T-literate precollege students will increase the number of majors in college and technical schools who will request training in SME&T-related fields.

Ideally, undergraduate SME&T education for potential teachers should be developed through collaborations of local school districts and universities. For example, the National Science Foundation funds the Maryland Collaborative for Teacher Preparation, an alliance of the University of Maryland system, Morgan State University, Baltimore City Community College, and three Maryland public school systems. This project focuses on elementary and middle school science and mathematics instruction and supports joint efforts to meet the needs of teachers new to the profession. Many informal collaborations coexist with such formal arrangements. Thus, individual public school staff members interact frequently with their colleagues on college faculties because of numerous projects that tie them together. In addition, a number of institutions of higher learning assist local districts in meeting their identified needs.

The standard school district/University interface, however, is the student teaching program, where young people preparing to be teachers work in classrooms under the joint guidance of a classroom teacher and a college professor. Because individual school systems are institutionally separate from the teacher training institution, school district needs are not always met as quickly or directly as possible since universities must meet their own goals and objectives. This "extended reaction time" sometimes keeps the teacher training institutions one step behind the needs of the school district. What is needed is a process for more rapid and direct implementation of system needs into college programs.

Improved articulation between school districts and teacher training programs also would reduce the need for "remedial" teacher training. Because so many new graduates need in-service training to perform satisfactorily, it appears that the training programs at the college level lack content and pedagogy or lack understanding of the needs of the school district. New teachers must be able to apply educational theory in their daily teaching practices. Too often, the practices demonstrated by professors in teacher preparation courses are not the state-of-the-art pedagogical methods that are needed for instruction in precollege classes.

SME&T curriculum for both majors and non-majors must be broadened and deepened if we are to improve elementary and secondary instruction. Preparation of secondary teachers, for example, usually includes almost as many courses as a SME&T major; however, new teachers should be up to the standard of all other graduating SME&T majors. Elementary teachers enter the workforce with very little content background in science and mathematics. Further, they are not challenged to become more prepared because “seasoned” administrators whose backgrounds may be lacking in science and mathematics content supervise them. Thus, a self-perpetuating cycle of "science and mathematics weak" elementary curricula establishes and maintains itself

Both pedagogy and curriculum can best be improved through the collaborations of precollege and undergraduate faculties. With such alliances, curricular and pedagogical innovations could better address the knowledge and performance bases of students -- and better prepares them for jobs and career paths.

Finally, as colleges and universities work with school districts to update and upgrade teacher preparation programs, states should reevaluate their requirements for teacher certification. Currently, a limited number of SME&T courses is required, especially for elementary teachers. New standards should emphasize the integration of mathematics and science in other disciplines such as art and history where high-level skills in problem solving and decision making are required. States also need to increase their requirements for certification of mathematics and science teachers as more rigor is introduced in college and precollege courses. In general, certification requirements should give all potential teachers more practical and comprehensive "hands-on" experience in mathematics and science.

To meet the requirements of the 21st century workplace, we must work harder to disseminate needed improvements in educational practice. On the national level, roundtable discussions and other forums involving school districts and teacher education institutions could address problems. Direct local interaction on a regular basis can resolve problems as they occur. Collaboratives already address some of those needs, but superintendents and college administrators need to interact more frequently. This will prevent the bureaucratic needs of either institution from overwhelming the common goal of providing and employing a competent SME&T workforce in education.

Local districts such as the Baltimore City Public Schools look forward to continued partnership with the National Science Foundation, other federal agencies, and other funders. Specially funded programs have produced many positive outcomes. For example, more minority students enter the SME&T pipeline and consequently enter lucrative career paths where they have historically been under-represented. These programs have also provided the dollars to assist these young people as well as dollars to assist colleges and universities establish SME&T programs. NSF grants to colleges and universities have provided equipment -- and resulting technological literacy -- for students training to function successfully as scientists, engineers, or teachers. Specially funded projects have developed teacher-training programs, such as "STARS," featuring state-of-the-art hands-on/minds-on pedagogy. In the future, we hope organizations such as NSF will develop more collaboratives to help us meet critical needs.

In recent years, changes in our society have produced changes in the direction and practices of education. We have become more sophisticated. We have adopted the principle of ethnic and gender equity. We expect all students to know more and to perform at higher levels. The growth of technology and its application in the mathematics and science classroom require that new teachers be computer literate and that they be adaptable to new technologies and techniques as they appear. Because we expect students to know more, we expect new teachers to know more and be prepared to learn more throughout their careers. Also, as we implement performance-based instruction, cooperative learning, and "hands-on/minds-on" strategies, teachers must be prepared with an expanded "bag of tricks" so they can deliver a 21st century curriculum.

Walter G. Amprey *has been Superintendent of Public Instruction of the Baltimore City Public Schools since 1991. From 1973 to 1991, he served in administrative positions in the Baltimore County Public Schools – associate superintendent for staff and community relations, associate superintendent for physical facilities, director of staff relations, and principal and assistant principal. In 1966, Dr, Amprey began his career in education in the Baltimore City Public Schools as a social studies teacher then served from 1971 to 1973 as a school administrator, He holds a doctorate in education from Temple University, a master's degree in educational administration and supervision from Johns Hopkins University and a master's degree in history/social science and a bachelor's degree in history/secondary education from Morgan State University. Dr. Amprey was honored as Maryland Superintendent of the Year, 1994-95, and served as president of the Large City Schools Superintendents of U.S. and Canada, 1995-96. Most recently, Dr. Amprey served with Reverend Jesse Jackson as facilitator of the Rainbow/PUSH Coalition's Public Policy Education Conference, "Closing the Gap," in Chicago, Illinois.*

Testimony to the NSF Undergraduate Review Subcommittee

Eugene Galanter

Professor of Psychology, Columbia University
New York, New York

Real improvement in science education (SME&T) at the baccalaureate level will require: a) revisions in instructor attitudes and interests; b) attention to multiple cognitive and motivational functions of students; c) revisions in standard modes of instruction; d) new evaluation procedures; e) augmentation of new technology; and finally f) serious longitudinal studies. I will attend mostly to items a - d. The last pair are technical issues that need attention by experts in these fields.

To begin with, instructors (clearly not all) must recognize that students don't think science or math is much fun. They are mainly forced into science by curricular or career path requirements, e.g., chemistry or biology for medicine, psychology for aspects of medicine or social or technical professions, and physics and math by those with self-recognized quantitative or computational skills for technical or scientific program management. Engineering students are self-selected for these skills, and comprise a less intense problem for engineering instructors. However, many of these students at research institutions are more interested in engineering science than real engineering. In my discipline (experimental psychology), students choose our introductory courses to satisfy (effortlessly they hope) a requirement, or to find a less demanding career with the cachet of science. They may then discover that some of the materials are daunting, or that the substantive materials barely speak to their interests.

I attack the question of how to advance science education at the undergraduate level by asking several questions. First: how many students really want to take science in college? The answer is very few. Which sciences do the students take? Our data show that except for pre-meds, they opt for the easiest, the least quantitative, and the most descriptive. The third question: Do these sciences provide opportunities for such students to engage seriously in the technical world: The answer, I am afraid, is maybe not. The fourth question is: What can we do? And that constitutes the heart of my suggestions. These suggestions must be tempered by the enormous revolutionary events that are occurring now in our colleges and universities. My colleague, Eli Noam in the Columbia Business School, has just published an article in *Science* on the demise of the university as the mechanism by which information transfer occurs. His point is that, in the past, the user went to the source. Now the source is distributed to the user. So what does the user need our real estate for? The consequence is that this will engender enormous changes, changes in which instrumentality's that we have never thought of as the educational base of our activities will become the instrumentality's by which information does flow to our consumers, if you will pardon that expression.

Back to our primary topics. Once instructors recognize these default attitudes of students – requirements or jobs – they can often loosen-up the relentless drive to provide technical materials that span a broad spectrum. They must remember that their own initiation required many years of hard work. Part of the difficulty is a failure to notice that our students are taking other courses as well as our own. The demands on their time can create a climate of anticipated failure. I will say more about this phenomenon later.

Students have limited experience. The kinds of experiences they have are not connected to atomic structure, to spiral nebulae, et cetera. They are connected to why can't my grandfather remember things any more? How is it that (I have been told) still images on a television screen look as if they are really people moving around? What is virtual reality? How can athletes do the stuff they do, and so on.

My own field of experimental psychology is useful for discussion because it covers an enormous class of phenomena, and also interlocks with biology, chemistry, and physics through neurosciences and psychophysics on one side, and the personal and social sciences on the other. As such it will serve to illustrate and informally substantiate my views on undergraduate SME&T in the large. To summarize the discussion to follow, I suggest that the paths to continuing progress in SME&T are:

- increasing relevance
- restructuring content
- modularization
- motivational design

In order to make science attractive to students who are not yet career driven, but who may be drawn into a career choice by their college experiences, our offerings must have *relevance*. This much-abused concept refers here to the ability of a course of study to raise and answer questions important to (the limited experience of) students. In the last ten years many curricular efforts have attempted to achieve this relevance, sometimes, unhappily, with a loss of precision. In my first attempt to make psychophysics an integral part of introductory psychology[1], I opened with the question of how an airliner is guided to a safe landing during weather conditions that defeat direct visual control. Such tasks depend on translating visual codes into skilled action. In recent text materials[2] topics in signal delectability theory center on issues of radiological diagnoses of breast cancer, and failure of memory in recognizing faces. Such questions engage the student with problems they can understand. If science informs the answer, relevance is insured.

Are there enough relevant topics? Again in my own field consider a spectrum of subjects such as memory loss through aging or accident, virtual reality from apparent motion through full-fidelity simulations, individual differences in intelligence and other personal characteristics, cognitive development, social and political consequences of individual attitudes and prejudices, motor skills and athletics, sexual preferences and aversions, human error and its consequences; the list could continue to a score or more.

We are *restructuring* the content of early science education in psychology to motivate interest and to offer rational and more importantly –plausible – ways to understand and solve real problems. I mean to do this by making data collection one of the centers of effort to confront the questions of fact and theory. Students who collect their own data as compared with students who do problems in a book *own* the data in a way that the book never provides. When they are really your reaction times to stimuli of various kinds, then you may say, "hey, can I respond faster to red or green." Having those personal data becomes and intrinsic motivator that is critical to the continuing activities of the student. And so rather than follow some preferred sequence, including prerequisite course work, structure has been changed to show relevance. The tested retention of such

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1 Eugene Galanter, *Contemporary Psychophysics*, in *New Directions in Psychology*, ed. by T. Newcomb. Holt, Rinehart and Winston, New York, 1962.

2 Eugene Galanter, *Psych Tech Notes V. 2.1* Adams • Bannister • Cox, 1994.

information in our admittedly minimal current evaluations suggests enhancements suggest enhancements in understanding by a factor of six.

A third advance in my own field, and extendible to other disciplines, is the technique of *modularization.* This refers to the construction of independent sub-parts of a discipline along with its own auxiliary technical materials. Units of study do not need to be timed to coincide with rigid time frames. If we want to talk about memory and about lapses of memory, then, we could have a memory module, and that memory module might last for two lectures or four lectures or six lectures. It might include experiments to see how memory works, how it dissolves and disappears, et cetera.

Our current NSF support has helped us develop a variety of stand-alone quantitative modules on topics in the human sciences from biology to sociology. We have modules of varying duration on human genetics, evolution, psychophysics and decision theory, space and motion perception, and social psychology. We plan to construct additional modules on cognitive mechanisms in perception and action, motor organization, language and thought, theories of memory, virtual reality, human engineering and ergonomics, psychometrics, animal conditioning, learning and cognition, and quantitative sociology.

Each of these units is supported by quantitative material that undergirds the topic. We do not demand prerequisites in, say, calculus, statistics, algebra, or probability theory. Rather, we incorporate the required techniques in the module itself. Any single module is studied for its nominal duration, which currently ranges from 4 to 14 fifty-minute lecture/labs. The ancient bookkeeping of academe proscribes such plans. Our modules currently fill the standard semester time scale, and are given in a “rational" order. The ramifications of these historic constraints are reviewed later.

Table 3.1:

Theory of Intelligence	**Goal Orientation**	**Confidence in Present Ability**	**Behavior Pattern**
Entity Theory (IQ is fixed)	**Performance Goal** gain positive judgments avoid negative judgments	if **High**	**Mastery Oriented** seeks challenge, high persistence
		if **Low**	**Helplessness** avoid challenge, low persistence
Incremental Theory (IQ is malleable)	**Learning Goal** increase competence	**High** or **Low**	**Mastery Oriented** seek challenge, high persistence

From Dweck, C. Motivational processes affecting learning. *American Psychologist,* October 1986.

In psychology the computer has become the required instrument for experimental research and field data tabulation. It is our microscope, centrifuge, accelerator, or telescope. Few institutions provide adequate access to these machines for undergraduate use. In my own department of fifteen tenured faculty, our financially challenged administration has recognized the importance of such investment, and has provided 16 machines for undergraduate labs. These sequestered microcomputers have made "open" labs possible. Only one graduate (or often an advanced undergraduate) supervisor is needed, and the lab is available to students in several courses on an essentially ad lib. basis. There are *ca.* 600 undergraduates per semester in our course offerings, so the ratio is quite small. On the other hand only about 150 students need access to the machines. With increased curricular implementations, we anticipate that this 1:10 ratio will probably increase to 1:25, a figure that is probably close to optimum. As with any computer implementation, we are hampered by software limits. We have developed some experiments for use on our machines, and will be offering these materials on our Internet home page.

Just as lab equipment (in our case microcomputers) is often in short supply, so also are teaching materials. In the modules we are developing, primary sources are the vehicle of choice for students to read. However, for many undergraduates it is often necessary to provide some intellectual resources that may not be part of their apperceptive mass. To this end we need texts that can provide explicatory material to permit students to engage the primary source scientific writings that have cast light on the central issues they study. We are trying to provide such texts in our curriculum development program, but as any teacher will recognize, this task is enormously difficult and time consuming.

The limit imposed by academic bookkeeping prevents us from using new formats and methods creatively. With free standing modules on a variety of topics keyed to questions of obvious and direct importance, we need to allow students to select a group of such modules based on their own interests. If we intelligently metricize the credit value of each module, we can allow students to select from a menu of topics a personalized subset for study during a standard academic time period. Students might be expected to take a variety of admixed modules, any combination of which would be accepted by a registrar for appropriate academic credit. In combination with newly designed evaluation procedures that we are currently exercising, the entire task of selection (i.e., advising), pedagogy, and credentialing could be simplified and packaged to minimize student anxiety and time constraints. These revisions have direct implications for various sorts of distance learning, and other forms of non-institution based education.

The previous reference to evaluation needs expansion. In science education we have commonly used so-called objective test formats to evaluate student comprehension. Critics have charged that "constructive" tests better measure student knowledge. Indeed, this topic is quite current,[3] but fails to recognize the cognitive continuum between, say, a true-false test and a constructive essay. We have developed several waypoints on this continuum, and is currently analyzing correlation between double blind scoring of quasi-constructive answers, and items on objective (four-alternative) examinations. Our preliminary findings support the view that the correlations are very high (*ca.* +.85). We score the objective tests by requiring students to eliminate incorrect answers. Originally we gave unit weight to each incorrect answer. Now we have installed our examinations on our Web page, and process the test data by more sophisticated statistics. We will shortly be able to differently weight the incorrect answers as “easier" or "harder," and in this fashion improve the ostensible validity of the score. Of course, all of these improvements are based on plausibility, and wait real longitudinal validation.

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[3] *Construction vs. Choice in Cognitive Measurement,* ed. by R. E. Bennett & W. C. Ward. LEA, Hillsdale, NJ, 1993.

Finally, the fourth topic – *motivation* – stands at the center of our efforts to bring science to those who are traditionally absent from the feast. Of the 186,013 baccalaureate degrees in science and engineering awarded in 1989, 9325 were awarded to blacks[4] (the data are similar in structure for Hispanics and Native Americans). Roughly 5 percent of the students are drawn from 13 percent of the population. We characterize this as a motivational deficit, not an intellectual one.[5]

To attack this problem we must recognize the distinction between learning and performance. What we mean by the goals of learning are to increase confidence to act. What we mean by performance goals are to seek positive personal judgments. That is, performance means you have gotten such a good score on the test, or you have gotten such a bad score on the test. Either of those two can lead to problems down the road. When we can make clear that failure to learn is a natural part of learning, and if we ensure that the goals of learning are learning goals, then we may observe mastery after failure. There are now more than 50 studies that demonstrate that this is the case. We also believe that an entity theory of intellect can be replaced by an incremental theory, one where IQ is malleable. The format of our modules tries to accommodate these principles.

We know that failure in performance goals leads to hopelessness and rejection of the intellectual content. We must examine how we frame our material so students understand that it is not their performance that counts, but rather their ability to grasp the issues and solve the problem. And if they can't solve the problem, then that failure is intrinsic to actively searching for more information.

Let me conclude with some tangential remarks about how we might fix some parts of SME&T; in particular how some aspects of these revisions would work. Change would occur because students would do things. The teacher would say as little as possible. That is hard to implement. After all, because of my competence in language and delivery, I can amuse you, and it rewards me to see you smile, applaud, and so on. Teachers are mostly like that everywhere. However, the rewards to the teacher are mostly irrelevant to the student. What the student wants to know is how to do something, not to be told about something. In science, doing is everything. Ideas are cheap. It is work that is costly. We have concentrated too much on the transmission of ideas, and not enough on the transmission of effort, activity, and the way to do it.

Unless we are proactive in respect of the changes that have to occur, we are going to be left in the dust. But there are things we have to know, e.g., whether any of these revisions have consequence. I can talk about students being happier, students getting better grades, students inviting others to join the course, et cetera. But if we don't know how many students go to the right jobs or whatever, then all of this is just talk.

We need to plan major longitudinal studies to assess the consequences of science education. We must answer the hard questions: Do the things we are trying to do now have real consequences? To find such answers will require a coherent and well-organized research enterprise to see what happens 5, 10, and 15 years after these changes go into effect. In order to do this I think we must mount a federal enterprise with continuity in design and support. Management has to be administratively structured in such a way that students can be tracked into graduate school, the market place, and their later lives. Do we change from 3 percent entering technical work to 7 percent because of the changes we make now or not?

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[4] Adapted from *National Science Board, Science and Engineering Indicators,* Tenth Ed., 1991.
[5] Carol Dweck, Motivational processes affecting learning. *American Psychologist.* October 1986.

Finally what about our input? What is K-12 science education today? We know that an enormous problem is the turnoff that has occurred in the middle and senior high schools in science. Now, attempts to rectify that by talking about imitation science – I don't mean that in any disparaging way – but things like nature studies and fanciful ecology are not going to increase our entry quality, because the first time these kids take a college course that is serious about these issues, they are going to have to look at population densities and distribution functions of animals, and genetic structures, and they will say, "hey, where is the ecology." And we must answer it is in there somewhere, but we have to work to get to it. K-12 education, as you know, is run in a political environment that is essentially inviolate when it comes to attempts by people in collegiate education to impose anything. We have to suck them into it. We can't push it down. They will simply walk away. They may not have exactly the training that is needed to accommodate the materials we suggest they provide. In which case they are going to be very tough about saying, "well, I think the stuff I am teaching is much more important than what you are doing, and my kids love it, and they are doing very well, thank you, and furthermore 70 percent of the class got A's." To reach the common schools will be a much harder job than getting our own act together.

Professor Galanter received his Ph.D. from the University of Pennsylvania in 1953, and advanced from Instructor to Professor from 1952 to 1959. He was appointed a Research Fellow at Harvard from 1955 to 1957. He was a Fellow at the Center for Advanced Study in the Behavioral Sciences *in 1958-59. His work with George A. Miller and Karl Pribram on a new cognitive psychology was published in 1960 as* Plans and the Structure of Behavior. *Following his return from the* Center, *he began a collaboration that resulted in the three-volume* Handbook of Mathematical Psychology, *published during 1963-65. He completed his* Textbook of Elementary Psychology *in 1966. In addition to these books, and his three popular books in the* Kids and Computers *series published in 1982-84, he has contributed more than 100 reports, journal articles, and book chapters in the fields of psychophysics, mathematical psychology, aviation psychology, and utility measurement. Professor Galanter was made Chair of the Department of Psychology at the University of Washington in 1962. In 1966 he went to Columbia University as Joseph Klingenstein Professor of Social Psychology and Race Relations. He was named Professor of Psychology and Director of the Psychophysics Laboratory in Columbia University in 1967.*

Testimony Delivered to the National Science Foundation Review of Undergraduate Education Hearings on Employers Views on Desired Capabilities of Undergraduate Students Entering The Work Force

Peggy Ruth Cole

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Flushing-Meadows Corona Park, New York

Before coming to the New York Hall of Science 11 years ago, I was principal of an independent school in New York City, and before that a graduate faculty member of Bank Street College of Education, a teacher training institution also in New York City. I have 15 years of classroom teaching experience at both the elementary and secondary levels.

While I will limit my examples to issues related to our particular science center, I am also speaking on behalf of the 300 science-technology centers around the country serving over 76 million annual visitors including children, families, school groups, and teachers. Informal science institutions offer training to 150,000 teachers annually. All these institutions have an informal approach to science, mathematics, and technology in common. Unlike schools, they are discretionary environments where visitors chose to come and select their experiences based on interest, attraction, and a variety of other factors. To quote the late Frank Oppenheimer, founder of the Exploratorium in San Francisco, "Nobody flunks a museum.”

Science centers have the potential to improve the undergraduate preparation of new teachers. We have an externally evaluated program in operation for 9 years, which is a model for other science centers. Our Science Teacher Career Ladder, a program within our Science Career Ladder, serving mostly women and minority youth, involves cooperation among the science center, colleges and universities and schools. Together, we provide a support and training package which colleges and universities cannot supply alone.

The program design is effective. A survey of almost 25 percent of our Career Ladder alumni showed that 34 percent of them are now teaching. And our record of attracting women and minorities to teaching is high. Of our Science Career Ladder alumni now teaching, 21 percent are African-American compared with a national average of 5 percent of current teachers; 14 percent are Asian compared with a national average of 1 percent; and 13 percent are Hispanic compared with a national average of 3 percent.

How does the program work? We employ 40 high school and 60 college youth annually as our floor staff. They work part time in a science- and technology-rich environment, and receive both pay and school credit for the experience.

Their job is to explain science to a broad public, from pre-schoolers through senior citizens. The stimuli for both Explainers and visitors are l70 hands-on interactiveexhibits, ten on-floor demonstrations, and science activities delivered through workshops and special events. Our youth staff learn science and they learn how to teach science in an environment free from grades and exams, but rich with science phenomena. As a result, many discover both an interest in science and pleasure in sharing it with others. Consequently, the majority decides to become teachers.

These students have, on the whole, come through a school system that teaches science through the traditional avenues of textbooks, lecture/demonstrations, and structured laboratory experiences with a reward system centered on high grades. Most never see the real-world application of science and math and they rarely get to meet and interact with people who work in these fields while they are still in decision making positions that will effect their entire futures. The result, as we all know, is an early turnoff to math and science by the very population of women and minorities that will, by the year 2000, be the majority entering the workforce.

The Science Career Ladder is almost 10 years old. It has been a model for 12 other science centers around the country that have adapted aspects of the program. In the past decade we have worked with 20 colleges and universities and 14 local high schools. Almost without exception, we have been able to develop meaningful partnerships with Cooperative Education Departments who do not offer content course credit. In some cases we have developed relationships with Schools of Education but rarely with departments of academic science: physics, biology, chemistry, etc. The culture of undergraduate institutions is curriculum driven, departmentally structured, grade oriented – formal. The culture of science centers is content driven, discretionary, intergenerational, exploratory, visitor driven – informal. We are working hard to bridge this gap and to help colleges see our program as relevant and meaningful to their enterprise, but the academic structure that informs course development and credit makes it very hard.

As employers of youth, in a rapidly expanding industry, with a significant shortage of well-trained minority youth, we have learned to "grow our own." We identify women and minority youth who traditionally are not represented in science and technology fields, and offer them science-related employment to both serve our public and to prepare them for the workforce. And we are succeeding. In addition to producing science teachers, the 1994 survey showed that 9 percent are working in museums, and 15 percent are working in science and technology fields. The majority of our Career Ladder alumni are African American, Latino, or Asian, and the minority of white students includes recently immigrated ethnic groups. They are poor, often first generation college students.

What are the workplace literacy skills we are developing in our youth staff? Because these positions are authentic, paid, and essential to the functioning of the museum, our demands are those of any other employer. We expect punctuality, responsibility, appropriate dress and professional demeanor, teamwork, the ability to meet performance standards, and above all, knowledge of science. We pay for training and we expect students to learn the science needed to work with the public.

The science content we teach is directly related to our permanent, temporary and traveling exhibitions, and school and public programs. Interpreting our 170 permanent exhibitions demands a knowledge of anatomy, psychology of perception, optics, wave theory, resonance, atomic structures, physics of light and color, feedback systems, quantum physics, audio-technology, microbiology and chemistry. Delivering programs and interpreting traveling and temporary exhibits involves knowledge of astronomy, information technology, navigation, earth science, manufacturing technology, architecture, and the biology of AIDS. We also expect our youth staff to use instruments from scanning electronic microscopes to a functioning steam engine. Students tell us the skills they need to work at the New York Hall of Science test and exercise what they learn in the university in new and more interesting ways.

Career Ladder participants learn questioning techniques, how to adapt demonstrations for kindergartners and high school seniors, how to present the same content in different ways to meet different learning styles, how to use manipulatives to illustrate principles, how to attract and keep attention, and how to control large groups. Our Preschool Science Place is a laboratory for learning about early childhood development and how to work with very young children and their caretakers. Unlike traditional undergraduate pre-service students who get one or two student teaching placements, our Science Career Ladder participants interact with students at every grade level from preschool through graduate school, students with disabilities and learning problems, students who are intellectually gifted, and everyone in between. Many Career Ladder participants discover an affinity with a particular grade level or learning style as a result of their experiences at the Hall of Science. Our Career Ladder students get to observe teachers handling groups on class trips and they form ideas about teachers and teaching from a perspective unavailable in any other setting.

Some schools of Education offer field credit for the experience, one or two offer student teaching credit. Our experienced pre-service Career Ladder students work in our teacher training programs, interacting with classroom teachers as museum staff. But most importantly, our students are rewarded for exploration, discovery inquiry, experimentation, flexibility; the very attributes essential for good science teaching and learning and, unhappily rarely modeled in high schools and colleges.

In sum, the Science Career Ladder and similar programs around the country, are providing students with workplace skills and science, technology and math know-how within informal settings that supplement and enhance undergraduate education. The evidence is rapidly accumulating and it indicates that work experiences explaining science in an informal setting have a positive impact on career choice, science knowledge, and a sense of self-confidence and self esteem.

The major obstacle science centers face is neither designing nor implementing successful work-study programs for undergraduates. It is, rather, convincing the formal education community that experiences provided by science centers are legitimate and valuable ways to provide young people with skills, motivation, and know-how in science, mathematics and technology. At the moment, science center staff are included in reform efforts as advisors, committee members, and representatives of community-based organizations. But they are not taken seriously as an integral part of undergraduate teacher preparation despite the advantages I have just described.

These hearing are designed to help you assess what further needs and opportunities we see in undergraduate education reform. I would strongly recommend a National Science Foundation program that provides major funding for a fewmodel programs which, like our Science Career Ladder, offer undergraduates carefully constructed, content rich experiences in informal science centers. If requirements for successful proposals included: 1) academic credit in the disciplines for participants; 2) college level administrative commitment to such programs; and 3) a planning team of college and science center staff; we could show the formal education community ways they might work with the informal science community to reach our mutual goals, which are the preparation and employment of a scientifically literate, and science- and technology-oriented workforce.

***Peggy Ruth Cole** is a senior staff member at the New York Hall of Science responsible for the planning and implementation of new programs and for the development department and its fundraising activities. She is the founder of the Science Career Ladder, the signature, minority access education program of the New York Hall of Science which is replicated nationally. Before joining the Hall, Dr. Cole was special project coordinator at the Chrysler Museum in NorfoL4 , Virginia and the conceptual advisor to the Staten Island Children's Museum's exhibition, " Once Upon An Island." She was Principal of the Fieldston Lower School in New York City from 1981-1983. Prior to this, for 12 years, Dr. Cole was a graduate faculty member of the Bank Street College of Education in New York City. She serves on the editorial board of* Curator*, the journal of the American Museum of Natural History. Dr. Cole is nationally active as a reviewer, author, and speaker in the field.*

Math, Science, and Technology Undergraduate Education in America: One Small Business Perspective

Israel Joseph Galvan

President, GHG Corporation
Houston, TX

Introduction

These are the personal views of one small business owner deeply involved in current and emerging technologies. However, I wish to emphasize that I claim no special expertise on education.

My name is Israel Joseph Galvan and I am President of GHG Corporation, a computer systems engineering company based in Houston, Texas. We have been in business since 1979 and employ about 200 people.

Criticism of the American educational system comes from a variety of directions. It has increased in volume and intensity and, worse, it has become a permanent issue in every political campaign. Whether the fundamental role and purpose of a university education is in need of a serious national debate is problematical. However, there appears to be some confusion and lack of a unifying principle in our educational system—a lack of clarity.

Arguably, the last serious debate on the role of the university occurred in the 1930's between the camps of Robert Maynard Hutchins, the traditionalist, and John Dewey, the progressive. These two giants proposed ideas that were fundamentally different, but their views were clear and unambiguous. Hutchins believed that the university should be a community of scholars, a place to train the intellect and to transmit a Great Tradition of culture. Dewey saw education as an experience and a process for coming to grips with and solving real world problems, a bridge between school and society. Hutchins opposed professional schools; Dewey embraced them. It is safe to say that a hybrid of Dewey's ideas won.

As it should be in any democracy, the debate on the nature and function of higher education continues, but the current issues are not as fundamental. The debate is less on the role and more on quality, efficiency, and economics. It is centered principally on delivery and implementation issues. The core of contemporary criticisms, I believe, validates our present educational system. Our educational system is sound. It is only in need of minor adjustments. Yet there are some aspects of our educational system that do require further clarification.

What is the role of our educational system in training our work force, as opposed to educating our work force? What is the role of our community college system? What is the relationship between our university system and our community college system?

These questions are beyond my simple musings. Contrasted to the complex problems visited on our educational system, I fear that this modest presentation may be too narrow and parochial. My intent is to simply share the personal observations and views of a small "high-tech" firm.

The Environment

The world is undergoing a transformation not seen since the Industrial Revolution, but at an increasingly faster rate. The time from idea to development to implementation has virtually disappeared. The forces driving this change began in the early 1960’s and were not anticipated. Our finest research institutions and our finest minds thought that the 1960’s were going to be the decade of nuclear energy. It was going to satisfy our every need for energy. Energy was going to be so cheap it would not have to be metered.

They were wrong, of course; it turned out to be the decade of the computer, with IBM as its corporate manifestation. For most of the next two decades, IBM became the corporate model for the world, emulated for its technical and business innovation. Little did we know that the heart of IBM's computer, the Central Processing Unit (CPU), consisting of a dozen circuit boards, would be replaced by another CPU the size of a dime. Driven by this new CPU, which is embedded in every facet of our lives, including our psyche, our world and our perceptions of that world changed, and continue to change before our very eyes. It has created, and is continuing to create, new industries. It has changed, and continues to change, existing industries. It has transformed, and is continuing to transform, every sector of our economy. It has eliminated, and is eliminating, jobs; created, and is creating, new jobs; and is contributing significantly to our country's anxieties and sense of uncertainty. Indeed, even IBM feels threatened. It is threatening the classic American corporate model and creating new ones. It has empowered the technician and the small business.

Much has been written and said about the economic importance and significance of the small business community. Small businesses:

- provided virtually all of the net new jobs from 1987 to 1992;
- were 99.7 percent of all employers in 1992;
- employed 53 percent of the private work force in 1992; and
- are the source of considerable innovation.

So says the U.S. Small Business Administration. And yet most of our national educational and economic policies do not reflect the uniqueness, diversity, and role of small business in the current transformation.

These are fast changing times; these are exciting times; and these are perilous times. However, there appears to be one universal constant: "Knowledge is Power.” For the present, this verity could possibly be restated "Mathematical, Scientific, and Technical Knowledge are Power.” And it is the role of our educational system and this board to insure that all Americans are armed with this knowledge. Of course, nothing much is at stake, except the economic well being of this country.

Small businesses, especially "high-tech" ones, live, operate, succeed, and fail in this environment. Most small businesses share common problems and concerns, but "high-tech" small businesses, I believe, have a number of unique concerns and problems intimately tied to undergraduate science, mathematics, and engineering education. Generally, the small business community has very little direct contact with the university community, except as a source of talent. In the university research and development world, cooperative agreements and sponsored research is the exclusive domain of the large corporation. The overhead cost of a typical university is daunting to any small business wishing to fund a research project.

The Real World

Recently, a colleague said that the three most important concerns of his business were: capital, capital, and capital. Hyperbole not withstanding, capital is always a problem, but equally important is good management and good people. This, of course, is true for any business, small or large. We both face a rapid and sustained force of technological change, and a diminishing life expectancy and relevancy of particular skills. It is challenging our abilities to maintain our skill base tuned to this change.

Unlike the large, well financed corporation, the small "high-tech" business has minimal redundancy in its skill base and less resources to keep that skill base continuously trained. The loss of a key employee can be devastating. Thus the recruitment, retention, and continuing training of a quality work force, while always important, has become critical. In this highly competitive market place, we can not afford to lose employees, lose our sense of unity, or disrupt the "team." We can not afford to treat employees as expendable commodities. We have to nurture them, train them, in short, value them. This is not without a significant financial burden and increasing pressure to make tough management decisions. Yet, we must remain competitive. We are still subject to all of the forces of a competitive market place: being raided by highly skilled professional recruitment agencies, market demands for increasingly narrow job descriptions, competitive compensation packages, and the bottom line.

For example, it is not unusual for us to have to pull a highly skilled computer scientist from a revenue generating project in order to send him or her to an expensive short course on some very specific emerging and proprietary technology. An alternative is to establish an internal training program with our own courses and instructors, and we have. But this is very expensive. Another option is to lay off employees when their substantial skills are not considered adequate for more narrowly defined skills. To retain a competitive posture, we are forced to make decisions at odds with our sense of fairness, our sense of community with our employees, and the long-term health of the firm. However, survival is basic and immediate. Though necessary, it is no longer sufficient to have a solid education in a particular technical discipline, thus demonstrating a compelling need for the development, implementation, and delivery of continuing education programs that keep pace with the changing technical environment.

This fact is equally true in non-degree technical fields. For example, the transition from mainframes to distributed workstations is abolishing the need for the traditional computer operator and other affiliated paraprofessionals. This same transition is creating new jobs such as local area network (LAN) administrators, managers, and other related jobs. However, instead of training the current work force, businesses are replacing them.

We expect recent college graduates to arrive at the work place fully armed and ready to contribute to the bottom line. Perhaps our expectations are misplaced. Perhaps it is the role of the business community to provide the necessary training. Additionally, it appears that recent college graduates generally lack practical, immediate skills; skills demanded by current market forces; skills such as being able to work in teams, being familiar with current technologies, and a fundamental understanding of systems engineering are glaring examples. Unfamiliarity with working in teams and with current technologies and systems thinking may be a manifestation of dated curriculums. The currency of detailed technical skills is important, but graduates also lack fundamental skills. Skills with the written and spoken language are deteriorating. In fact, it has become a cliché that scientists and engineers can not write. This paper is probably a good example.

In summary, the most glaring deficiencies in Math, Science, and Technology Undergraduate Education that I have observed are:

- Lack of team skills in recent recruits;
- Lack of communication skills, both oral and written;
- Lack of a dynamic and current curriculum and continuing education program; and
- Inability of small businesses to access the applied research and development capabilities of our educational system.

Modest Recommendations

The National Science Foundation should promote greater participation between the Small Business community and our educational institutions. More specifically, the Foundation should:

- Encourage the development of curricula allowing undergraduates to work on more relevant projects; projects that require multiple disciplines and an integrated team effort. This will allow them to experience a project through its entire life cycle. This will encourage teamwork, systems thinking, and significant practice in the development of their oral and writing skills.
- Encourage the continuous improvement and relevancy of the curricula.
- Encourage the development of a better, more relevant, and more accessible continuing education program. This program should be made available to non-degree technical people, post graduates, and even post doctoral students. Considerations should be given for small businesses to consult in the development of such a continuing program. In addition, small businesses should be considered in its implementation and delivery.
- Encourage an active partnership between small business and our university system. Undergraduates should be encouraged and allowed to work on small business sponsored projects and receive credit.
- Encourage and sponsor more relevant and applied research projects at the undergraduate and masters level. The small business community should be allowed and encouraged to participate, share cost, and benefit from the research.
- Encourage the small business community to sponsor application research without the burden of the educational institution's overhead. Perhaps, the Foundation could make overhead moneys available to the university community if they could match it with appropriate direct cost moneys.
- Finally, the Foundation should encourage the small business community to work more closely with the Community College System in the development of curricula more efficacious to small business and to the paraprofessional.

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Employers Views on Desired Capabilities of Undergraduates Entering the Workforce

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Introduction

We applaud NSF for having these hearings and for focusing on undergraduate science, math, engineering, and technology (SME&T) education. Significant change in how we educate in these critical areas is required, and NSF is uniquely positioned to take the leadership in encouraging this change. NSF is the Federal agency looked to by the Academy as having the general health of higher education as its focus, without the encumbrance of specific, narrowly defined missions, such as the Departments of Defense, Health, or Commerce.

The organization for this presentation is:

1. The Environment and Why it Requires Change in Undergraduate SME&T Education
2. The Characteristics Required of Graduates to Succeed in This Environment
3. The Kind of Undergraduate Education for There to be Such Graduates
4. Specific Programs to Move Towards These Kinds of Undergraduate Experiences
5. The Environment and Why it Requires Change in Undergraduate SME&T Education

The Environment and Why it Requires Change in Undergraduate SME&T Education

Our society is radically different from the one in which the current educational system developed. Changes in our world have had a major impact on our sense of what students need to learn and how the learning should be delivered to them. Increasingly, we are recognizing that mastering a body of knowledge is simply not enough. Students must acquire lifetime skills, such as critical thinking, quantitative reasoning, effective communications, along with such abilities as finding needed information and interacting well with others. We want graduates who have the capacity to learn not who know everything.

Some institutions are rethinking and redesigning their curricula to reflect the shift from teaching content to enabling students to develop life-long learning skills. Some faculty understands the implications of the information explosion and has re-engineered their courses accordingly.

An important, and not so subtle, change has been a shift from life-long job security to a more realistic hope for career security. This shift is not greatly appreciated because it places responsibility on employees to manage their careers, and to continue learning in order to avoid technological obsolescence.

Today's worker has to learn to survive and thrive in a world that is globally interdependent. Workers must be able to operate and communicate cross-functionally, cross-culturally and across geography.

Teamwork, group problem solving and collaboration characterize today's high-performance workplace. Learning in industry shifts from the classroom to peers and teams. Knowledge creation shifts from the individual to the organization where problem solving and decision-making skills are important components.

Characteristics Required of Graduates to Succeed in this Environment

This environment requires that all graduates have skills for continued learning. Workers must assume responsibility for managing their careers, for continuous upgrading of their skills and acquisition of new skills in order to be prepared for emerging opportunities. Managing one's career in this way is the way to guarantee career security--to position oneself to have a career for as long as one wants to work. The onus is on the individual.

To prepare students to be productively employed for life in science, math, engineering and technology, the undergraduate experience must consist of a solid foundation in mathematics and science fundamentals.

They must have an understanding of the modern, rapidly changing, high-performance workplace and knowledge of what is required to succeed and thrive in such a workplace.

They must have the flexibility to expect and embrace change throughout their careers, skills for and the commitment to working in teams, cutting across vastly different areas of expertise whether it is development, manufacturing, marketing, or whether it is with other people from around the globe.

Workers must have an appreciation for the global interdependence of our communities and have the ability to work across geographies. In particular, students planning for careers in science, math, engineering, and technology must be prepared to understand the business and social implications of the activities in which they will be engaged.

The Kind of Undergraduate Education for There to be Such Graduates

To prepare graduates, who have the above skills, schools must drastically change the undergraduate educational enterprise, especially in SME&T education.

An expectation of all undergraduates in the next millennium must be basic science and technology literacy, regardless of area of concentration. Information technology will increasingly impact our lives as citizens, voters, politicians, and parents. Without an understanding of issues arising from science and technology, it will be difficult to be a fully functioning member of a democracy dominated by technology and public understanding of science and technology will remain very low.

K-12 teachers must have better preparation in SME&T. K-12 teachers who are science, math, technology-illiterate, will not be able to encourage students to consider careers where SME&T skills are needed.

A much higher percentage of our populace must understand science, math, engineering, and technology to be successful in the workplace, and hence, to lead financially secure lives. For this reason, ways must be found to make SME&T education interesting and attractive for a much broader cross-section of our populace.

To make education interesting and attractive requires a shift to student-centered learning environments in which the faculty are guides, in contrast to the current, largely mass production, teacher-centered ones, in which the faculty are lecturers imparting information. Someone said it requires a shift from the sage on stage to the guide at your side.

It requires faculty who are knowledgeable of careers outside the academic world so that they can make their courses more relevant and advise students of career opportunities using SME&T knowledge in jobs that are not closely aligned with the narrow interests of most faculty.

Acquisition and application of a better understanding of the learning process and of different learning styles is required, especially those which may be the prevalent styles of segments of our society which have not traditionally been attracted into mathematical, scientific, and technological careers. We know a lot about how people learn, but too few faculty, especially in science and engineering, are using the results of research on learning in their courses. The knowledge is there, but our faculty does not use that knowledge.

Individualizing education will lead to much heavier reliance on current and shortly forthcoming technology, enabling learning experiences to be delivered on the learner's demand across space and time (just-in-time, anytime, any place learning). Faculty must become proficient at using the technology for education. They must have both the willingness and commitment to use technology and also the support and time from the university for professional development.

Undergraduate education programs must find and apply ways to impart basic written, visual and oral communication skills and skills in working in teams. In addition, students aiming for science, math, engineering careers need to learn about business and societal issues to be able to understand implications of decisions they make.

At a Hewlett-Packard sponsored conference in October, 1995, attended by 18 faculty involved in SME&T education, the topic of appropriate characteristics of institutions of higher learning in the year 2000 was discussed and debated. The conclusion of this group was that the college or university of five years from now must be learner-centered and include the following:

- Anytime, anyplace access
- Collaborative learning and problem solving
- Support for life-long learning
- Significantly improved learning outcomes
- Equity, access and success across all populations; and
- Economic viability and globally competitiveness

They also concluded that this requires a very different kind of academic environment: one, which has agile and change-oriented institutions. One which applies and integrates appropriate technologies, exhibits cooperation and resource-sharing among government, industrial, and other educational institutions, disseminates and applies best practices from elsewhere, effectively evaluates the results of its activities, and has a faculty reward structure which encourages these activities.

We absolutely agree with these conclusions.

Specific Programs to Move us Towards These Kinds of Undergraduate Programs

The discussion above indicates where the focus of Federal programs should be, and they should be designed to move as quickly as possible to the academic environment outlined above.

To reinvent institutions to be more agile and change oriented, those individuals within the institution who are change agents should be supported and rewarded. For example, a program of summer grants and awards to faculty for significant curricular development, application of best practices into their behavior, etc., could be developed.

To encourage use of technologies, infrastructure for learner-centered anytime, anyplace activities could be mounted. Faculty at the HP October 1995, workshop recommended leveraging funding by requiring matching funds from the institution. Faculty saw this as a way to get institutional commitment and begin to institutionalize successful programs. NSF might also require institutions to state how they intend to sustain funded programs through operating expenses or endowments for technology upgrades and enhancements.

To enhance collaboration, NSF might fund faculty time to work with industry to transfer insights from the corporate world to the academy. Much of the breakthrough research today is coming out of industry, and faculty would benefit from the experience. Similarly, encourage faculty to work with K - 12 teachers with, for example, summer funding to increase the number of high school graduates ready to pursue the undergraduate experience.

Faculty who attended the HP workshop ranked new models of collaboration -- among institutions, commercial-industrial collaboration, as well as collaboration with government – among their highest priorities. They also felt it was important to launch some grand experiments, especially grand experiments with multi-campus involvement. To disseminate best practices, NSF could fund centers for accumulating and distributing best practices much in the model of the Synthesis coalitions' NEEDS project, which is funded by NSF.

To develop and apply evaluation methods, NSF could fund research into evaluation of program design to enhance learning, especially learning in populations previously under-represented in SME&T programs.

To encourage modified faculty reward structures, NSF might consider awarding summer grants to faculty and administrators to create alternative ways to recognize faculty involved in educational innovation. Finally, on this point, NSF has special leverage with its research programs and could require descriptions from institutions as to the steps the institutions are taking to modify their faculty reward structure as a condition of (or at least as a significant factor in) the award of a research grant.

Conclusion

Thank you for the opportunity to appear today. Our environment mandates changes in SME&T education if we are to produce graduates who can succeed in today's rapidly changing information society. We applaud your interests and believe your focus can have a unique and positive influence on American higher education.

Alfred L. Moyé *became Hewlett-Packard's Director of University Affairs in May 1996. He leads HP's worldwide interaction with key universities, including the company's ongoing programs in such areas as research, recruiting, marketing, training grants and public advocacy. In addition, because of the crucial role of universities in developing skills and technologies needed to improve national competitiveness, Dr. Moyé leads the formulation and communication of HP's views on U.S. policies for technology and higher education. He was previously Manager of Engineering Education Performance Technology at Hewlett-Packard. Prior to joining HP in April 1984, Dr. Moyé was national educational sales manager and director of the Atari Institute for Education Research He was also vice president for academic affairs at Roosevelt University, Chicago, and vice chancellor for student affairs and associate professor of chemistry at the University of Pittsburgh. During the Carter Administration he served as deputy assistant secretary for higher and continuing education He has published an organic chemistry laboratory text and has authored several articles in chemistry and chemical education journals. He is an officer of the Board of Trustees of West Virginia Wesleyan College and the National Technological University, and a member of the Board of Visitors, Faculty of Arts and Sciences, University of Pittsburgh. He was recently elected to the Board of Trustees of the University of Pittsburgh. Dr. Moyé received his B.S. degree from West Virginia Wesleyan College and his Ph.D. from the University of Pittsburgh, both in chemistry. He is also recipient of five honorary doctorates.*

From January 1990 until his retirement in 1996, ***Robert W. Ritchie*** *served as the first Director of University Affairs at Hewlett-Packard Company. He led HP's worldwide interaction with higher education, including the company's on-going programs in such areas as research, recruiting, marketing, training, grants and public advocacy. Prior to becoming Director or University Affairs, Dr. Ritchie was Director of the Computer Systems Center in HP Laboratories from 1988 through 1989. From Science Laboratory of Xerox Corporation's Palo Alto Research Center. From 1962 to 1983, he was on the faculty of the University of Washington, first in mathematics and, subsequently, computer science. He formed the Department of Computer Science there in 1966, was its first chair, and then chaired the department again from 1977 to 1983, helping it achieve its current rating among the top ten in the country. While at the university, Dr. Ritchie also served as Associate Graduate Dean and Vice Provost of the University. From 1960 until joining the faculty at the University of Washington, he was John Wesley Young Research Instructor in Mathematics at Dartmouth College. He has served as the chair of the Committee on New Areas in Applied Mathematics of the Conference Board of Mathematical Sciences, chair of the Computing Research Board, and co-chair of NSF Workshop on Quality in Engineering Education.*

Enhancing Engineering and Manufacturing Education: Industry Needs, Industry Roles [6]

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The problem of how to provide quality-engineering education (as contrasted with training) in our universities, and the appropriate role of industry in this endeavor, has been a topic of controversy and debate for decades. Ever since the proliferation of research-oriented universities began in the early 1960s, a widening gulf has been developing between our colleges of engineering and the industries they support. It has become increasingly clear to those of us with an interest in industry-university interactions and recruiting that the curricula in most of the major universities in this country are now badly out of balance, with a too heavy emphasis on engineering science (analysis) and competition at the expense of design (creative synthesis), manufacturing and cooperative learning (teamwork). Despite an increasing number of recent refreshing signs of change, the current under-emphasis on the quality of undergraduate education is further cause for major concern with respect to the impact this may have on the overall competitiveness of our future industrial technical workforce. Of particular concern is the inadequate exposure to manufacturing issues given to most undergraduate engineering students. Design (engineering) and manufacturing are inextricably bound together in modern industrial practice, and this fact generally is not reflected in current engineering education programs in the majority of our research oriented universities. This situation poses a significant long-range problem for industry in this country unless sustained, cooperative actions are taken to restructure and rationalize the present system. Furthermore, industry needs a greatly increased level of continuing education and training, much of which could be provided by developing strong and continuous linkages with our universities and community colleges.

> *"Poor ... education wastes human potential If schools are sound...[students] will graduate with the knowledge, skills and motivation to help further build our nation, and with the foundation needed to help them enjoy full and productive lives.*
>
> *Frank Shrontz*
> *CEO, The Boeing Company*

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[6] Presented at the 1995 American Society for Engineering Education Annual Conference and Exposition, Anaheim, CA June 25-28, 1995

> *"A scientist discovers that which exists. An engineer creates that which never was."*
> *Theodore von Kármán*

> *"In time, the ... public and possibly even the 'educated class' will come to appreciate that engineering is no more applied (and therefore second rate) science, than science is theoretical engineering."*
> *C. R. Chaplin*[1]

> *"The mind is not a receptacle; information is not education. Education is what remains after the information that has been taught has been forgotten. "*
> *Robert M. Hutchins*[2]
> *(after Benjamin Franklin)*

The Current Situation

The state of education in this country, especially in science, engineering and technology, has become a matter of increasing concern to many of us. The recent National Research Council working paper (*Major Issues in Engineering Education*) of the Board on Engineering Education, as only one recent example, identifies many of the major issues that need to be addressed. While the problems we perceive encompass the whole system from pre-elementary through post-graduate education and training, the focus of the present paper is on needed changes in university undergraduate education programs. Our paper is sometimes strongly worded, but we believe that the assertions made can be adequately documented and defended. Extended discussions with a large number of our colleagues in industry, academia (including many students) and government show that while there are significant exceptions to what we have written, and continued denial that anything very basic is wrong with our current system of higher education, there is now an increasing degree of admission that the following observations have validity.

- Too many of the faculty and administrators in our colleges of engineering remain complacent. The primary message from academia continues to be: Give us more money and we will do more (of the same) good things.
    - Improvements in curriculum, etc. are always needed, but nothing basic is broken in the educational system we now have. Witness the number of foreign students in our graduate programs as only one measure of the success of the system.
    - Research money continues to come (from largely government sources) to those willing to work hard enough to get it, which is good because so many departments are now so heavily dependent on it. The fact that too much of this research is of very limited value to our industry seems to be irrelevant.
- From an aerospace industry vantage, as potential employers of the universities' graduates, we see vast opportunities for improvement. We are increasingly "dissatisfied customers."
    - New hires must serve excessively long apprenticeships (three-to-five years) before they become fully productive (i.e., we must fill significant gaps in their education's as well as provide job-specific training).

    - We see too many new graduates with an inadequate grasp of what engineering (as contrasted with engineering science) is and how one practices it, particularly in the currently evolving industry environment. Too few of our engineering graduates seem to have any idea of how to work in teams or how to manufacture anything. Fewer still seem to understand the process of large-scale, complex system integration, which characterizes so much of what we do in our industry.

    - Based on limited data available to us, academic success (as measured by test scores and grade point averages) shows little discernible correlation with subsequent performance on-the-job (as measured by salary growth and perceived value of an employee to a company). Those students who are judged the "best and brightest" on the basis of grade point average are Frequently those who have worked hardest in a highly competitive academic environment of separate, specialized courses, and are often least prepared to work cooperatively in teams to engineer an integrated complex system which is economically and operationally viable.

- Industry continues to be limited, and sometimes-underutilized partner in the engineering education process. Merely throwing money into the system is inadequate.

    - Industry recognizes its vested interest in education, but is largely preoccupied with staying in business while producing a proper return on the investment of its shareholders. Improving the national educational system is not in most corporate charters.

    - The modern international marketplace is highly competitive and volatile (particularly in the aerospace industry). Historically, industry has tended to be shortsighted in its planning, while longer-range forecasts have generally proved unreliable. The unknown consequences of the present era of world political and economic uncertainty only exacerbates the difficulty of making sustained, long-term commitments to "lower priority" supporting activities such as generic research and pre-employment education. At best, industry has too often been viewed as a "fair weather friend" by much of academe.

    - Discussing appropriate engineering education programs is made very difficult when a higher-level manager from a given company (with a background in one discipline, as practiced when he was an engineer years earlier) tells a dean of engineering one version of "what industry needs" while a working lead engineer from another discipline tells a department chairman quite another story. In the end, both stories get lost or the one closest to what the listener wants to hear gets heard. *Industry really would do all involved a great favor by developing and delivering a more coherent position to academia on this issue--even if the message is complicated or a mere statement of principles.* [A listing of the “Desired Attributes of an Engineering Graduate” is appended as on candidate for such an industry-wide message].

Much more than the above has been written[1-13] on the faults (and less frequently, the real virtues) of our educational system in general, and a large number of documents have been prepared recommending a wide range of reforms. The university system has proved remarkably resistant to many of these assaults, however, and little real change has been apparent until quite recently – spurred in part by the massive dislocations caused by the end of the Cold War and the concomitant "right-sizing" (downsizing) in our industry[14] which has been further fueled by increasing international competition. In defense of our universities it also must be pointed out that the increasing complexity of our technology, the past availability of large sums of government money, the changing economics of maintaining a high quality (largely graduate student focused) academic and research program, a lack of adequate industry attention, and the perceived weaknesses of K-12 public education are in part responsible for the higher education system we have today – which in the face of greatly increased international competition, is no longer good enough. While it is easy enough to point fingers or blame "outside" causes for our current situation, the problems we now face remain ours to deal with. Since we all (industry, government and academe) share some measure of culpability for what we have created, we should now be able to go beyond the point of deciding "whose fault it is" and work together in a spirit of enlightened self interest to create a new system which better meets the future needs of all of us and our nation as a whole. Further studies of the problems we face are not needed; what we do need are practical plans and processes for cooperative act ion. These plans should be based on rigorous use of systems engineering principles to define requirements for and develop the design of, the new approaches needed. Appropriate metrics must also be developed and applied.

What We Need - Some Opportunities

What is needed is a long-term, sustainable and fully cooperative effort based on systems engineering principals aimed at producing the sort of education (the most valued product of the university system from an industry perspective) which will develop future engineers with the skills and attributes listed in the Appendix. This program would be based on:

- Recognition of the basic distinction between "engineering science" (analysis) and "engineering" (design/creative synthesis) in both the education and employment of our future engineers. "Design" and "engineering" are fundamentally synonymous[16] and thus we must accord design education the respect to which it is due.
- Recognition that what you design is what you have to (attempt to) build and therefore that design and manufacturing are inextricably bound together – both in professional practice and in university curricula.
- Recognition that no 4-year (or 5- or l0-year) university program is ever going to be able to produce a fully and permanently qualified professional engineer, and thus that efforts to cram "everything a student must know" into this time frame is futile. A student must be prepared for life-long learning and major new partnership efforts are required to provide continuing education at all stages of an individual's career.
- Recognition that our future prosperity depends on industry/university teamwork and cooperation at all levels, including student course work and in university faculty interactions.
- Development of a modern approach to teaching design and manufacturing as a fully integrated, team focused, part of the university curriculum (including such exposure in core engineering science courses) beginning at the beginning of a student's freshman year. Intrinsic in this is the recognition of the profound importance of systems engineering and information technology (far more than mere "computer literacy") both in the curriculum and as a means of educational program delivery.

- Providing our students a proper view of the context (the whole system) within which engineering is practiced. This context includes economics, history, manufacturing as well as environmental, legal and ethical aspects of our profession.
- Providing an appropriate hiring and reward system for engineering (design) and manufacturing educators within a given university structure, and which at least provides a faculty with sufficient experience and dedication to teach these topics well.
- Recognition of the distinction between education (a primary university function) and training, much of which must be viewed as an industry responsibility. We must understand the appropriate (and perhaps new) relations between our research universities and our community colleges in providing both initial and continuing educational and training services. The differing requirements and available resources of large corporations and smaller companies for training must also be recognized and dealt with.
- Proactive leadership and involvement from all relevant professional societies (e.g., AIAA, ASME, ASEE, SAE, etc.) in building processes to link industry, academia and government participants. Their traditional role should be expanded and integrated across societies in recognition of their members' current needs. Their role, along with ABET, in formalizing and enforcing educational standards provides strong leverage to develop and implement engineering curricula changes and to achieve results on a national level.

Roadblocks

It is easy enough to make lists of what we in industry need, but it must be clearly recognized that there are some serious stumbling blocks to be overcome in accomplishing the changes previously advocated. Some of the most obvious are:

- While many in both industry and academe now recognize the need to change, there is a serious discrepancy between our two cultures with respect to the sense of urgency we each feel regarding the rate at which changes must occur.
- Too many university administrators and faculty members have little or no knowledge of what industry does, how it does it, and what their graduates need to know to function effectively in an industrial environment.
- Too few in industry have an adequate understanding of how our current universities function, how the faculty reward system works, or the constraints under which faculty members must operate in the system we have.
- Design education generates little research revenue and leads to few publications in "the right journals." Manufacturing has been held in even lower esteem until quite recently since, in academic terms, it is perceived to lack “intellectual content."

What We Can Do - Recommendations for Action

Engineering education has become “big business” and there is much inertia and resistance to the sort of changes advocated here, which also echo recommendations in several recent national studies (i.e., those prepared under the auspices of the ASEE[15] and the NRC). Many believe that no further studies are needed. We need action. These actions include:

- Establishment of a process to develop an industry-wide position on: “What we (industry) want from our colleges of engineering and what we are prepared to do to help provide it.”

- A much better focused use of our “aid to education” resources (both money and people). This includes a balance between government-funded research and educational programs.
- A change in the university reward system that recognizes that quality teaching must be at least on parity with funded research with regard to faculty promotion and tenure.
- Changes in the degree structure to establish engineering as a true professional program and which are consistent with future industrial technical workforce needs.
- Greatly expanded faculty - industry exchange programs. The objective of such programs should be to provide faculty with first-hand knowledge of industry practice and issues which would allow them to devise curricula which are truly responsive to industry needs rather than to merely allow faculty to continue their usual research at another (industry) site. Models for such exchanges exist in NSF Grant Opportunities for Academic Liaison with Industry (GOALI) and the Boeing-A.D. Welliver Faculty Fellowship programs.
- No culture change of the magnitude we believe to be required can be accomplished in a single meeting or by conducting yet another study. Likewise, no single party, working in isolation, can resolve the diverse problems we confront What we must do is establish and support (at both national and local levels) processes which encourage individuals from industry, academe and government to work together on a sustained basis to address the practical aspects of how we are going to change. A national forum to include relevant professional societies, perhaps in the leadership role, should be sought to address these issues and to create the continuing process for discussion and resolution. Agreements on curricula options should be sought on a periodic basis. ABET accreditation criteria and the ABET accreditation process can be used as a mechanism for now to formalize and enforce the agreements.

Concluding Comments

The central message of this paper has been that the world is changing dramatically[14] in the wake of the Cold War, and just as broad sectors of industry are changing to meet new challenges and opportunities, our universities (particularly in technical education) must change as well. The needed changes we can foresee will not come as swiftly as some would wish, nor will they come easily. But change must come if we are to sustain our prosperity in an increasing complex and highly competitive international environment. Of the changes advocated in this paper, perhaps the most profound and sweeping must be the rethinking and implementation of appropriate partnerships between industry and academe in the education and training of engineers. In our view, it is no longer tenable (if indeed it ever was) to accept a practice in which a university "educates" a student to some level of competence, and thus having done its job and "completed" its task, turns this "finished product" over to an employer to do with as may be fitting. From now on we must truly prepare a student to become a "life long learner" - an individual who will require and actively seek continuing education as well as training opportunities for the entirety of his or her career. In this process, industry and academe (appropriately aided by government) must become active partners, each doing what it is best qualified to do in fully cooperative efforts from the beginning of the educational process. We all have much to gain if these new partnerships can be established, and much to lose if they are not.

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Acknowledgments

This paper is an outgrowth of a series of position papers written for various audiences over the past several years, the most recent version having been prepared as part of a study of aeronautics materials and manufacturing technologies needs conducted in 1994 under the auspices of the National Center for Advanced Technologies (NCAT) in Washington, D.C. The authors believe that the issues raised in this paper transcend the more narrowly focused concerns of the NCAT study, however. We are greatly indebted to a large number of individuals for providing thoughtful comments and encouragement in the preparation of this paper and its predecessors. While too numerous to list comprehensively, a few key individuals must be cited for their special contributions: Richard Hartke (NCAT), Drs. Joe Bordogna and Elbert Marsh (NSF), Stephen G. Moran (NASA), Earll Murman (MIT), Lee Nicolai (Lockheed), and Daniel P. Schrage (Georgia Tech). In addition, P. M. Condit, A. R Mulally, R. L. Bengelink, R A. Davis, A.M. Erisman, J. F. McGuire, T. Tobey, B. J. White, and M. H. Wiese of The Boeing Company provided major input and inspiration for earlier versions of this paper. The authors remain solely responsible for all opinions expressed, however, and these do not [yet] necessarily represent the positions of either The Boeing Company or McDonnell Douglas Aerospace.

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Appendix: DESIRED ATTRIBUTES OF AN ENGINEERING GRADUATE

- A good grasp of engineering science fundamentals.
    - Mathematics (including statistics)
    - Physical and life sciences
    - Information technology

- A good understanding of the design and manufacturing process (i.e., understand engineering).

- A basic understanding of the context in which engineering is practiced.
    - Economics
    - History
    - The environment
    - Customer and societal needs

- Possesses a multi-disciplinary, system perspective.

- Good communication skills.
    - Written
    - Verbal
    - Graphic
    - Listening

- High ethical standards.

- An ability to think both critically and creatively - independently and cooperatively.

- Flexibility - an ability and the self-confidence to adapt to rapid/major change.

- Curiosity and a desire to learn - for life.

- A profound understanding of the importance of team work

Note: This is a list of basic, durable *attributes* into which can be mapped specific *skills* reflecting the diversity of the overall engineering environment in which we in professional practice operate. In specifying desired attributes (i.e. desired outcomes of *the educational process*), we avoid specifying how a given university goes about meeting industry needs. Curriculum development is viewed as a university task to be done in cooperation with their "customers," and in recognition of their own local resources and constraints. Industry, as an important customer, must be an active partner in this process.

Testimony on the Views of Employers on Undergraduate Education in Science, Mathematics, Engineering, and Technology[7]

Robert T. Jones

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Washington, District of Columbia

Permit me to make three statements that generally characterize business community positions regarding higher education.

First, higher education should demonstrate greater understanding of the needs of the private sector. Too often higher education seems unaware of job requirements and changes in the workplace. I believe that maintaining a close connection between what goes on in our educational system and the rapidly changing work environment is essential.

Second, higher education curricula should reflect the changing conditions in the workplace. More students need to experience the challenges and rigor of contextualized learning.

Third, higher education should help develop the work ethic that will sustain students in their eventual careers. Note that many corporate leaders say that new employees are fine– even more responsive than they used to be. These same leaders point out that they screen a substantial number of potential applicants, selecting only the best from that pool. As long as that pool is large enough and active enough and vital enough, firms will always manage to hire the kind of people they need. We must however be concerned about all the rest, those who do not enjoy the skills needed for employment and advancement.

Corporate leaders tend to believe that the factual knowledge derived from undergraduate education can quickly become obsolete. Further, the life expectancy of new entrants in their first job is very short. Relatively inexperienced employees move on to another company or another function or task more rapidly than ever. Companies are also increasingly reluctant to hire recent college graduates. Before they invest in hiring on a long-term basis, they want to see degree holders with three to six years of work experience in the modern corporate system who can show an effective adaptation to the updated demands of the new workplace.

The typical employer no longer defines educational preparation solely on the basis of scientific knowledge or experience, or mathematical and technical competencies. Increasingly, employers are looking for the ability of new scientists to think clearly and communicate their thoughts, to write clearly, to negotiate, to listen, to work on teams, and to function effectively as part of a diverse work force. Employers' perceptions are that schools are not paying enough attention to the development of these skills. They do not seem to be taking business very seriously, nor listening to our cues that how we hire is now different.

I urge you to look at the hiring processes that companies are utilizing, to study carefully the methods of testing and interviewing. What are the broad and durable skills and competencies they

[7] This text is an edited version of Mr. Jones' verbal testimony to the EHR Advisory Committee on November 1, 1995.

seek? It is very clear that when applicants don't understand the needs of employers, they are not likely to be hired.

New employees are increasingly expected to demonstrate as one CEO calls it “boundary-less” skills. This all happens because of the changing nature of the way we work. Engineers and scientists are now “on the factory floor.” They are not isolated in a lab. Engineers and scientists now deal with customers and their ability to deal with customers is key to their being hired in the first place.

There is a growing perception that a college degree per se is of minimal value to business. Business is more concerned about the level of a job applicant's competencies, the breadth of that applicant's competencies, and the applicant's ability to assimilate, manage, and utilize information. How those skills are acquired -- whether during studies for an MBA or a MS in science or math, or as part of some other educational experience -- is not of great import.

Related to this focus on competencies rather than credentials is the increasing demand for certification programs. The demand is growing for continuing education programs that let employees re-enter the education community in order to update their skills, to stay current on new technology and procedures and to do so in short certifiable bites that employers can recognize. Simply taking people out of employment for two or three years for an advanced degree for the sake of improving skills and knowledge doesn't work effectively for many jobs. The way we traditionally boxed up these degrees doesn't match well with the needs of today’s work force. We will probably see within the next 24 months a very rapidly growing discussion about how we create certification programs where people can engage frequently and efficiently in continuing education.

In summary, business believes more strongly than ever that post-secondary and continuing education are crucial for all potential workers. How to sustain the strengths of our existing system while responding to the vibrancy of the business environment is a challenge that higher education must meet.

A nationally recognized expert in the workforce development field, ***Roberts Jones*** *has over thirty years of organizational management and public policy experience in the training and education field. As a lifelong advocate for investing in people, Mr. Jones is widely credited with helping place workforce development at the forefront of the nation’s public policy agenda. Prior to joining the Alliance, Mr. Jones was vice president of RJR Nabisco, Inc. Mr. Jones served both Presidents Reagan and Bush as Assistant Secretary of Labor, responsible for federal workforce development and training policy addressing the significant changes in work and the workplace. Jones played a key role in the Hudson Institute’s landmark research project and report,* Workforce 2000: Work and Workers for the 21st Century*, and was responsible for the Department of Labor’s SCANS Commission, which for the first time spelled out the skills necessary for success in the workplace. Mr. Jones was awarded the Presidential Distinguished Executive Award, the highest honor in the Federal government, in 1986. Mr. Jones received his B.S. in Psychology from the University of Redlands in Redlands, California, and performed graduate work in Public Administration at the American University in Washington, DC. He also served for four years in the United States Air Force.*

Testimony to the National Science Foundation Undergraduate Review Subcommittee: Employers Views on Desired Capabilities of Undergraduates Entering the Workforce

John L. Sisler

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Thank you for the opportunity of share views on undergraduate science, mathematics, engineering, and technology (SME&T) education from the perspective of an Energy Industry employer of graduates from these programs. As manager of E&P Training in Shell Exploration and Production Company, I am increasingly aware of the challenges and demands placed on BS and MS SME&T graduates in out technical professional workforce. How well our Company, Industry, and Nation surmounts this challenge is of critical importance to future success and survival in a global market place.

While this testimony is from the viewpoint of a large, primarily domestic oil and gas exploration company, many of the phenomena discussed appear to extend beyond the upstream portion of Energy Companies. They are reportedly commonplace throughout other portions of US Industry.

One characteristic of the upstream Energy Industry's technical professional workforce is the mixture of scientists and engineers. Geosciences (Geology and Geophysics) together with Physicists and Computer Scientists are combined with Electrical, Geological, and Petroleum Engineers to form the skill pool responsible for finding and delineating new hydrocarbon deposits. Engineering graduates become increasingly important in developing, producing, and managing existing oil and gas reservoirs through economic lives to eventual abandonment. These include Geological, Petroleum, Chemical, Electrical, Mechanical, and Civil Engineering graduates. They are integrated with the skill groups used to find and delineate who are also involved in the later phases of the E&P cycle. This workforce is predominately BS and MS level with a lesser number of Ph.D.s who typically transferred from Research into the operating organizations. The way work gets done by this mix of SME&T graduates across the spectrum of E&P activities has changed significantly in the last five years.

Organizational Characteristics

Changes in the job environment associated with organization redesign are profound. An ongoing process attempts to create work group structures that are focused, efficient, and responsive to change. Nearly all upstream US Energy companies, including Shell E&P Company, have experienced dramatic organizational changes. In most cases these resulted in somewhat smaller SME&T workforces and significantly fewer supervisors and managers. Work now being done often exceeds levels prior to the changes. Further change is very unlikely but a return to the type of work group structure characteristic of the past is very unlikely.

Integration

Currently, most U.S. Energy companies have emphasized integration at every organizational level. Formerly organizations were divided into separate groups based largely on skills and type of work performed. Exploration was typically separate from Production, and within each there were subdivisions such as Geology and Geophysics in Exploration, and similar splitting within Production into Operations and Engineering that was in turn split into various engineering scientific specialty groups. Today, multidisciplinary teams that are formed to accomplish a specific project or manage a group of assets within a defined geographic area do work. These teams are interlocked to form multi-disciplined project groups responsible for major business segments.

Today's integrated work team organization has far fewer managers and supervisors. Typically, supervisors lead large, diverse work teams and do not exercise the level of detailed control characteristic of past more hierarchical work structures. Someone will probably lead the SME&T graduate with a dissimilar educational specialty.

Leadership Style

The style characteristic of successful leaders today is one of coach and coordinator rather than command and control that was possible when past supervisors frequently were experts in subordinates' jobs. Some work was associated with personnel administration and the individuals now do development formerly done by managers and supervisors themselves. The SME&T graduate will probably find the leader not as deeply involved in how work is done, provided it is timely and correct. Today's leader is far more interested in results than style. Because of the size and diversity of typical work teams the leader today is rarely as involved in each individual's personal skill development as were past supervisors. Individuals are expected to be proactive in defining their needs and seeking our opportunities to grow. The leader's role is to enable and encourage, but not to be prescriptive.

Performance Measures

Performance measures for individuals in today's organizations attempt to focus on business-relevant results. Compensation is more directly tied to current business results. To a growing extent individual results are tied directly with Team results. In contrast, past performance measures too often dealt with style and activity level. These may have had only an indirect linkage with business objectives. The SME&T graduate is finding that it is increasingly difficult to prosper personally while the ship of which he or she is a crewmember sinks. Coming from an undergraduate system that exclusively recognizes individual achievements this change may cause some to question "fairness."

Skills

Skills needed to successfully function in today's work team environment are somewhat different from the past. Each person needs an awareness of the role and contributions of others on the team. In-depth specialized knowledge must be accompanied by skill at relating various parts to the whole and finding solutions to problems that formerly might have "fallen between the cracks" of the different specialties and departments. Skills such as communications and teamwork are essential. Unfortunately these are often given low priority during the SME&T professional's undergraduate education. Working together interdependently in a team to achieve a common goal rather than competitively to garner individual recognition is a very satisfying change for many, but one that does not come easily to some SME&T graduates who have thrived in their former arena.

Personal Characteristics

Along with the organizational changes there have been changes in expected personal characteristics of the Technical Professional workforce. Skill areas deemed important for success in the current and future work environments include many areas besides the traditional SME&T subjects.

Technical

Sold preparation in the relevant sciences and mathematics together with their application to create beneficial products remains the most valuable asset that a SME&T graduate can bring into our workforce. Without this, chances of success are slim. It is particularly important to gain a broad foundation during the undergraduate period. This will provide the means to adapt and thrive as changes occur that impact the various applications used in the workplace.

One characteristic often missing in graduates of US SME&T programs is ability to understand system versus segments. Too frequently graduates who have impressive transcripts from highly acclaimed universities exhibit limited understanding of how their segmented knowledge fits together. An ability to understand context and to fit pieces into a larger framework are essential in working in an integrated, multi-disciplined environment. Critical thinking has greater importance than problem solving.

Commercial

SME&T graduates are expected to possess more commercial acumen than in the past. The necessity for improved financial performance has caused accountability for profit and loss to be at much lower levels, frequently at the work team level. A vocabulary once restricted to Business School graduates is now routinely used by technical staff. Engineers and scientists are no longer as insulated from accounting, financing, and marketing.

Risk management is particularly important. SME&T graduates typically are expected to define uncertainty, develop risk assessment, and play a major role in managing risk.

While SME&T graduates are not expected to possess abilities to perform specialized commercial tasks, they do need to understand their importance and how they must be integrated with technical work to achieve business success. Clearly SME&T graduates need to respect the importance of the commercial context of their work.

Information Technology

Without question, advances in computing and information technology (IT) are enablers for many of the changes discussed here today. All SME&T graduates are expected to have skills that allow application of advances in IT to their work. In fact, many technical professionals in E&P spend the bulk of the time at work at workstations or PCs. Most are not developing new software, but are using increasingly integrated applications systems provided by others. Major concerns are with data management and getting work done in complex internal IT systems. Many find their undergraduate programs did not provide sufficient expertise in the personal productivity tools.

This is one area in which recent SME&T graduates as well as technicians have exerted leadership. Without their training that embraces IT as just another of the natural work tools, progress would have been much slower.

Teamwork

All SME&T graduates must possess teamwork skills. While many factors go into developing these, one that is partly a consequence of the undergraduate educational system stands above the rest. Respect for others who have different educational backgrounds is essential.

Academic divisions between sciences and engineering and further subdivisions within each too frequently imprint SME&T graduates with personal biases. These are obstacles to effective teamwork. Rivalry between academic schools, departments, and even specialties within a particular field, create stereotyping of various groups. Academic role models that participate in such activities are sending very wrong messages to their students. In today's business environment, one's leader and office mates may well be from one of the groups held in low regard by his or her academic role models. The need to respect others extends beyond the SME&T disciplines to include those in business, humanities, and other groups such as law, which must work together in teams.

Communication

Good communication skills are even more important today. In addition to the long-standing expectation that SME&T graduates be able to write and speak effectively, the challenge today is the audience. Former audiences were often composed of specialists who all spoke and understood their specialties' jargon. Today an important audience is the multi-disciplined work group and its leadership. Increasingly the SME&T graduate is also communicating with external customers and stakeholders who generally do not understand the "insider" language of science and technology. This becomes particularly important to those working with environmental issues.

Electronic tools are playing a bigger role as a means of communication. However, the skill needed is to understand the cycle of listening, understanding, creation and delivery of a clear message to a specific audience. These are independent of the tools and should be incorporated into SME&T undergraduate programs.

Leadership

More leadership skills are expected from everyone in flat organizations. Fewer opportunities exist for formal management jobs, but there are many more opportunities for individuals to hold ad hoc leadership roles. As mid-level managerial and coordinational jobs have disappeared, individuals in teams are doing some of the work. The leadership roles and skills are very closely associated with teamwork rather than exercise of the power of an organizational position.

Change Management

The final personal skill in this list is the ability to proactively participate in the processes used to continuously improve. Change Management is now a part of every SME&T graduate's responsibilities. Each must acknowledge that the future is unpredictable. Major changes and retaining flexibility to alter strategies will probably be needed to survive both as business and individuals.

Individuals who accept personal responsibility for their own deployment and take actions to grow personally and professionally will be more likely to succeed. The employer of SME&T graduates is no longer providing the level of security and development direction seen in the past.

Recommendations

1. Support programs, which are interdisciplinary and integrated. Do not restrict this to just the SME&T fields. Opportunities for undergraduate SME&T students to become involved must be provided.

2. Support programs that instill rigor and breadth in BS/MS SME&T studies. Focus on teaching and shaping those who constitute the bulk of our workforce. Meaningful recognition must be available to faculty and institutions that do this well.

3. Support programs that provide BS/MS students with the interpersonal/organizational/ teamwork skills now essential in today's workplace.

John Sisler *is Manager of Exploration and Production Training for Shell Oil Company in Houston, Texas. He has 36 years of varied Shell experience as a geoscientist, engineer, and manger. During his career he has worked on domestic exploration and production projects in Alaska, California, New Mexico, Texas, Louisiana, the Gulf of Mexico, and outside the United States inThe Netherlands and Iran. Prior to joining Shell he received a BA in geology from Rice University and a MS in geology from Stanford University. He is a member of the American Association of Petroleum Geologists, the Society of Petroleum Engineers, the Geological Association of America, and the Houston Geological Society.*

Testimony on the Views of Employers on Undergraduate Education in Science, Mathematics, Engineering, and Technology[8]

Patrick E. White

Vice President, Strategy, Bell Atlantic Corporation
Arlington, VA

I certainly appreciate the opportunity to be here to talk to you about undergraduate needs, particularly with regards to the telecommunications industry.

As the telephone industry evolves, one of the first things I think we need more of is engineering programs designed to educate generalists, to produce graduates with almost the same kinds of skills that John Sisler of Shell Exploration and Production Company was just describing.

Very frequently, the kinds of issues that at least our undergraduate engineers face require participation in multidisciplinary teams, but more than that, they are often not focused on one specific area of technology. They cover a variety of different areas. I think that a program in undergraduate education designed to produce engineering "generalists" would perhaps better match that need.

Our situation is analogous to the issue of the best strategy for educating medical doctors. A general practitioner course of study often meets the greatest need of communities for medical services. General practitioners can be coupled with the selective use of specialists. In the past there was a tendency to stress the education of medical specialists. Now we realize the importance of general practitioners.

We clearly do have that need for specialists in telecommunications, but for the vast majority of jobs, a general program matches our needs much better than specialized programs. Where we do need specialists, a bachelor's degree or even a master's degree is often not enough to cover the field in depth. We really need to hire Ph.D. level scientists or engineers to get the best contributions in specialized areas.

Another aspect that I wanted to bring out is that telephone technology, like most high-tech, electronics-type fields, is undergoing pretty much a revolution. For example, just look at one aspect of this field over the last ten years, fiber optic transmission. Ten years ago, engineers were talking about multi-mode fiber with LEDs. That has shifted very quickly through a number of different technology stages. Today, ten years later, nobody ever talks about multi-mode fiber, and nobody talks about LEDs. Instead, the talk is about lasers, fiber amplifiers, and dispersion-shifted fibers. In other words, the field is moving so fast that it is pretty hard for me to imagine how the universities can really keep up with current technology.

In fact, if you look at most programs in engineering, you typically see that they are pretty much covering the same old topics, and that is surprising, given the pace at which the technology seems to be moving along.

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[8] This text is an edited version of Dr. White's verbal testimony to the EHR Advisory Committee on November 1, 1995.

I think that there is certainly several impediments or several areas within teaching that need to be dealt with. Tenure policies, I think, need to be looked at to make sure they are really encouraging faculty to keep abreast of technical areas, and that universities continue to hire the best-equipped faculty or the faculty with the most knowledge in some of these new technology fields.

I also think that the types of research that are being funded also have an impact. If you pick up almost any journal these days, I would say at least two-thirds, maybe three-quarters, and in some cases even 100 percent of the selected papers seem to represent minor tweaks in insignificant technical areas, most of which isn't all that relevant to what industry really needs in terms of research.

If you have faculty who are moving in that direction, then you can easily see why there will be a widening gap between what the universities are actually teaching young engineers and what industry needs if we are to remain at the cutting edge.

The last thing I wanted to talk about in my prepared remarks – related to the plea I made at the outset for more a general education in engineering – is that I believe we should reexamine the lack of a foreign language requirement in most colleges and universities. Increasingly there is globalization of just about every aspect of industry. Too often we go to meetings with the French, Germans, and Japanese and find that they can speak English plus their own language. In negotiation, I think we are at a significant disadvantage in only knowing English.

I also would put in a plea that the types of elective options that are associated with engineering, currently drawing from a traditional liberal arts menu, might also sensibly include wider options, e.g., business-oriented courses, finance, economics, intellectual property law. These are all very vital aspects for a young engineer's education.

***Patrick White** is Vice President of Research and Development at Bell Atlantic Corporation. Prior to his current assignment, he was Vice President of telecommunications strategies and before that he held a number of positions with Bell Communications Research, Inc. ("Bellcore"), including Assistant Vice President of the Network Architecture and Analysis Research Center and Assistant Vice President, New Architecture and Service Concepts Planning. Prior to joining Bellcore in January 1984, Dr. White held various software development supervisory positions with Bell Laboratories, commencing in 1973. Dr. White holds a Ph.D. degree in Electrical Engineering/Computer Science from Northwestern University. He has authored numerous technical papers and edited technical journals. Dr. White is a member of the Eta Kappa Nu and Tau Beta Pi national engineering honor societies as well as a member of the IEEE and the Association for Computer Machinery.*

Written Contributions to the EHR Advisory Committee Social Sciences Workshop

Convened February 22, 1996
at the National Science Foundation
Arlington, VA

Participants in the Social Sciences Workshop
Convened February 22,1997

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Contributions of the Social Sciences to the National Science Foundation Review of Undergraduate Education

Overview

On February 22, 1996, a group of eight invited scholars from the social and behavioral sciences met to discuss the improvement of undergraduate education. Joining them were members of the Advisory Committee for Education and Human Resources at NSF, the Assistant NSF Director for Education etc. (Luther S. Williams), the Assistant NSF Director for Social and Behavioral Sciences (Cora Marrett), representatives from several education and policy associations in Washington DC, and NSF professional staff concerned about undergraduate education. Over 50 people participated in this workshop during the course of the day. The discussions were joined by most that were present at the workshop.

The workshop was designed as part of the extensive review of undergraduate education being conducted by a Subcommittee of the Advisory Committee for Education and Human Resources, which began the previous spring. This review is examining the status, conditions, and needs of undergraduate education in the broad disciplines of the sciences, mathematics, engineering and technology.

The invited participants were asked to prepare short statements prior to the workshop in response to a set of questions that focused on the contributions of the social and behavioral sciences to improving our understanding of how to improve undergraduate education. The questions were:

- What has social and behavioral science research contributed to our understanding of how students learn?
- What are the obstacles to implementing change in curriculum and instruction in undergraduate education? How do we overcome them?
- What are the unanswered questions about student learning that research needs to address?
- How does knowledge of the social sciences and of technology prepare students for the next century?

The following is a summary of the key points made during the workshop. The comments can be organized around four major themes: the undergraduate learner, the teacher, the curriculum, and the institutional context. To maintain a sense of authenticity, direct quotes from participants have been included in a number of places.

The Undergraduate Learner

How the student learns, as well as individual and group characteristics of the learners, are important factors to be considered. At the beginning of the workshop, participants agreed to a basic principle: the mind is active. Research in cognitive psychology indicates that "the mind always interprets," and is not simply "a passive receiver of information that is broadcast to it" (Rochel Gelman, Department of Psychology, New York University). Thus, the presentation of new and interesting information in the classroom is not enough; we must also understand how the minds of students interpret and manipulate that information.

The processing of information by students is a vital point of concern. Students rarely realize the applicability of information and knowledge from one context to another, and often view information as facts to be memorized and mechanically reproduced in an exam. In a rapidly changing world, a more desirable outcome would be for students to possess the ability to apply abstract principles to different situations, e.g. to “recognize situations in their own environments where the Law of Large Numbers applies” (Neil Stillings, School of Communication and Cognitive Science, Hampshire College, Amherst, Massachusetts).

Undergraduate students come from diverse communities and cultures with distinctive expectations about the education process. The values, norms, and expectations of students about what to expect from undergraduate studies in their chosen institutions of higher education are influenced by the size of the institution, the selectivity of that institution, and the region of the country in which it is located (Maureen Hallinan, Department of Sociology, University of Notre Dame). Learning is inhibited when the values, norms, and expectations of the student “come into clash with what we are at the moment doing in institutions” (Rochel Gelman). This point was underscored by some participants with respect to the rapid pace of change that has occurred in some institutions. Change should proceed in an orderly fashion, because “radical change in course design breaks an unwritten social contract between faculty and students” (Jill Larkin).

As will be developed in the remaining sections, developing educational technology has a lot of potential for students in higher education. However, in the short run, technology scares a lot of students (Rochelle Gelman), and the heavy use of technology scares more women than men. “What we need from the social sciences is some architectural perspectives on how to make technology work” most effectively (Uri Treisman, Department of Mathematics, University of Texas, Austin, and member of the Advisory Committee for Education and Human Resources).

The Teacher

Because the teacher controls both what is taught and how it is taught, the teacher is vital. Five themes were discussed in the context of describing effective and ineffective teaching techniques.

The disadvantages of the “broadcast model of education” were discussed. Many faculty consider the prerequisites for good teaching to be met “if I know and understand my discipline, and I get up in front of the class and give good lectures, and I give good assignments” (Jill Larkin, Department of Psychology, Carnegie Mellon University). However, there is evidence to suggest that simply giving students more information does not improve learning. A preferable teaching paradigm is where teachers interact with their students and act as facilitators in the learning process.

While traditional teaching methods often attempt to counter students’ misconceptions by teaching the ‘correct’ way to think, “curricula which take misconceptions as a point of departure rather than a road block can be more successful” (Nora Newcombe, Department of Psychology, Temple University). New techniques for teaching science should thus “arrange experiences in which students realize how different aspects of their thinking are incompatible, then work to resolve this impasse” (Nora Newcombe). This will help to counter a major problem, that many students have a “strange and impairing view of the natural sciences and mathematics,” seeing them as a collection of facts that are hard to grasp (Jill Larkin). More stress on applied research in the classroom will also help, many agreed.

Research conducted by sociologists suggests “that working in groups in a cooperative setting produces greater growth in achievement that straining for relative gains in a competitive environment (Maureen

Hallinan). Thus it is important for teachers to provide students with opportunities to work in groups.

Technology, such as email and bulletin boards, provides opportunities for faculty to interact with students at a greater frequency, while Web pages provide new information resources for students. However, technological innovation is costly in terms of the "human effort that has to go into designing it," as well as the human investment of educating teachers to use these innovations (Neil Stillings). Evaluating the effectiveness of new technology in the classroom is also problematic because "we don't have quality benchmarks ... to bring these innovations together with some of our learning theories" (Kenneth Foote, Department of Geography, University of Texas, Austin).

Improving undergraduate education by teaching faculty how to teach includes helping them to effectively use everything from "the oldest and most transparent technology" of a blackboard, to "tens of thousands of dollars worth of multimedia equipment" (Daniel Goroff, Derek Bok Center for Teaching and Learning, Harvard University, and National Research Council). Improving undergraduate education entails that teachers as well as students invest in learning new skills. It is important to use technology effectively, to promote interactions among students, faculty, and material, and to avoid using it as merely another method of broadcasting information to passive student recipients. In learning to use technology, and use it wisely, many older faculty are seen as irretrievably lost, while younger faculty typically recognize that print media is losing its effectiveness (Andrew Abbot, Master, Social Sciences Collegiate Division, University of Chicago).

Curriculum

Much of the current curriculum of the sciences, mathematics, engineering, and technology in college courses "follows an instructional paradigm, not a learning one" (Luther S. Williams, Assistant Director, NSF). The following themes focus on how curricula can facilitate learning by students.

Students interpret new information in the context of what they already know. However, students in a classroom begin from different places. To promote learning in the classroom, faculty must provide "stepping stones from the minds of our students who may not overlap" with the structure mapped by teachers, "to the point where they have in fact achieved understanding that they didn't have in the first place" (Rochel Gelman). Thus, the content of the curriculum should be flexible enough to accommodate students' different learning styles and starting points.

In many institutions, the majority of students fulfill science requirements through social science courses. The "social sciences tend to be great fields for hands-on experience with science" (Neil Stillings). To the average undergraduate, the social sciences offer better accessibility to knowledge relative to the physical and biological sciences. "… It's very important to put students in a context where they can connect their understanding of physical and biological knowledge with social life, with the life of the mind, and that means we have to put them in classrooms where things about the brain and about behavior genetics are being taught together with things about behavior and society so that they can make that connection" (Neil Stillings). If the study of experimental design and statistics in the social sciences are combined with topics in cognitive science such as causal reasoning and normative models of thinking, and this is done effectively, then greater numbers of students will achieve a reasonable level of scientific literacy by grasping the significance of these connections. Also, "cognitive science is a good vehicle for teaching a lot of mathematics and computer programming" (Neil Stillings). Thus, in general, students benefit from a curriculum that has an interdisciplinary approach.

However, “beyond the question of the social sciences contributing to the broad issue of the learning of science ... we have to give increased emphasis to the social sciences themselves” (Luther Williams). Despite the promise of the social and behavioral sciences as a metaphor for buttressing student understanding of the physical and biological sciences, there are problems specific to these fields that are more extensive than found today in the natural sciences, namely, that passive learning is perhaps more widespread, and basic research on curriculum and learning in these fields is considerably behind. This may be due to the fact that a growing majority of high school graduates now attend college and enrollments in the social and behavior sciences have been swelling. Consequently there is less introspection about student learning than is found in the natural sciences and engineering.

To achieve significant and lasting improvements in undergraduate education, we must be able to pinpoint whether students successfully learn curriculum content. Many students have the idea that “understanding something is kind of being familiar with it” rather than trying “to really master something” (Jill Larkin). From the perspective of most faculty, current forms of evaluation often mean that “we give an exam, hand it back and then go on with the next lecture (Jill Larkin). This does not tell us, in general, whether mastery of the material has been achieved. Successful evaluation should include a feedback loop where faculty and students together can determine the extent of mastery.

Institutional Context

In order for undergraduate education to improve on a large scale, the institutional context in which it takes place must be examined. Change is more likely to occur if it is supported at the institutional level. The following themes suggest some ways to accomplish this objective.

The potential for systemic reform has been improved by the development of new educational technologies. New teaching models, often incorporating some of the potential of new technology, “cut across traditional disciplinary and really university boundaries” (Kenneth Foote). With the appearance of the Internet and the Worldwide Web, the walls of departments and universities must be permeable enough to “cultivate ... more types of local, regional, and national collaborations” (Kenneth Foote). Institutions that promote these kinds of new linkages are more likely to benefit from new technologies and ideas.

Cost constraints already are demanding that most universities have large class sizes, despite evidence suggesting that smaller classes have an environment more conducive to learning. Thus, administrators of institutions of higher education need to “start to think about how to facilitate these kinds of needs within the environment” of large class size that currently exists in many institutions (Rochel Gelman). Investment in technology may allow for students and faculty to have more interaction at a lower cost by providing “other ways to communicate the same type of lecture material” (Ronald Ehrenberg, Vice President for Academic Programs, Cornell University).

In the existing institutional context, “we don’t have good integrative mechanisms for thinking about making sensible decisions about how to affect the trajectories” or paths that students take throughout their undergraduate education as well as after they leave (Melvin George, Chair of the Subcommittee of the Subcommittee of NSF Advisory Committee for Education and Human Resources). We must focus on issues of choice of major and course-taking, and pay increased attention to the high percentages of students who do not complete their undergraduate education.

Meanwhile, the discussion continued to emphasize that though the pace of institutional change is accelerating, it is important to retain the “human touch” of contact between faculty and students. There has been a lot of research on the impact of mentoring on student achievement and persistence that informs us that careful mentoring is a powerful force. Furthermore, even modest indications of faculty interest in their students and student learning outcomes have a big impact on student effort and persistence. For example, faculty tend to get high marks on student evaluations even in courses with difficult material and examinations if the faculty have demonstrated a minimal level of caring, for example, being able to call on students by name, keeping track of class attendance, and demonstrating a willingness to discuss problems outside of class time.

The Social Sciences and Undergraduate Education

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There are two aspects to the role of the social sciences in undergraduate education. The first is the place of the social sciences in the content of instruction. The second is the contribution of social science research to understanding the impact of undergraduate education on those who are taught.

Social Sciences in the Curriculum

Of the place of the social sciences in the content of undergraduate education there is little doubt. In the ideal curriculum, the social sciences are both an essential, freestanding constituent of "core learning" and an important subset of majors for upper level students. That is, the social sciences are crucial to both general and specific education at the undergraduate level. In my own university, social sciences constitute six courses in the required curriculum of 22 (of 42 total) quarter courses, and social science majors constitute the plurality (about 42 percent) of undergraduate majors.

At the level of general education, the social sciences raise two kinds of issues. In our curriculum these are contained in the two different required sequences: core and civilizations.

Our core sequences inquire into certain basic problems of social life: individual and group, freedom and determinism, equality and inequality, personality and culture, difference and similarity. The exact content of our five core courses varies, although there is a tendency to focus on classic texts and on particular modes of inquiry. What does not vary is the classroom structure and pedagogical technique. The classes are small (maximum 25-30), are taught largely by Ph.D.-level faculty (about 75 percent), and are largely discussion-based. This reflects our strong belief that general education is not about content but about the skill of critical reading and thinking. We aim to create citizens who can think clearly, critically, and creatively about the social life that surrounds them. This can be accomplished only in small classes, where faculty can intimately model the process of reflective thought, and where students' work – both oral and written – can receive the detailed comments that alone promote effective learning.

Each of the five core sequences has a number of "tracks" – from five to fifteen at any given time – taught by individual faculty. Within a course, tracks share about 70 percent of their curricula, so that student learning continues in the dormitory and lounge as students from different tracks argue about common themes. Across tracks, faculty meet weekly to discuss pedagogy, to argue about text materials, and to plan future curricula. Such staff meetings offer an important resource to faculty, both in terms of sharing of pedagogical secrets and in terms of interdisciplinary learning, for the courses are generally staffed across disciplines.

The five core tracks really shake down to two curricula: Plato-Aristotle-Machiavelli-Locke-Hobbes-Marx and friends and Smith-Marx-Durkheim-Weber-Freud and friends. From time to time, we have also had a core sequence based on empirical social science, which takes students from a quarter on philosophy of inquiry through a quarter on actual social science research to a quarter on policy. Even in such a sequence, however, the focus continues to be on addressing basic questions; classic texts continue to provide an organizing role, augmented by doing actual social science research.

The other required social science sequence is civilization; a much more complicated pedagogical structure. There are three teaching rationales behind the civilization sequences: a concern with contingency and diversity, a concern that students contact a culture or cultures different from theirs, and a concern that students truly understand their own culture, whatever that may be. Two of our civilization sequences are taught in "core format," as just described: Western Civilization (about 40 percent of students in 16 tracks) and American Civilization (about 10 percent of the students in 4 tracks). The others are taught in the more standard lecture/recitation format. All, however, tend to focus on classic texts. These are reviewed and updated periodically. (Those for American Civilization are on-line, for example.)

The civilization sequences (the largest eight of them cover 95 percent of the students) generally involve history and anthropology faculty. For faculty, the problems of curriculum planning and design again produce the interdisciplinary contact of the core courses. For students, this interdisciplinary gives rise, again, to a complicated, nuanced approach to learning.

Beyond the required curriculum, we also have, as I noted, a steady 40-45 percent of the majors in the College. As in most colleges, the largest is economics, but social science in fact dominates the University of Chicago undergraduate scene; we have four of the largest six majors (economics, political science, psychology, and history). Extensive research, which I mention below, shows that students treat their majors essentially as an advanced form of liberal education. Most of our students do not perceive their choice of major as related to a career decision. (Two-third of our premeds major outside biological sciences, for example.) As a result, learning in the majors is driven again by the problem of mastering a specific body of skills and thinking, the skills and thinking of advanced inquiry in a particular field. It is this specific discipline, not the content that alumni report as important in their later lives.

The center of this specific learning is the B.A. paper, required in most of our majors. At its best (in our history program), the major introduces the student to the problems of advanced thinking with a junior colloquium, then advances by associating paper-writing seniors with preceptors at a ten to one ratio. The resultant papers are read and improved by faculty in their later drafts, once they have been effectively pre-prepared. Other majors work essentially like mini-curricula, with introductory sequences, methods courses, and upper-level electives. In general, our majors are effective but "quick" curricula. The exigencies of the core, the tendency of students to front-load their science requirements (we require year-long sequences in BOTH physical and biological science), and the tendency of many students to switch into social sciences late in their career. It means that the social science majors must move students through the discipline of advanced knowledge faster than is done elsewhere.

It should be noted that our curriculum assumes that the social sciences are an independent area of knowledge, between the social sciences and the humanities. They are not a stepchild of either, but rather proudly freestanding. In part this reflects institutional history; we are perhaps the only major university in which the social science departments enjoy higher national rankings than those in either humanities or natural sciences, a situation that has persisted from the 1920s. Moreover, the curricular structure has been etched into the internal administrative organization since 1929, when Robert Maynard Hutchins divided the faculty into Divisions (Humanties, Social Sciences, Physical Sciences, Biological Sciences), each with a Dean responsible for graduate teaching and general oversight and (since the end of a separate College Division in 1963) a Master responsible for undergraduate teaching and the College's half of the personnel jurisdiction. We have no faculty of Arts and Sciences and no overarching Dean. Divisions report to the

Provost.

Thus a central question of this [EHR Advisory Committee] Review – whether the social sciences can serve as a vehicle for "science education" – is ruled out of court. Our faculties do not feel that social science learning can be collapsed into natural science learning or vice versa.

Social Science Research and the Undergraduate Experience

In the area of research on the curriculum, however, the social sciences have much to say. I here report on a large investigation under way at Chicago with the help of the Ford Foundation.

Three years ago, the Foundation provided us with a grant for the support of social science majors at the University. (This was part of a larger program involving a number of leading universities.) With this funding, I have undertaken a large body of research aimed at two fundamental questions, neither of which has ever seen much study.

The first and simpler of these questions is that of origins. Nobody seems to have asked why we have majors in the first place. There was one dissertation, long ago, on the subject. I have supported research into the history of majors with an idea to finding out the original pedagogical rationale as well as the administrative forces driving the change. It has indeed proved that to a considerable extent we have majors because we have departments, majors proved a way of solving the administrative problem of regulating universities that, for the first time, had numbers of faculty concentrated in particular areas. On the other hand, majors were also a crucial part of reining in the chaos of the electives-based curriculum of the late 1 9th century, and in that sense an alternative to the core-based programs (at Columbia, Chicago, and elsewhere) that attempted the same structuring of the curriculum but in a different manner. Other than the conflict with core-based curricula, there has been no serious challenge to the idea of majors in the 20th century. As with the graduate intellectual life, however, it seems that there is much more overlap in the actual contents of majors than in the disciplinary origins of the faculty teaching them. On the ground, considerable interdisciplinarity has probably been the normal state of affairs.

The second and more difficult question we have addressed is the impact of the major on the later life of students. Because Chicago has had for at least twenty years a curriculum with both a serious core and serious majors, we are able to ask specific questions about the relation of these for students in choosing Chicago, in studying here, and in their later lives. Ideally, such research should be prospective, and I would certainly propose that for the future. But at present, we have mounted a large "synthetic cohort" examination of the problem.

This analysis includes the following components:

1. A survey of the class of 1995
   - 300/700 responded information on parents' majors, employment, hopes for children on respondents' aims in high school and later, choice of major, choice of career, satisfaction with education, etc.
2. A sequence analysis of exact transcripts of 1995 class (entire) to study changing of majors, juggling of required curricular elements, the actual "experience" of education in terms of order and structure.

3. A survey of all alumni who have been out 2,5,7,10,15,and 20 years 1400/3600 responded (still coming in)
   - information on parents' majors, employment, hopes on respondents' choice of major, impact of major and of core on later occupational and intellectual experience (we have data at the level of specific intellectual skills – problem analysis, writing, creativity, etc.)
4. A diary project
   - ten students have kept detailed diaries of their educational experience across three years.
5. A retrospective course examination
   - twenty-five students (1996 seniors) will prepare essays discussing their experience in retrospect.

These data will permit us to examine the impact of different parts of the curriculum on later experience.

Our central research questions here all involve the "trajectory" of education; a topic that seems relatively little studied. Questions include:

1. How are core and major related to later occupational life?
2. How is core and major related to other parts of respondents' lives? citizenship? participation in cultural life?
3. How do students imagine their college careers?
4. How does reality cut across students' expectations and early college experiences?
5. What are the impacts of parents' hopes and dreams on students' lives? are these specific to specific ethnic groups? occupational types?
6. Which parts of the curriculum produce or support which kinds of skills in adult life?

The underlying vision here is one envisioning education as a process and seeking the forces that channel that process in a particular direction. My own expectation is that skills training lasts far longer into and proves more valuable for adult life than does specific content, and that the disappearance of major content from the horizon of adult experience is quite quick. But these are empirical questions, to be addressed only by surveying an alumni body with long-standing experience of a particular curriculum.

The University of Chicago is an elite institution. Results, and indeed research questions, will probably be quite different at another kind of university. This issue seems to me one of the most difficult facing the workshop. I am confident we could agree more on the content of the kind of education proposed here than we can either on the content of other forms of education or indeed upon the idea that education for elites and masses are likely to be fundamentally different. But the latter point – the recognition that elite and mass higher education is likely to differ – seems a crucial one. Such research as we have on learning seems to indicate that amount and quality of feedback to students is the strong predictor of good education, and effective feedback requires staff quality and intensity unreachable at most public institutions. I propose this issue without any idea of how we should address it.

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Scientific Literacy and the Social Sciences

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In a world increasingly shaped by science and technology, a fundamental understanding of science is an essential aspect of contemporary education. We can no longer talk of science *and* the liberal arts; science must be an integral part of a liberal arts education. While I suspect that there will be little debate about the importance of scientific literacy, there may be fewer consensuses about *how* this can be generally achieved. The focus of this brief presentation will therefore be on question #3: In *many institutions, students take courses in the social and behavioral sciences as a means to fulfill their science distribution requirements. In what ways can and do these courses effectively promote scientific and quantitative literacy?*

As a basis for the presentation, I will use the case study of Colgate University. Colgate is a selective undergraduate liberal arts institution enrolling approximately 2,800 students and employing about 240 faculty members. It has a strong emphasis on majors (concentrations), as well as a distribution requirement – two courses in the sciences: social sciences, and humanities and a core general education program. Of course, I choose this example not solely because of its representativeness, but also because of the availability of the data I will be presenting.

Despite the increasing need for general science education, there are currently several practical barriers to achieving this objective successfully. *First,* although there is renewed interest in the sciences among students compared to a decade ago, still relatively fewer students major in the science compared to the social sciences and humanities. Five years ago, 22 percent of the graduating Colgate students majored in the sciences; today that figure has improved to 28 percent. Nevertheless, 33 percent currently major in the humanities and 39 percent major in the social sciences. Therefore, we cannot necessarily depend on science concentrations to provide a science education for students in general. The vast majority of students do not major in science. *Second,* perhaps because of lack of interest or lack of preparation, a substantial portion of students take the minimal amount of science possible within the liberal arts curriculum. As I noted earlier, Colgate has a two-course-per-Division distribution requirement. Thirty-four percent of Colgate students graduate with only these two science courses on their transcript (compared to 24 percent with the minimum social science and 9 percent with the minimum humanities requirements). *Third,* in a time of diminishing financial resources to higher education, the costs of traditional science education are high and are escalating. At Colgate, the average department budget allocation per faculty member in the sciences is six times what it is in the humanities and four times what is in the social sciences. Start-up costs are ten times higher in the sciences than in the humanities or social sciences. Because of teaching credit for laboratories, science instructors teach only .8 of the range of courses per year as other instructors, and the sciences accommodate only about 28 percent of the total enrollments. Recently, the controversial study from the University of Rhode Island has raised questions about the overall cost-effectiveness of pursuing research grants. An Important question then becomes: *How can we provide a better general science education for students in the face of these barriers?*

The answer I propose is that the *social sciences can effectively and efficiently contribute to science education in ways that complement and support the traditional sciences.* Colgate's experiences offer some insights because it’s unusual Division structure. The Division of Natural Sciences and Mathematics consists of biology, chemistry, computer science, geology, mathematics, physics/astronomy *and psychology*. Psychology is considered a social science on many, if not most, other college campuses. Using the social sciences more effectively can help overcome each of the obstacles I just raised; the first issue involves *capturing student interest* in courses that can potentially make major contributions to scientific and quantitative literacy. Among the seven science departments, psychology's enrollments have consistently been the highest. In addition, unlike each of the other departments, it did not experience the dramatic decline in enrollments of the 1980s. Among those students taking only the minimum two-course science distribution, psychology courses are clearly the courses of choice: 73 percent of those students had a psychology course as one of those two courses. Geology was second with 37 percent. The traditional, central sciences, such as chemistry and physics were largely represented in these students’ records (3 percent and 4 percent; see Figure 2.2). The attraction of Psychology is not likely easy grades; the average grade in the introductory psychology courses is the lowest of all of the introductory science courses. Thus, social science courses may provide an inherently attractive avenue among students for achieving the essential goals of a general science education.

The curricula of some social science disciplines may also be particularly well-suited to developing general scientific and quantitative literacy because of their explicit focus on methodology and statistical analysis. Table IV.1 lists the departments in which a statistics (or mathematics course) is a required or elective course in the major.

Table IV.1

Departments with statistics or mathematics courses as required or elective courses (science departments in boldface type).

Required	Elective
Computer Science	**Biology**
Economics	Education
Mathematics	Geography
Physics	Political Science
Psychology	Sociology

The science concentrations not on this list – astronomy, chemistry, and geology – instead have required *instrumentation courses*. Although experience with sophisticated, state-of-the-art scientific equipment may be essential for students continuing on in science, the development of transferable quantitative and information management techniques may be significantly more useful to the general student who will not pursue formal scientific training beyond graduation – and can be provided effectively at a fraction of the cost of equipment, supplies, and overhead.

At the introductory course level, social science courses that emphasize the application of the scientific method and experimental approaches to verification can be as effective as traditional science courses in achieving essential goals of scientific literacy in a context or personal relevance to students. Figure 2 [projected slide not published here] illustrates a comparison of student responses (1 = “disagree strong1y” to 7 = “agree strongly”) to three statements identified by science faculty as central objectives of a general science education: (1) “The course required me to engage in scientific reasoning”; (2) “After taking this course, I am more able to evaluate current issues and problems”; and (3) “The course improved my problem-solving skills.” The responses to these items for three traditional introductory science courses (biology, chemistry, and geology) are compared to Introductory Psychology and to an interdisciplinary Introductory Environmental Studies course (reflecting an integration of areas of biology, geology, and geography). The two "non-science" courses are generally as effective – and in some ways are more eff6ctive – in achieving the general goals identified by the faculty.

Because of the hierarchical nature of science curricula, the burden of providing the prerequisite factual information to prospective majors may interfere with an emphasis on the *process* of scientific inquiry that may be an essential aspect of a general science education for non-majors. Thus curricula that offer alternative entries to the major, rather than a strict linear sequence, may offer more opportunity for pedagogical innovation and flexibility and time to devote to an understanding of the process of scientific inquiry. Among the sciences, only geology offers multiple alternative entries to the concentration. The majority of the social sciences (i.e., not psychology or economics) allow different entry points. Recently Colgate has introduced a series of pilot Scientific Perspectives courses, which are staffed by social scientists as well as natural scientists as part of the required Liberal Arts Core program. These are designed to enhance scientific literacy, by focusing on the process of scientific inquiry with the mastery of a specific body of factual information, as a secondary concern. The results of student responses to these courses, separated by those taught by social scientists (economists and psychologists) and those taught by natural scientists, are presented in Figure 3 [projected slide not published here]. These results compare favorably to the results for the traditional science courses depicted on the previous figure. Thus, teaching introductory science may not be the only or the most effective way to achieve scientific literacy among non-science majors. In addition, science literacy may be achieved at least as effectively through selected social science courses.

In conclusion, it is currently particularly important to recognize and support the role of the social and behavioral sciences in science education. The incorporation of selected social science courses to complement traditional science courses in scientific education programs is valuable because:

- Social science courses are currently attractive to students
    - the topics and issues are of immediate relevance to students
    - these courses may be accessible to a wide range of students because they normally do not rely on pre-requisite high school preparation
- Social science courses may provide a cost-effective alternative
    - these courses normally have lower start-up equipment expenses and reclaiming costs for supplies
    - these courses do not normally require dedicated laboratory space; when equipment (such as computers, network links, graphics equipment) is needed, it frequently can be used for multiple other purposes
    - the skills that are acquired in laboratory experiences (e.g., computer or networking skills, skills in information retrieval, evaluation, and management, and skills in quantitative analysis) are highly transferable skills that will benefit students beyond graduation.
- The social and behavioral sciences may offer curricular and pedagogical flexibility
    - this flexibility may allow the adaptations needed to meet the needs of non-science students
    - more flexibility in the amount and nature of information presented can permit a more deliberate and self-conscious examination of the scientific method, experimental procedures, and data analysis
    - the topics of study may offer more obvious and direct connections to the use and misuse of scientific information and technology
    - the use of less structured laboratories can encourage the use of a wider range of pedagogical strategies, such as cooperative learning and creative problem solving.

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Why Study Economics? Why Teach It Using Frontier Technology?

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Teaching Introductory Economics at Cornell University Using the Worldwide Web

Cornell University has revamped the way it teaches Introductory Microeconomics using Worldwide Web technology. Partially as a result of the need to conserve faculty resources, Cornell reduced the number of lecture sections of Introductory Microeconomics that are taught throughout the University and increased the average lecture class size by roughly 50 percent (from 250 to 380). My colleague, John Abowd, who is a continual NSF Economics Program grant winner and a former NSF Economics Program Advisory Committee member, assumed responsibility for one of the classes. He did so motivated by the belief that students at selective research universities should be exposed early on in their education to prominent researchers and that they should be taught using frontier technologies.

Abowd's course is structured as follows:

On the first day of class students are given a multiple-choice exam that tests their knowledge of, and ability to apply, all the concepts to he learned throughout the semester in the class. Scores on each question for each student are stored on his server for future use by him.

Students are forced on to the Worldwide Web as lecture notes for the class are placed on the Web in advance of the professor's in-class lectures. Not surprising, attendance is lower than one observes in comparable size classes in which the lectures have to be attended to learn the professor's views. However, as noted below, Abowd can actually test if attendance, *per se*, improves performance.

Given the scale of his class, Abowd has enough teaching assistant (TA) resources to conduct office hours for multiple hours each day. Cornell is located on a very spacious campus and while the TAs are physically located in one room, students do not have to actually go to that room to see them. Rather, they can go to any one of a number of locations on campus and be "connected" to a TA using a computer technology that allows two way audio and visual contact between the students and the TA. Alternatively, they can communicate with the TAs by electronic mail.

Whenever a student asks a question relating to a point in the lecture notes, a star is placed on that spot on the Worldwide Web copy of the lecture notes. By "clicking" on that star *any* student in the class can read the question and see the answer. Effectively, use of the Web has multiplied the value of office hours. All students now have the potential to learn from the questions of any one. In the language of economists, office hours, which once were a private good, have become a public good.

Periodic exams are given in the course. Some of the questions are, in fact, identical to those given on the pretest. Thus Abowd can learn which specific concepts/questions are the ones that the students are having the most difficulty learning. Put another way, he can learn which sections of the lectures confuse rather than clarify things. Given the students self-reported class attendance, he can also estimate if attendance *per se* influences what students learn.

Weekly problem sets are given in the form of spreadsheets found on the web sight and answers must be submitted over the web. While students have complained about being forced to learn a new technology that is not essential to economics, they quickly master it and then observe how spreadsheet programs facilitate "what if?" discussions.

This course has not been an easy one to get off of the ground in spite of the Herculean efforts of Abowd for a number of reasons. First it has required a substantial initial capital outlay for equipment, including remote teleconference sites. Individual departments do not have the resources needed to develop such equipment funds; the university as a whole has to at least be partially responsible for them.

Second, it has required funding for all of the Web programming for the lecture notes, problem sets and exams. While it is rapidly getting easier to translate word processor files into Web-compatible format, this is not something that most "mature" professors feel themselves capable of doing. Many new undergraduates have mastered the technology and they provide the necessary labor pool for this activity.

Finally, Abowd is easily among the top 5 percent of all Cornell professors in terms of his facility with new technology. Once he has created the course structure, other colleagues can adapt it for their own courses. But how many of us will? And who will pay for the extra support costs such courses entail? Our saving in faculty time is only a saving to the university if we reduce the size of the faculty and/or use the freed up faculty type in some other revenue producing activity (e.g. off-campus learning or continuing education on campus). So far, most faculty and universities show little inclination to do either.

The Importance of Economics in the Curriculum

Research by economists (some of it funded by NSF) has demonstrated that the likelihood that any individual will spend his or her career with a single employer, or even in a single occupation, has declined in recent years. To have a successful career, individuals must be flexible and adaptive to continually changing technologies and economic forces. Learning to become accustomed to the former while in college may be almost as valuable to students in the long-run as the subject matter they study.

I say "almost" because I strongly believe that it is important that students study economics in college. Economics provides a conceptual framework that they can use to analyze private and public decision problems throughout their lives. Such basic (to an economist) concepts as demand and supply, the tendency of markets to move towards equilibrium, maximizing behavior under constraints, marginal analyses, externalities, opportunity costs, the prisoner's dilemma, the importance of relative prices, moral hazard, unintended side affects of decisions, adverse selections and rational expectations provide students with "tools" to help them evaluate their own private decisions and the issues they read about in the newspapers that policy makers continually face.

I regularly taught a course at Cornell for about 15 years called the "Evaluation of Social Programs." For six weeks I dazzled the students with my knowledge of quasi-experimental design and Campbell and Stanley's "threats" to internal and external validity. Showed the students how to implement the designs in the context of regression models and how each of the "threats" corresponded to an econometric problem, demonstrated how to compute sample sizes needed to obtain statistically significant program effects, and finally introduced them to benefit/cost analysis in a social context. I then spent the final eight weeks applying these models and techniques to the evaluation of labor market programs and policies, always using simple microeconomic models to conceptualize things. By the end of each semester I was always convinced that I had "wowed" students with how much I knew and with how exciting social policy analysis was.

Several years ago I ran into one of my former undergraduate students, who by then was high up in the human resource department of a major corporation. He told me that my course was the most valuable course that he had taken at Cornell and that he used concepts from it regularly in his work. I was dumbfounded. My course dealt with social programs; he was working for a private corporation. Ultimately I realized that he understood much better than I did what the course was really all about. Our job as academic economists is to increase our student's analytical abilities, not to cram them full of specific applications that interest us. Fortunately, the tools of economists are sufficiently useful that sometimes students understand this point, even if we don't ourselves.

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Social Science Education, Information Technologies, and Virtual Universities

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I wish to concentrate on only a few of the issues that are the focus of today's agenda. My stress will be on technology and the way it is transforming the entire learning process, affecting our vision of how and what to train students, and changing our repertoire of best practices. First I want to draw attention to the role of the social, behavioral, and economic disciplines in basic science education.

On my campus, the fact is not always appreciated that the social, behavioral, and economic sciences play a major role in basic science education, whether measured in student numbers or innovative projects. For a large cohort of students, basic science requirements are met by courses outside of the natural and biological sciences and engineering. Instead, their contacts will arise from courses in sociology, demography, anthropology, archeology, psychology, economics, geography and the like. Even though this is the case at many other campuses too, I realize that it is not always weighted as heavily as it perhaps should be in efforts to improve scientific literacy and the quality of the American scientific workforce. Yet within these disciplines, faculty is clearly concerned with these issues. They are taking the challenge of scientific literacy to heart and developing very promising models that address the broader concerns of general science education, in at least two ways.

In the first, stress has been placed on cultivating the analytical and problem-solving skills of students through active learning strategies. Too often, science curricula seem to value mastery of content over comprehension of the process of research and investigation. New prototypes seek to redress this situation and reassert the importance of cultivating analytical reasoning skills in the undergraduate curriculum. Social scientists are using small-group learning techniques and collaborative problem-solving to engage students in active debate and investigation of pressing scientific, political, and social issues.

Second, many social scientists are attempting to span disciplinary boundaries by challenging students to consider concepts and issues from interdisciplinary perspectives. The sense here is that conventional disciplinary boundaries are increasingly blurred in both theory and practice and students must learn to apply conceptual and analytical skills from many disciplines, rather than those of a single field. These projects often rely on a team of faculty drawn from several departments to address a single important and interesting topic, such as sustainable development or environmental quality, from a variety of perspectives. All of these projects take a fresh look at the curriculum and attempt to move away from compartmentalizing knowledge within time-worn disciplinary categories. Such projects are likely to increase in number and scope in coming years as means of reintegrating specialized undergraduate curricula.

The Impact of New Technologies

Some of the most exciting curriculum development projects involve creative applications of information technology. As recently as a few years ago, information technology was equated solely with the use of microcomputers in traditional quantitative subfields such as econometrics, demography, experimental psychology, or my own field of geographic information systems.

But it is now apparent that information technologies are rapidly and irreversibly transforming higher education and the ways in which students and scholars learn, teach, communicate, conduct research, disseminate knowledge, and serve the public. Scholars from all disciplines are experimenting extensively with multimedia, hypertext, Internet resources, distance learning, and many other techniques that fall under the broad heading of information technology.

Hypermedia authoring techniques have just recently become accessible to large numbers of scholars and in the past two years Internet and the Worldwide Web have made it possible to develop high-quality on-line course materials. As the academic community masters these resources, experiments will go even further. It is now easy to envision "virtual" departments, disciplines, or universities in which ready access to educational resources of all sorts is available through an easy-to-use graphical interface. The idea of using the Internet and hypermedia resources to link faculty and students from many departments and universities is, in some respects, just around the corner. Such cooperative endeavors would not only expose students to a richer educational environment but also help to average out the high development costs of hypermedia resources. This summer I am starting up NSF-funded Geography Virtual Department Project. Over the next three years, geographers from all over the United States will gather at the University of Texas to plan and develop materials to support an entire undergraduate geography curriculum on-line in the Worldwide Web. The Western Cooperative for Educational Telecommunications has just made public a sound plan for a Western Virtual University that can begin to be realized almost immediately.

Toward the Virtual University: Needs, Requirements, and Programs of the Future

Support will be required for disciplines and entire universities as they re-invent themselves to serve new and diverse clienteles throughout the nation and world using a new generation of learning technologies, but how? It is not just a question of massive new investment. Change is taking place so rapidly that large investments in unproved technologies can be very risky.

But, unfortunately, a wait-and-see attitude is just as risky. It can jeopardize the lead American universities have assumed in cyberspace. My suggestion is to look carefully at the processes of change themselves. If these new technologies are to benefit students and society through the educated used of information, people and systemic reform of institutions will be as critical to the process of change as the evolution of the underlying technologies. The "virtual university" must be viewed as the product of a process of change across the entire knowledge base of higher education. The transformation will involve:

1. Active collaboration of faculty, students, and staff in the development of new teaching and curriculum models and materials that will link across traditional disciplinary and university boundaries and result in systemic change of undergraduate and graduate education.
2. Careful evaluation and testing of prototypes including the cultivation of new modes of peer review, planning, and collaboration.

3. Comprehensive support for time invested in developing these new models including equipment, staff, and rewards that cut across conventional distinctions among educational, research, and public service.
4. Sustained support for collaborations and partnerships that will contribute to and draw upon far broader efforts to interlink advances in K-12 and collegiate instruction at the local, regional, national, and international levels.

This means that some traditional distinctions are gradually losing their relevance. Even the clearest divides among disciplines are disappearing as faculty and students build intellectual bridges electronically. Separate universities are finding themselves no more than a click away from one another on the computer screen. The sharp distinctions that were once made among research, teaching, and public service have blurred substantially. The most pressing question in this situation is what can be done at the national level to insure that these changes support the nation's lead in science education. Attention should be give to programs that:

1. Stress systemic reform of science education within individual institutions by reinforcing collaborative linkages among disciplines and approaching the knowledge-base of higher education as more than the simple sum of the social, behavioral, economic, biological and natural sciences. A strong faculty enhancement component is essential so that faculty can gain the skills and support needed to make a success of these efforts. American universities have never before been asked to “retrain” faculty on the scale they are today. It will be very important to adjust the academic rewards system to recognize this fact
2. Promote innovative educational partnerships at all levels to highlight the fundamental relationship between K-12, collegiate, and graduate science education. Such partnerships might also benefit from close connections with business and industry. Consortia must be cultivated at the local, regional, and national levels.
3. Establish rigorous benchmarks for the review, testing, and evaluation of these internal linkages and external partnerships. These benchmarks must be suited to the demands of new modes of technology enhanced learning and must address both the process of development and the products that are created.
4. These internal linkages, external partnerships, and quality benchmarks must be conceived with an eye toward broader education horizons, both temporally and spatially. What are needed are models and prototypes that can be scaled up to encompass the emergence of other linkages and partnerships through time and are robust enough to be applied to many different types of institution all across the country.

Kenneth Foote *joined the faculty of the University of Texas at Austin in 1983 after training at the University of Chicago and the University of Wisconsin-Madison. In addition to his research in cultural geography and American landscape history, Dr. Foote has many years’ experience teaching computer cartography, geographic information systems, and spatial statistics. He is the director of his department’s Environmental Information Systems Laboratory. He is now beginning the Geography Virtual Department project to interlink geography curricula nationally and internationally using the Worldwide Web. Dr. Foote was awarded the University of Texas President’s Associates Teaching Excellence Award in 1992.*

Contributions to the NSF Social Sciences Workshop

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The last twenty years or so of research on learning and cognition has born witness to a theoretical sea change. The widespread view that the mind absorbs whatever data it is offered has given way to an alternative. This is that the mind actively selects, interprets and even creates environments with reference to existing knowledge bases.

These active tendencies of mind are pervasive; they reveal themselves as much in studies of social cognition as they do studies of learning about mathematics and physics. When the same news clip is shown to Israelis and Palestinians, both report that it is a biased presentation in favor of the other. When fractions are introduced to the curriculum, children interpret them as novel examples of the natural numbers, reporting that 114 is more than 1/2 "because 4 is more than 2" or 1/76 is more than 1/65 "because 76 is more than 65." We are more inclined to attend to things we know something about; we interpret what we encounter with reference to what we already know. These active tendencies of mind have deep implications for education.

Educators no longer can assume that they material they offer learners will be interpreted as intended. Whether or not learning proceeds depends heavily on whether there is structural overlap between what is already known and the to-be-learned body of knowledge. When there is overlap, there is a reasonable chance that students will move along domain-relevant learning paths. When there is not overlap, there is a non-trivial chance that students will unwittingly misinterpret what they are offered, often enough in ways that are hard to anticipate. For example, it never occurred to me that my undergraduates would "hear" Kant as Can't. (I now write Kant's name on the board when I first introduce his ideas about knowledge and learning).

These facts about cognition are especially relevant to our discussions for today. When our goal is to teach a new body of knowledge to undergraduates expertise in one's discipline does not guarantee success in the classroom. The odds are high that there are qualitative differences between the knowledge structures of learners and teachers. Indeed, there is reason to anticipate gaps between learners and learners given our commitment to universal literacy be it in the humanities, social, physical or biological sciences, sciences, humanities. I will expand on this point in my remarks about the way that cognitive research can facilitate the goals of undergraduate education.

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Social Science Research and the Learning Process

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Learning is a function of student ability, motivation and effort. These three factors interact in a non-linear manner to produce knowledge. In addition, learning takes place in a social context, which differs for each student by their ascribed and achieved characteristics. The contribution of the social sciences, and sociology in particular, to an understanding of how to improve undergraduate education is based, in large part, on the research that has been conducted on the various components of this learning model.

In general, psychology has led the social sciences in broadening our understanding of student ability. Recent research on the nature of intelligence has challenged old narrow definitions of intelligence that were almost solely related to analytical abilities and to cognitive thinking. Identifying different bases for intelligence and for understanding the world has made a significant impact on attitudes toward the learning process and toward achievement. More research needs to be conducted in this area, both to increase our understanding of intelligence and to disseminate this work to educators. The implications of this work for curriculum content, pedagogical techniques and performance evaluation are profound.

Psychologists also have made significant advances in understanding of individual differences in learning strategies. Their research has identified several different learning styles, such as visual learners and kinetic learners, and demonstrated that the better the fit between a teacher's instructional techniques and the student's learning style, the more the student learns.

Both psychologists and sociologists have addressed the issue of student motivation. While psychologists have been concerned about intrinsic motivation, sociologists have studied extrinsic motivation in the form of rewards and sanctions. Sociological research has examined whether students are more motivated in cooperative or competitive environments and working individually or in groups. Findings suggest that working in groups in a cooperative setting produces greater growth in achievement than straining for relative gains in a competitive environment.

Motivation also is affected by student interest in the subject matter. Sociological research on the organization of instruction in secondary schools demonstrates that the higher the quality of instruction, the more interesting the curriculum and materials, and the greater the amount of time exposed to the curriculum, the greater the growth in achievement. The social organization of students for instruction affects the quality and quantity of instruction. Organizational arrangements such as ability grouping and tracking at the middle and secondary levels have been shown to differentially channel opportunities to learn to students who differ in ability. The higher the ability group or track level, the higher the quantity and quality of instruction and, even with ability controlled, the greater the growth in achievement. At the college level, the quantity and quality of instruction also varies across courses. Access to the most favorable learning situations varies by student characteristics, such as ability, and linkages to faculty and peers who can provide relevant information about courses.

Another factor affecting student motivation is the influence of peers. A large body of sociological research demonstrates that peer groups are a significant factor in the learning process. Students who belong to a peer group that devalues academic work are less likely to succeed academically than those who have peer models who are serious about academic achievement. Peers affect the amount of time spent studying, the nature of non-academic activities (wholesome or dangerous), the choice of courses, educational aspirations and academic achievement. Some studies show that school personnel can modify an anti-academic peer culture through the creation of desired rewards and through the expansion of the bases for social hierarchies.

Research reveals that individuals differ in the relationship they see between motivation and effort. Students with similar levels of motivation may expend different amounts of effort to attain their educational goals. Coleman's research identified a race effect on students' sense of "locus of control", with black students believing that luck played a greater role in outcome than white children. Cultural differences in the value and effects of effort also have been documented. With the increased racial, ethnic and cultural diversity of college campuses, the need to take these differences into account only increases.

Other contextual variables that affect learning include the size and composition of the class. A large body of research demonstrates that the larger the class the slower the growth in achievement. The linkages between class size and academic achievement include degree of student participation in class, number of teacher-student interactions, and student self-esteem. Studies also show that the stronger the academic climate of the class, usually related to the student distribution of achievement, the greater the effort and achievement. Here, the mechanism connecting academic composition to learning involves role models and socialization.

In addition to the contextual variables that affect the dynamics of learning depicted in the learning model, individual ascribed and achieved characteristics affect learning. In a recent article in *The Chronicle of Higher Education*, Jerome Kagan cites studies showing that the components of self-esteem differ by the history and cultural background of the individual.

Similarly, the way the components of the learning model interact to produce knowledge differ by the gender, race, ethnicity, socioeconomic status and age of students. They also differ by family characteristics and by school factors. This is undoubtedly true at undergraduate institutions as well as primary and secondary schools. A better understanding of these interconnections will provide better direction to educators who design and implement college curriculum and instruction.

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The Social Sciences Contribution to the EHR Undergraduate Review: Comments on Guiding Questions

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Background

Personal experience underlies many of the following comments. Therefore, I provide here a brief summary of the most relevant experience.

The Carnegie Mellon Center for Innovation in Learning

Carnegie Mellon University provides funds for a center with a charge to use research results, experimentation, and technology to improve education at Carnegie Mellon. Four tenured faculty, as well as one senior scientist, have full- or part-time appointments within the Center. Other faculty may apply for one-semester sabbaticals at the center. During this time they work to improve one or more undergraduate courses, and gain general expertise in the science of education, which they can continue to apply to their work and share with others in their department. These faculties remain associated with the Center as “affiliates” and have desk and computer space to continue to work there when they wish.

The center also supports graduate students and post-doctoral fellows who work jointly with CIL faculty and an outside faculty member to apply scientific education to improve a target undergraduate course.

Applying Cognitive Science to Pre-College Education

For six years I headed the James S. McDonnell Foundation's Program in Cognitive Studies for Educational Practice. It provided good support (~$300,000/yr for three year terms), for cognitive researchers to begin to move research results towards pre--college classroom applications. The program produced some stunning examples of how well this approach can work. (See, Bruer, J. and McGilley, K.)

Developing an Innovative Introductory Course in Cognitive Psychology

Over the past 12 years I have taught an increasingly innovative course which provides an introduction to cognitive psychology. I organize the course around three main models appearing in modern cognitive psychology (network models such as ACT, rule models such as Soar and CAPS, and neural or parallel-distributed processing models).

The student body is diverse, including students from all four years and all five of the “colleges” of Carnegie Mellon (Humanities and Social Science, Fine Arts, Engineering, Mathematics and Mathematical Sciences, Computer Science). Thus there is an enormous range in type of interest and ability to handle the quantitative aspects of the course. I have experimented extensively with technology use, and with various pedagogical methods.

At this time, I believe the course is a cognitive success, with highly mixed sociological and motivational results. By the end of the course, most students can solve problems, write essays, and answer a special kind of very challenging multiple-choice question indicating understanding of the three model-types, and ability to apply them to a variety of data and every-day situations. However, as indicated by course evaluations and student comments. Many students do not "feel" they have learned much, and are others dissatisfied with the course format.

What other research efforts in the social and behavioral sciences inform us about the learning process?

Social Psychology

Social psychology has had little attention from scientific educators with consequences that are now becoming obvious. Everyone I know who dramatically restructures an undergraduate course initially experience hostility and unhappiness from the students. (A recent report in *Science* dramatically documents this effect for NSF sponsored introductory calculus courses.) However good the instructional design, and even the instructional effectiveness, unhappy students are undesirable. Ultimately courses that students don't like are not viable.

We need to understand how school-sophisticated undergraduates' view their "social contract" with a professor. What should and should not happen and why? Can we work with students' expectations instead of against them? Can we exploit other features of the student-professor relationship in achieving good learning outcomes? This is uncharted territory, and crucial to continued success in applying results of behavioral science to improve instruction.

Applied Research

The McDonnell Program (briefly described above) was successful because it recognized an area ripe for exploitation and provided realistic funds to attract first-rate scientists to attack the problems of doing the exploitation. Research results do not jump to classroom application without several years of experimentation, and trial and error. Prototypes must be expanded to coherent curricula. Materials appealing enough in the laboratory must now catch and hold attention of more varied students in an environment with many distractions. New methods, practical for groups of students must be developed. Through this process, one wants to avoid simply trying to make a curriculum, but to maintain a goal of keeping the instruction tied to learning principles. Without this, the result is merely one more curriculum, and not a contribution to the science of education.

Meta-Knowledge of Science

Students have well-known misconceptions in both physical and behavioral sciences (e.g., the so-called "cognitive illusions" in probability). Less well documented, but apparent to all thoughtful teachers, are students' misconceptions about the goals and nature of science. Most students believe science is a collection of facts and rules, and that their learning task is to memorize some of this collection, perhaps along with some straightforward ways to apply the rules.

The behavioral sciences can, in my view, provide a particular opportunity for teaching how science works. Introductory physics (for example) teaches a well-developed theory that has been stable for many years. It may look to students like immutable fact, unconnected with human enterprise. In contrast, the younger behavioral sciences involve smaller scale models, which are regularly challenged and modified as new experimental evidence appears. Most students find this sequence baffling at first. (But in Chapter 3, they said...!) But this confusion gives an entree to discussing science as a process for better describing observations.

Most students lack the ability to construct a scientific argument, including data, theoretical statements, and links between them. We have repeatedly observed students' omitting any or all of these components in both history and psychology.

General learning skills

Just as students lack knowledge of the nature of science, and often have misconceptions that interfere with effective learning, there are parallel problems in students' knowledge and beliefs about learning.

Passive Learning

Many students see learning as a passive process. They attend lectures, read assignments. Study consists of ... “sitting somewhere comfortable, preferably in bed, and paging through notes and textbook” – quote from a parent. The idea that learning requires active practice seems often entirely foreign. “It's a strange thing with this course. 1 don't understand what's going on until after I've done the homework and taken the exam” – email from a student in my psychology course. “I've learned twice as much in class as in the other two Psychology courses combined. The reason is that this is a hands-on course. Here I've *done* things” – paraphrase of a comment from another student in the same course. Students' model of understanding often seems to be mere familiarity with the terms and phrases.

Failure to Learn from Errors

Students too rarely have the ability (or the motivation) to use mistakes as an opportunity for learning. For example, in my course, if a student believes there is a correct explanation for a multiple-choice answer graded as incorrect, sending me an explanation by email produces either a grade change (if I agree with the student) or a careful explanation of where the student's thinking is wrong. About 30 percent of the students never use this opportunity. The answers I've heard to the question, “Why not?” include: “I didn't really understand that I could do this. It's so firm in my head that an exam is an exam, and you get the grade, and that's that.” “Arguing with the professor is for grade-grubbers and poor students.” “I did so poorly I just didn't want to think about it any more.”

Although my particular treatment of tests is unusual, these quotes illustrate clearly that many students do not use test results as an opportunity to learn. (See also Gagne, E., *Cognition & Instruction*) We need to teach students how to use errors as a cue to their own misunderstandings, and how to work towards detecting and preventing similar misunderstanding in the future.

Lack of Even Primitive School and Learning Skills

Colleagues who regularly visit many classes at Carnegie Mellon tell me that 40-50 percent attendance is common, and that of those present, there are still the sleepers and the note-passers in the back. I have reluctantly developed a system of requiring and checking attendance (collecting a class assignment in each lecture). Many students have great difficulty taking notes, especially on class discussion. And, as reflected by some of the previous comments, many have little idea how to study.

Specifically, I believe that many of my students have no idea how to study “actively.” I suggest repeatedly a technique of working either with oneself or a partner to generate and answer questions about the material. I show a method for generating such questions. We maintain a bulletin board where students post questions they can't answer. Sometimes other students answer. Ultimately I either endorse some students’ answers, or provide comments of my own. But, as indicated by some of the comments quoted above, this is clearly not an activity many students use.

The difficulties are almost certainly both cognitive and social or motivational. The methods of effective study are certainly as difficult as the methods of psychology or physics. We need to analyze them and teach them effectively. But, even more than subject-matter procedures, these must be procedures students are motivated to use. Thus again, I emphasize the need for more social psychology to use as a base in improving instruction.

In many institutions, students take courses in the social and behavioral sciences as a means to fulfill their science distribution requirements. In what ways can (do) these courses effectively promote science and quantitative literacy?

Difficulties

1. Traditional teaching methods (lectures & reading)
   The student is passive, except for one or two exams, and perhaps a term paper.
   There is no weekly homework, often any regular discussion sessions. If there are discussion sessions, the teaching assistants may receive little or no training or guidance.
2. Little background of basic research
   There has been little research in cognitive processes in these arenas (and little financial support for such work). Thus we must translate from research in other fields (e.g., physics, mathematics), and begin some basic research in these areas.
3. Current textbooks
   - Textbooks (at least in psychology) usually have a historical organization, and do not integrate material so as to make it easier to learn.
   - Worse, textbooks often make integration especially difficult for students. For example, introductory psychology textbooks universally refer to experiments by authors' names and publication date. Since few students know automatically what Posner and Boyes did, if they wish to integrate, they must go to the author index, and then back to the page describing Posner & Boyes' experiment. Use of mnemonic titles for key experiments could solve this whole problem.

Opportunities

1. Modern social science is highly quantitative.
   Therefore perhaps we can transfer approaches similar to those effective in the physical and mathematical sciences.
2. There are educational journals in this area, which may contain useful lore to use as guidance.
3. As the behavioral sciences mature, it becomes possible to better integrate the material we teach. (See, for example, my comments on structuring cognitive psychology.

What are the ways in which technology is being incorporated into courses in the social and behavioral sciences to enhance learning and the curriculum and also to promote technological literacy?

The notes below summarize how I use technology, or have seen it used effectively.

1. *Presentation software:* sideshows, animation, integrated video material.
2. *Visualization:* before presenting formal models, I use animation to show how the model works qualitatively.
3. *Interaction software:* class response systems (Classtalk) bulletin boards; Web.

4. *Computational instruction:* computer-assisted learning, tutors, hypertext.
5. *Commercial software:* spreadsheets, graphs, outlining, and writing.
6. *Public domain research-level models*. Increasingly researchers make available their model code.
7. *Data analysis:* Many commercial packages aid in qualitative and visual as well as quantitative data conceptualization.
8. *Distribution:* Material placed on the web often gets a lot of access from surprising places.
9. *Evaluation:* (See appended essay by F. Reif.) In my course, using some computer-assisted grading, three people grade roughly 100 exams (half essay, half multiple choice) in one afternoon.

What can the social and behavioral sciences recommend that will enable faculty to meet the challenges posed by a student body that is increasingly diverse with respect to level of academic preparation and cultural background?

Long-term stable effort

Many of these issues are addressed above. A central remaining issue is how more effective practices can become available to a wider group of faculty.

The central issue, I believe, is that most faculty have a "broadcast" model of pedagogy. That is, a professor who knows the subject matter, lectures clearly provides good assignments, grades well, etc. – this professor teaches well, and the rest is up to the student. Shifting to a model of analyzing the learning task, and asking how to facilitate that learning in a particular course – this is a difficult shift of view. Once the shift is made, then there is a large body of knowledge about learning mechanisms and how teaching can make use of them. This needs to be mastered, at least in a form relevant to the professor's own teaching. We believe that this process takes at least one semester of dedicated effort, and therefore provide the one-semester "sabbaticals" at the Center for Innovation in Learning.

What are the obstacles to determining, implementing, and evaluating "best practices"?

Evaluation

I have appended an essay by Frederick Reif discussing possibilities for evaluating instruction in physics. There has been far more work in physics education than in the behavioral sciences (and far more financial support of such work). Thus the behavioral sciences may or may not be ready for such an approach. However, an effort such as Reif describes could aid in better defining reasonable learning goals, a crucial step towards improving instruction.

Collegial support

(Quoted from an abstract for a talk by Herbert A Simon) One striking contrast between our research lives and our teaching lives are that research is a highly social activity, teaching most often a solo performance. Research is carried on with colleagues, local, national and international; It's products are widely published; it is constantly judged by peers – and sometimes rewarded. Typically there is little intellectual interchange with colleagues about teaching, and few of our thoughts about it or its products are communicated.

Thesis: To give teaching the same intellectual excitement as our research (if it doesn't have it already), and equal claims on our attention, we must convert it into a collegial activity like research.

New talent

Other than the new and small effort at Carnegie Mellon, and a slightly larger effort (aimed at technology) at Georgia Institute of Technology, there are (to my knowledge) no locations for training new talent in instructional research, application, and innovation at the undergraduate level. NSF could have a big influence by providing relatively long-term training grants to establish or support centers that could train the new young talent desperately needed if we are to address any of the issues discussed above.

Jill Larkin *has joint appointments in the Psychology Department and in the Center for Innovative Learning at Carnegie Mellon University, where she also has a courtesy appointment in the Computer Science Department. Her research has demonstrated strategic differences in problem solving between physics students and expert physicists, and has elucidated how diagrams and displays function in supporting effective reasoning. These observations have been part of the research base used to develop an introductory physics course that raised students' scores on comparable final exams from averages in the 60's to averages in the 80's. For six years Professor Larkin directed the McDonnell Foundation's Program in Cognitive Studies for Educational Practice. During this time a number of cognitive scientists, using results from cognitive science, produced new learning results in a variety of pre-college classrooms.*

Appendix

To be published as a "guest comment" in the American Journal of Physics.

Standards and Measurements in Physics: Why not in Physics Education?

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Standards and measurements have played a centrally important role in the development of physics. They have yielded reliable data based on accurate and reproducible observations. They have facilitated meaningful sharing of results among different scientists. They have allowed unambiguous checks of theoretical ideas and have thus led to cumulative improvements of valuable knowledge. For these reasons physicists have, throughout history, expended considerable efforts on refining their standards and measurement methods.

The situation has been quite different in physics education, although the needs are no less. There, a lack of reliable standards and measurements has made it difficult to assess the efficacy of different instructional approaches. Although it is easy to *proclaim* the virtues of various innovative curricula or teaching methods, how do we really know in what respects one teaching method is more effective than another? Or how do we know whether a teaching method, seemingly effective in helping students acquire some abilities, does not fail in helping them acquire other abilities that are even more essential?

Can we expect to achieve much progress in physics education (both in understanding of the basic issues and in practical efficacy) if we lack at least reasonably reliable common measurement standards? Could we not perhaps develop and use better standards? The following comments explore these questions in the hope of stimulating more serious consideration of them.

Formulating basic standards

Scientists, concerned with accurate measurements, who sometimes officially meet to arrive at a consensus reflecting their best judgments, establish standards in physics. Standards in physics education would similarly need to be formulated by a careful process leading to a consensus among knowledgeable workers in the field.

Better standards might perhaps most usefully be developed for the introductory college-level physics course for physical science or engineering students. Not only is this an important course faced by many instructors and students. Physicists would probably also find it easier to agree about the aims of this course than about courses intended for biology majors or non-scientists.

The first need would be to agree about *what* the standards should specify. The aim of any instruction is designed to endow students with new capabilities enabling them to cope better with later courses, jobs, or other tasks in their lives. Mere specification of a syllabus, listing the topics to be "covered" in a course, does not indicate what students actually learn. Accordingly, educational standards need to be *performance standards* specifying what students should actually be able to *do* after completing a course.

One should, at least, be able to agree on some *minimal performance standards.* e.g., on a half dozen or so kinds of *basic* capabilities expected of all students emerging from a one-semester course. One might perhaps hope that students learn more than that. But any course in which students fail to acquire these basic capabilities could then be clearly judged a failure.

The mere discussion of basic standards would force physicists to examine more closely their teaching goals and to specify the actual capabilities expected of their students. I am sure that there would be heated debate reflecting diverse points of view and previously unexamined assumptions. But the debate would be very healthy in confronting issues that are often not explicitly addressed. For example, should students rely on various memorized formulas or be able to reason from a few basic principles? Should they be able to solve problems mathematically or should they also be able to do qualitative reasoning? Should they mostly engage in numerical manipulations or also be able to obtain algebraic results that they can examine for their qualitative implications? Should they just be able to obtain answers or also be able to articulate well-based scientific explanations?

Operational specification of standards

Operationally meaningful standards need to be accompanied by procedures specifying *how* they can be determined by actual measurements. Some detailed work would, therefore, need to be done to design questions or tasks exemplifying the basic capabilities specified by these standards. There would also need to be agreement that a student's ability to answer such a question, or to perform such a task, would provide good evidence that he or she possesses the specified capability.

The Hestenes tests[11] provide good examples of questions designed to assess one basic kind of capability desired of students in an introductory physics course. However, other basic capabilities important in such a course would also need to be specified (e.g., the ability to apply Newton's laws to solve simple mechanics problems).

Utility for assessments. Suppose that consensus had been reached on a few basic performance standards in a course and that each were accompanied by a set of N questions designed to assess achievement of the specified performance. These N questions (where N might be about 30) should be approximately equivalent and could have been empirically tested to ensure that they are of comparable difficulty.

One could then construct an assessment instrument (e.g., a final examination) by selecting at random one question for each of the specified kinds of performance. No one, including the instructor teaching the course would know beforehand, which of these questions would be selected. Hence one would eliminate the dangers of bias, e.g., of deliberate or inadvertent teaching directed at particular questions on the test. (If the number N of possible questions is large enough, trying to teach students to answer *all* of them would pretty much ensure that students have attained the desired competence.)

Persons interested in assessing instructional effectiveness would then have available measuring instruments allowing them to determine more reliably in what ways a teaching method used one

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[1] Halloun, I.A. and D. Hestenes, 1985. The initial knowledge state of college students. *American Journal of Physics.* 53:1043-1055. Hestenes, D. and M. Wells, 1992. "A mechanics baseline test." *The Physics Teacher.* 30:159-166. Hestenes, D., Wells, M. and G. Swackhamer, 1992. "Force concept inventory," *The Physics Teacher.* 30:141-158.

year is more effective than another one used previously – or more effective than another method used by others willing to use the same measurement methods[2].

Purely individual efforts might help to achieve some of these aims, but would suffer from some insurmountable limitations. In particular, there would then be no assurance that measurements made by one individual would be deemed legitimate or significant by others. Even more important, there would be no meaningful ways to compare the efficacy of instructional interventions devised by different people. Good standards and measurements in the domain of physics education, as well as in physics, necessarily require the collaborative efforts of the community of workers in the field.

Practical realizability

The preceding proposals are not beyond the bounds of realistic feasibility, especially if the following points are kept in mind: 1) These proposals aim to improve the present situation in physics education, but do *not* pretend to achieve perfect standards. However, even modest improvements could be quite valuable; 2) Standards are not to be cast in stone, but can be periodically reexamined and modified. (Even in physics standards get periodically refined or even redefined.); and 3) There is no compulsion forcing anybody to abide by any formulated standards. However, such standards could be used to good advantage by people interested in more reliable assessments of instructional effectiveness. Furthermore, the very existence of these standards could beneficially influence teaching practices.

Well-specified performance criteria in any field help to avoid fruitless debates and wasted efforts. When the goals are clear, it becomes much easier to decide the merits of alternative approaches and to ensure cumulative progress. It will probably always be more difficult to specify standards and measurements in physics education than in physics, but it seems possible to do significantly better than is currently the case.

[2] Some statistical sampling issues would need to be addressed in these measurement procedures, but they would be less severe than those prevalent at present.

Contributions of Cognitive Science to Undergraduate Education

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Cognitive science is an interdisciplinary endeavor involving cognitive and cognitive developmental psychology, computer science, and the neurosciences. The aim of cognitive science is to understand the workings of the mind/brain. Hence, its insights are basic to the development of an understanding of human mastery of mathematical and scientific material and habits of thought. An emerging subdiscipline within cognitive science aims explicitly to develop knowledge relevant to learning and instruction. (For a readable and eloquent summary of this movement, see John Bruer's 1993 *Schools for Thought*). This emerging sub-discipline can be seen as reinventing, or at least reshaping, traditional educational psychology.

Educationally oriented cognitive scientists have worked on several problems whose solution is necessary to effective teaching of mathematics and science. In this short paper, to give participants in the Social Sciences Workshop a sense of the potential for cognitive scientists to contribute to the improvement of undergraduate education, I discuss two problems which cross cut various mathematical and scientific fields, and two developments with specific relevance to the teaching of certain fields (physics and geometry). Thus, this paper is mainly addressed to answering the first question posed to the Workshop ("*What are the implications of cognitive research for an understanding of how students learn?*"), although I also touch on issues of promoting flexibility and life-long learning (question 6), issues of diversity (question 5) and what is needed in terms of a research agenda (question 8).

Transfer of learning from one context to another

One issue basic to effective education is devising conditions under which students will show *transfer*, or generalization of learning. That is, having 1earned a skill in one context (e.g., mathematical operations of compounding in the context of calculating compound interest), we want people to be able to apply this knowledge in a different context (e.g., velocity problems). Transfer of skills and knowledge from domain to domain will likely be increasingly important, as we move into an era in which workers will need to adapt flexibly to changing technology and to different work situations. Unfortunately, the cognitive literature shows that people are frequently distressingly narrow and rigid in their transfer, realizing the applicability of existing knowledge and skills only when its relevance is explicitly pointed out to them.

At the same time, there are beginning to be demonstrations that this narrowness and rigidity can be overcome. Teaching needs to be aimed at producing *decontextualization*, while at the same time not itself being decontextualized. That is, people learn best when they study a problem in context, motivated by interaction with physical materials and relevance to real-world problems. But they also need to encounter multiple instantiations of underlying principles, each in context, but with the deeper similarities a focus of instruction. For example, students appear to learn compounding in a more generalizable fashion in mathematics classes, in which they encounter a variety of problem types, than in finance or in physics classes, in which the domain of application is narrower. Teaching based on the principles of contextualized instruction with a range of domains of application can help students learn general principles and procedures, whose relevance to new situations they can see spontaneously.

This newly achieved understanding of the nature of the instruction, which is necessary to result in transfer, and generalization presents a research opportunity to NSF. Cognitive scientists can build on their understanding of when transfer is and is not achieved to work in partnership with instructors of specific mathematical and scientific disciplines to devise curricula which will maximize deeper understanding (and hence transfer) of an identified number of basic principles. Facilitating interdisciplinary research partnerships involving the mathematical and scientific disciplines with cognitive sciences should be an important priority for NSF.

Student diversity as related to patterns of cognitive ability and learning styles

As we all know, undergraduate student bodies are increasingly diverse in cultural background, age, and level of academic preparation. This fact is sometimes interpreted as implying that instructional styles need to be correspondingly diversified, to accommodate the different patterns of intellectual strengths and weaknesses seen in different groups and to accommodate what is conceptualized as different learning styles shown by different groups. However, while appealing, research support for these assumptions is largely lacking.

One subtopic in this general realm of discourse concerns *visuospatial ability*, generally agreed to be one of the two most important components of general intelligence, the other being verbal intelligence. Certain types of visuospatial ability show fairly sizable sex differences. There are recurring attempts to link this fact to sex differences in mathematical achievement and to recommend that different instructional strategies be used with males and females because of this difference. However, such recommendations are shortsighted. There is compelling evidence that visuospatial ability is underdeveloped in both men and women and extremely responsive to training and instruction (see review by Baerminger and Newcombe, 1995). There is a need for research on the benefits of linking interventions designed to maximize the spatial potential of undergraduates to facilitating their mathematical and scientific learning.

Second, diversity is frequently conceptualized in terms of hypothesized differences in learning styles across populations. However, the cognitive literature is not encouraging of this conceptualization. To be useful, learning styles would need to be operationally definable, reliably assessed, show long-term stability, and, most importantly, be related to instructional style so that particular types of instruction could be paired with particular students. The search for such *aptitude-treatment interactions* has been an active one, but few have been found.

There is a possibly interesting exception to this rule, however, in recent work by Robert Sternberg at Yale University. Sternberg has reported reliable and valid assessment of analytic, creative and practical intelligence, coupled with maximization of learning in an introductory psychology course when instructional styles are matched to student learning styles. Following up on this finding in teaching mathematical and scientific content represents another example of a research opportunity for NSF in efforts to pair cognitive scientists with instructors m mathematical and scientific subjects.

Changing student misconceptions about physics

Cognitive scientists have documented that students, even at the college level, frequently have intuitive notions of physics which are fundamentally different from physics the way physicists think of it. College students may predict that balls shot out of curved tubes will follow curved paths of motion after release, or think that a heavier object dropped from a tower will hit the ground before a lighter one dropped at the same time from the same height. Such misconceptions may appear discouraging to instructors. Or, instructors may simply attempt to contradict these beliefs, lecturing on the "correct" way of thinking about these problems. Unfortunately, traditional teaching techniques are frequently ineffective. For instance, students are prone to predict a curved path for the ball shot from a curved tube even after taking a college course covering mechanics.

Curricula, which take misconceptions as a point of departure rather than a roadblock, can be more successful. A program developed for a high school physics course by Jim Minstrell, in collaboration with Earl Hunt, a cognitive scientist at the University of Washington, is frequently cited as an example. The Minstrell approach takes students' thinking about physical phenomena as a point of departure, working to arrange experiences in which students realize how different aspects (or facets) of their thinking are incompatible, and then work to resolve these impasses. Teaching through impasse resolution is slow, but effective. Impasse resolution approaches could easily serve as the basis for college curricula as well. The research challenge for NSF is again to commission interdisciplinary groups of cognitive scientists and mathematicians/scientists to work together on curricular developments suggested by cognitive science.

A technology-based program of geometry instruction

Students frequently dislike geometry, and relatively few master the skill of constructing geometric proofs. John Anderson, a cognitive scientist at Carnegie-Mellon University, has devised an interactive computer program, which can impressively increase high school students' ability to do proofs. The approach taken in building the program is one that does not necessarily depend on technology. Teachers also could learn to teach using the ideas, which the program uses, such as those experts frequently approach proofs by trying both to reason forward from the givens and backward from the desired conclusion. Again, the research challenge is implementation.

Conclusion

This short paper was aimed to give workshop participants a sense of the relevance of cognitive science to instruction by presenting four examples. Much has been achieved, but basic research is far from over. For instance, there is still considerable controversy about how one can maximize transfer in problem-solving situations, and several competing models of the process exist (see review by Reeves and Weisberg, 1994).

NSF could contribute to improving undergraduate instruction by supporting cognitive science in two ways. First, funding is needed for basic research in cognitive science on topics with educational relevance. While there are, theoretically, existing funding mechanisms within NSF for such research, in actuality the SBER programs such as Human Cognition and Perception frequently look askance at educationally-oriented proposals and the EHR programs may find cognitive-science proposals too theoretical and too far removed from the field. Joint programs would be helpful, in which the announced goal is to fund proposals in the intersection of the two research domains. Second, funding is needed for the research/practice collaborations necessary to effective implementation of the insights and achievements, which already exist. There are many difficult steps between scientific understanding and widespread adoption of specific curricula and practices. Detailed recommendations, along these same lines, are elaborated in a report written on an NSF-sponsored conference on a very similar topic, namely the contributions of cognitive science research to K-12 mathematics and science education (Hawkins and Newcombe, 1994).

Nora S. Newcombe *is Professor of Psychology at Temple University. Her research is on cognitive development, and concerns spatial processes and also early memory. At Temple, she is working with the Center for Excellence in Teacher Preparation, a project to improve the ability of K-12 teachers to educate children in science and mathematics.*

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Cognitive Science and Undergraduate Education

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The primary purpose of this paper is to address questions 3 and 6 in the guide to the workshop discussion from the perspective of the cognitive sciences. From this perspective, question 3 asks how introductory undergraduate courses in the cognitive sciences effectively promote scientific and quantitative literacy. Question 6 asks how knowledge of the cognitive sciences prepares students to meet the challenges of the 21st Century. I will also address the research and development efforts (Questions 7 & 8) that are needed to realize the potential of cognitive science as an area of undergraduate science instruction.

Undergraduate education in cognitive science

Cognitive science is the science of intelligence in humans, other animals, and artificial systems. It includes the study of perception, learning, memory, knowledge, meaning, reasoning, language, attention, affect, consciousness, and the control of action. In undergraduate curricula, the field is offered both as a new scientific discipline that emphasizes computational models of cognitive processes and as an integrative interdisciplinary field that draws together insights from several traditional disciplines, including psychology, biology, computer science, linguistics, philosophy, and anthropology. In the context of the present workshop, it should be pointed out that cognitive science highlights the somewhat arbitrary nature of traditional distinctions between physical, biological, and social sciences. Cognitive science has significant social, behavioral, biological, and even physical (e.g., psychophysical studies of sensory systems) dimensions. Stillings (1995) is a recent report on the current status of undergraduate education in cognitive science. Stillings et al. (l995) is a survey of the field.

Scientific literacy and the social sciences

Before answering Question 3 for the cognitive sciences, the larger context of the question should be considered. We should not assume that the typical undergraduate science distribution requirement could effectively promote scientific literacy, if only the mix of physical, biological, and social sciences were optimal. Undergraduates may not be taking enough science, and the science that they take may not be taught effectively. Empirical research, of the kind described by other participants in this discussion, is required to assess the effectiveness of and to improve college-level science instruction.

We should also not assume that instruction in the physical and biological sciences alone provides, or is even capable of providing, a superior or sufficient path to scientific literacy. For the foreseeable future, many policy issues that will concern a scientifically literate citizenry fall at least partly in the domain of the social and behavioral sciences. Furthermore, as I will suggest below, the social and behavioral sciences are equal, and in some cases superior, to the physical and biological sciences as arenas for general science education.

How courses in the cognitive sciences can promote scientific and quantitative literacy

The contributions of courses in the cognitive sciences to science education fall into five areas. First, cognitive science provides a scientific approach to a distinctive set of questions that is of great interest to contemporary undergraduates: What is the nature of meaning? What distinguishes perception from knowledge objective? What is the relationship between mind and brain? What is consciousness? Cognitive science's empirical approach to such questions can bring science to a new group of undergraduates, and it can show them the connections between science and areas of life and academic pursuit that can seem distant from science. Cognitive science can also play a crucial role in helping students to critically understand mind-brain-behavior relationships in an era of rapidly expanding knowledge in neuroscience and behavior genetics, as well as in cognitive science.

Second, cognitive science is a superb field for giving beginning and intermediate undergraduate students hands-on experience with science. Instrumentation costs, even for sophisticated original research, are generally low, and many currently active research questions are accessible to undergraduates. Often, a personal computer can serve as the student's laboratory. A wide range of cognitive psychological experiments on perception, memory, language, thinking, and motor control can be run and analyzed on unmodified desktop computers. Students can both replicate experiments and work with high-level software that allows them to design and run original experiments. Artificial intelligence and cognitive simulation software that is powerful, flexible enough to support original research, and usable by undergraduates can also be run on personal computers (e.g., Anderson, 1993; McClelland and Rumelhart, 1986).

Third, students can study reasoning, critical thinking and the scientific method in a context where normative conceptions of rationality are compared with empirical research on human thought. This naturalistic approach to epistemology allows the student to see the motivation for normative conceptions and to learn to recognize situations in which biases and heuristics in everyday thinking lead to sub-optimal conclusions. Recent research suggests that it is possible to train people to apply abstract rules of reasoning more successfully in varying real situations (Nisbett, l993), and this research is finding its way into curricular materials on critical thinking (e.g., Halpern, 1995a, 1995b). A more naturalistic epistemology can also provide a realistic appreciation of the special strengths of scientific reasoning to students who have lost, or perhaps never possessed, an uncritical faith in science (Giere, 1988; Thagard, 1988).

Fourth, cognitive science is an excellent field for attracting students into an encounter with formal mathematical intellectual disciplines. Within the context of attractive questions about the mind and brain, the student can encounter such disciplines as experimental design and statistics, probability and decision theory, formal logic, the theory of algorithms, and the theory of dynamical systems. Students who become fascinated with artificial neural networks as freshmen, for example, discover that they must take calculus and linear algebra to pursue their interest further.

Finally, cognitive science is being applied in important areas of public policy and technology. Cognitive scientists are pursuing issues in human-computer interaction, workplace organization, reading remediation, mathematics education, cognition and aging, and the reliability of traumatic memories, among many others. Increasingly, some familiarity with cognitive science will be a condition for informed citizenship.

Not all courses in the cognitive sciences have all of the characteristics mentioned. The range of courses that possess at least some of them is fairly broad, including courses in cognitive science, courses in constituent disciplines of cognitive science such as psychology or psycholinguistics, courses in overlapping disciplines such as psychology or neuroscience, or special interdisciplinary topics courses such as critical thinking.

Considerable faculty development and research on and development of instructional approaches and materials are also needed to fully realize the potential just sketched.

How knowledge of the cognitive sciences helps prepare students to meet the challenges of the 21st Century

The characteristics of the cognitive sciences discussed above are equally relevant here. The cognitive sciences can engage students in science. They are a context for learning critical thinking and formal quantitative and scientific methods. They are critical to the understanding of many emerging public policy issues.

Students who major or minor in cognitive science tend to have a broad intellectual base and strong analytical and writing skills. Many of them, of course, go on to graduate work in the cognitive sciences, computer science, neuroscience, medicine, or education. There are also anecdotal reports from faculty members involved in cognitive science programs that their students are successful in the job market upon graduation. They have skills in computer programming, research design, data analysis, and writing, and they have knowledge of human cognition that is of value in the rapidly growing information-intensive sectors of the economy.

Research and development in cognitive science instruction

The potential for undergraduate instruction in the cognitive sciences has not been fully realized. The improvement of undergraduate programs in cognitive science and their curricula for majors are addressed in Stillings (1995).

The potential of the cognitive sciences to contribute to scientific and quantitative literacy in non-science majors would be enhanced by targeted support for the development of new instructional approaches and materials. The analysis above suggests three particularly promising areas for funding.

The first area is the development of critical thinking courses that blend the cognitive psychology of reasoning and decision making with training in normatively correct reasoning that is based on recent research in transfer of training and skill decontextualization (see Nora Newcombe's contribution to this workshop). Such courses might blend material in deduction, causal reasoning, experimental design, probability theory (particularly reasoning with conditional probability and Bayes’s theorem), and topics in elementary statistical inference, such as the law of large numbers and statistical regression.

The second area is the development of introductory courses that give students significant hands-on experience with cognitive science research, either by running original experiments or by performing original simulations.

The final area is the development of courses that explore public policy issues that have significant cognitive science content. Such courses could be taught in a way that focused on the learning of transferable critical thinking skills as well as on a particular content area. Such courses also offer many avenues for collaboration between the cognitive sciences and other disciplines. For example, a cognitive scientist, an economist, and a philosopher could jointly develop a course on cost-benefit and risk-benefit analysis.

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Section IV:

Findings from the Focus Groups Conducted During the Review of Undergraduate SME&T Education

The following section presents excerpted portions from the SRI (Stanford Research Institute) report on the Focus Groups conducted by the EHR Advisory Committee on Undergraduate Education (published 24 February 1997). Details on the full text, including the methods and presentation of the analysis, may be obtained by contacting the Division of Undergraduate Education of the National Science Foundation.

Introduction

Overview of the Focus Groups

As part of the year-long review of the condition and needs of undergraduate education in the United States in the areas of science, mathematics, engineering, and technology (SME&T), SRI International, under contract to NSF, conducted a series of 32 focus groups over an eight month period (beginning in November 1995). Six types of stakeholder groups were included, which together represented approximately 200 individuals:

- General employers (SME&T and non-SME&T)
- Teacher employers
- Teacher graduates (SME&T and non-SME&T)
- Current students (SME&T and non-SME&T)
- Recent graduates (SME&T and non-SME&T)
- Parents of current SME&T students.

The focus group methodology was well suited for eliciting the opinions and recommendations of individuals regarding SME&T preparation. The groups were set up so that individuals within constituent groups interacted with others from the same constituent group, and the opinions of all participants in a group related to one particular institution[1]. Groups were replicated to improve the validity of findings. The focus groups were audiotaped, allowing analysts to work directly from transcripts of the sessions.

NSF identified four types of institutions of higher education from which to select participants: two-year community colleges, liberal arts colleges (including one historically Black college or university [HBCU]), comprehensive universities, and research universities. In consultation with NSF staff, two institutions were chosen in each of four regions (the West, Midwest, South, and East).

Highlights of the Meetings

Summarized below are focus group findings that cut across the six constituent groups. The findings are grouped into two categories: (1) aspects of SME&T preparation that participants generally viewed as strong, and (2) aspects of SME&T preparation that most participants thought should be changed or improved.

[1] The Boston employer group was organized differently than the other groups in the study. Employers in that group recruited from a broad range of colleges and universities in the Boston area, rather than one specific college or university (as was the case in the other employer groups). Quotes taken from Boston group participants are identified as “northeastern college/university,” since multiple types of institutions were represented.

Strong Aspects of SME&T Preparation

- *General Quality of SME&T Preparation* **–** Undergraduate programs generally do a good job of preparing SME&T majors. Employers are satisfied with the depth of SME&T programs but generally favor more breadth. In general, most SME&T students feel confident that they will do well when they transfer to the next level, whether to a four-year institution, graduate school, or the workplace. Recent SME&T graduates were very pleased with the quality of the SME&T education they had received. One of the most valuable aspects of a SME&T education is that it teaches students problem-solving skills that are highly valued by employers.
- *Quality of SME&T Instruction* **–** Students and recent graduates from two-year, comprehensive, and liberal arts institutions were more positive than those from research universities regarding the quality of undergraduate instruction. Students enrolled in these non-research institutions saw their instructors as more caring and motivated to teach, and as more accessible and willing to provide help outside of class. Students from Historically Black Institutions were the most positive with respect to the quality of instruction they received.
- *Introductory versus Advanced SME&T Courses* **–** Students found the pedagogy and content of advanced SME&T courses (including laboratory work) to be stimulating and to reinforce prior learning in the area. These courses had a strong conceptual emphasis and smaller class sizes, and they promoted more interactions between students and between students and the instructor. In general, students recommended this approach to be used whenever possible in introductory courses. Students felt that the best introductory courses struck a good balance between facts and concepts, and provided a meaningful context for learning the material.
- *Access to SME&T Preparation* **–** Women and underrepresented minority students reported good access to SME&T programs. On the other hand, women and minorities continue to face barriers in pursuing SME&T careers.
- *Work Experience* **–** Students and employers were very supportive of work experience. Recent graduates felt that work experience facilitated transition to the world of work because it helped them to better understand their SME&T course work and better define their interests, and it provided a reality check on their expectations. Employers valued work experience because it gave them a chance to "try out" employees before formally hiring them. However, students acquire this experience infrequently.

Aspects of SME&T Preparation That Should Be Improved

- *SME&T Introductory Courses* **–** More than any other aspect of SME&T, students targeted SME&T introductory courses as being in need of improvement. They found that such courses often were not geared to their individual ability level, were boring and difficult to follow because of the large lecture format, and were taught by instructors who seemed to care little about the subject matter or student learning. They recommended that introductory courses be taught more like advanced SME&T courses, which they generally valued highly.
- *SME&T Laboratory Sections* **–** The relationship between the lecture portion of courses and supporting laboratory work is weak. Additionally, some students found laboratory experiences to be mechanical, with little connection between tasks and scientific concepts, and they found little support from faculty or teaching assistants while in the lab setting.
- *Experience of Non-majors* **–** Many non-science majors with an initial interest in SME&T drop out (or are "screened out") of undergraduate SME&T courses because of the large lecture format

typical of introductory SME&T courses. Early negative experience with SME&T courses is a major barrier to pursuing further studies.

- *Teacher Preparation* **–** Because of the current design of undergraduate SME&T courses, many new K-12 teachers enter school systems under-prepared to teach science and mathematics, and therefore lack the confidence and ability to engage their students in understanding scientific and mathematical concepts. Faculty often actively discourages SME&T majors from becoming K-12 teachers, seriously interfering with the recruiting efforts of teacher preparation programs.
- *Workplace Readiness* **–** SME&T graduates enter the workforce ill prepared to solve real problems and to apply the interpersonal skills most desired by employers. Employers put a premium on students with technical competence who also have social skills, a broad knowledge of different subjects, skills in synthesizing and communicating information, and the ability to work as part of a team. Many SME&T graduates lack these critical characteristics.
- *Partnerships* **–** Linkages among institutions and with industry are poor. For example, many teacher preparation programs do not work with K-12 systems, and there are too few examples of strong university-industry partnerships. Further, interdisciplinary collaboration within institutions is limited.
- *Technology* **–** Access to technology varies greatly across campuses. The fact that, in general, non-research institutions have much more limited access to current technology was a major concern for students. There was also general agreement that many instructors are "behind the times" when it comes to their knowledge and application of technology.

Summary of Employer Focus Groups

Together, the employer focus groups included 35 employers: 23 participants represented SME&T employers, and 12 participants represented non-SME&T employers. The majority of participants was in the human resources departments of their companies and had responsibility for recruiting from college campuses. Participants from small or start-up firms were often the owners or CEOs of their firms.

Summarized below are their opinions about the skills and attributes desired in recent graduates, diversity issues considered by employers, quality of SME&T preparation, and the need for industry/higher education collaboration.

Skills and Attributes Needed by Employers

The focus groups generated especially rich data with respect to what employers look for in new employees. We organized their input into five clusters:

- Interpersonal skills and teaming
- Proactive approach to work
- Technical competence
- Experience in the workplace
- Basic skills.

Employers participating in focus groups repeatedly mentioned these five clusters of skills and attributes. The initial focus group findings were summarized and presented to the *final* group (the Boston group). Participants in that group were asked to rate individual skills/attributes on a five-point scale, from 1, "factor not considered at all in recruitment/hiring," to 5, "upper-most factor considered." All of the individual skills/attributes were rated 3 ("moderate consideration") or higher. The ratings from the Boston group were used to order the discussion of the clusters, beginning with those rated as most important.

Participants were especially eager to share their views, opinions, and experiences with respect to characteristics of "successful" and "unsuccessful" employees. Much of what they had to say focused on particular skills or attributes within the clusters. However, the following two quotes, the first provided by a SME&T employer who recruited SME&T graduates primarily from a research university and the second offered by a non-SME&T employer who focused her recruitment on a two-year college in the same region, provide a flavor of the desired "mix" of employee characteristics:

> *Sherry, regarding a research university*: "We go in looking for students that are above average, with some basic qualifications, but then what we're really searching for is someone who has those basic qualifications and then has the communication skills, some kind of relevant technical experience, and has leadership skills and can really communicate ... They're screened out initially based on their technical experience, their grade point average, and technical ability... the two things that draw the line would be their communication skills or the fact that they don't have experience. They don't have internships."

> *Wendy, regarding a two-year college*: "The ideal candidate for us, at least for the training position, would have at least an associate's degree … What I look for most of all is the personality and the oral and interpersonal skills. Do they express themselves well? Do they have energy; do I see a spark upon that person's eyes? Are they vibrant? Are they well spoken? Are they dressed

> appropriately ... Major doesn't really matter. We'll have majors in history, psychology, sociology, engineering, technical, and computer, because if they are interested in going to college, we see some interest in higher education, which we prefer. There's some ethic there in studies and some belief in getting some kind of course work completed, and the effort of going to school is a plus for us, regardless of the degree."

Interpersonal Skills and Teaming

The attributes included in this cluster were interpersonal skills, or "people skills," and the ability to work as a productive member of a team.

Interpersonal skills, or "people skills." Participants could not say enough about the importance of interpersonal skills (e.g., "human relations skills," "knowing how to deal with people," "getting along with others") in the workplace. Given a choice of technical skills or interpersonal skills, employers invariably said they would opt for interpersonal skills. Employees who lacked interpersonal skills either did not last long in an organization or presented problems to their managers, who had to spend an inordinate amount of time working with them to develop such skills. Many employers voiced the concern that interpersonal skills cannot be "taught," as other skills can, and doubted whether colleges or universities could do anything to promote their development.

Ability to work as part of a team. Being a successful team member depends on strong interpersonal skills. In the workplace of today, teamwork is the norm. As one employer pointed out, "The R&D function has traditionally always been teamwork." Recruiters are so sensitive to this issue that they probe for it in screening interviewees.

Although the above quote was taken from an employer of an international high-tech firm, the concept of teaming applies to non-SME&T employers as well:

> *Johnnie, regarding an historically black liberal arts college.* "… what is important in this instance is how well you can interact in a team environment, because I don't care what your scenario is, you have got to be a team player – and you are not going to find that out until you actually get somebody in the job and see how they react in an adverse situation."

Several employers had ideas of what colleges/universities could do to promote this skill:

- Emulate the MBA model of team assignments.
- Designate that project work be done in teams.
- Use cooperative learning techniques in instruction.
- Do group performance assessment.

Such activities teach students about sharing the workload and depending on others for results.

Proactive Approach to Work

Prospective employees or new employees who demonstrated a proactive approach to work were highly attractive to employers because, according to participants, this type of individual tends to have good problem-solving skills, takes initiative, is capable of independent and self-motivated learning, and has leadership skills – all characteristics that relate to success in the workplace.

Ability to solve problems. Unfortunately, employers noted that they encounter many graduates, even from top-notch schools, who do not demonstrate good problem-solving skills. One employer said, “I think a lot of people don’t know how to attack a problem.” They related this deficit to the concomitant lack of critical-thinking skills they see in SME&T graduates.

One employer noted a particular school in the area that required seniors to do outside projects. Students were required “to go out and ask for help – talk to people, get answers – and that is a skill in itself. And when you interview: ‘Tell me what your senior project is.’” He said that in interviewing candidates about their senior projects, it was interesting what valuable information he could pick up about their problem-solving skills.

Initiative. Taking initiativeseems to go hand in hand with problem-solving capabilities. Employers put a high value on employees who can analyze situations and take steps to address a problem on their own.

Another employer, one who recruited from two-year colleges, said that she can tell from the interview process whether candidates have initiative and hence will be successful in her firm: “It really starts in the interview process. You can see it. They have the ability to inject themselves into the company, and they can articulate. ‘Okay, here is how I see myself contributing to the company.’ ‘Here is what I can do.’”

Independent and self-motivated learning. Employers stressed the importance of employees’ taking responsibility to learn what they need to know on their own because their academic preparation often does not prepare them for what they eventually do for a living. Technology and the needs of the workplace change so rapidly that no one, no matter how up-to-date he or she may be at graduation, can afford not to continue to learn and adapt as situations demand.

Leadership skills. Leaders must be able to solve problems, take initiative in their workplace, and seek out information that will help them make sound business decisions. Technically prepared graduates are particularly vulnerable, probably because their training is narrowly focused on specific SME&T skills. Some firms have addressed this issue with internal management training.

Technical Competence

When discussing “technical competence,” employers talked about specific technical skills related to programming, hardware or software applications, academic course work (major concentration or field of study), and (to a lesser extent) GPA. Although employers valued technical competence, many took it for granted that by the time candidates were undergoing the interview process, their technical competence had been established. Several employers said that technical competence was relatively not as important as the capacity to learn, because in-house training would supplement whatever technical skills were lacking.

Specific technical skills. Technical skills desired by employers varied according to their industry segment. The SME&T skills discussed by our employers ranged from the highly technical to general. As indicated by these two excerpts, one from a high-tech employer who recruits from the best technical research universities and one from a scientific staffing firm that seeks two-year graduates for entry-level positions in technology firms.

Academic Course Work. Many employers, especially large, high-tech firms, look at the number of graduates in particular technical fields (e.g., computer science, electrical engineering, mechanical engineering) as a guide to focusing their recruitment resources. Although academic course work is clearly a factor that is considered seriously by employers, one informed participant suggested that it may not be as important today as it was just a short while ago:

> *Dennis, regarding a research university*: "You know what is going on right now in Silicon Valley is that it doesn't matter what they graduate in. The companies are dying for people to do certain types of software, and they will just take anything technical and say, 'Come on in and we will figure out how to get you to be productive.' So, that is a big message that schools need to hear right now, and I do not know how long this is going to last."

Importance of GPA. Several employers said that they still relied on GPA as the first screen in weeding out candidates. But many others, SME&T and non-SME&T alike said that their firms are trying to get away from depending so heavily on GPA and cited shortcomings of that approach.

Experience in the Workplace

Judging from the sheer volume of discussion around particular topics, job experience would appear to be the most salient factor to employers. However, the quantitative ratings from the Boston group showed that it was perceived by employers as somewhat less important than interpersonal skills, having a proactive approach, and technical competence. Employers discussed three related characteristics with respect to work experience: specific job-related experience, understanding the work environment, and the ability to apply academic preparation to the workplace.

Specific job-related experience. Students often picked up job-related experience via internships, coops, work-study, and prior employment. The fact that there did not appear to be standardized definitions of "internships" or "coops," even within schools, was confusing to employers as they discussed the various work experiences they were familiar with. But, no matter what the specific structure of job-related experience, all employers agreed that it enhanced a candidate's chances of being hired and being successful on the job. Job experience helps the candidate really find out what his/her interests are; it provides "cultural exposure"; it helps students understand the work environment; it helps them have realistic expectations about work; it helps students "grow up"; and "it gives them confidence."

Understanding the work environment. Job experience is particularly useful in exposing students to the culture and norms of the workplace environment. Norms and expectations vary from company to company, but there are certain basic "rules" that most employers expect, such as taking direction from supervisors, acting in a professional manner, showing up for work at the correct time, dressing appropriately for work, etc. Employers noted that unsuccessful new employees often did not "pick up on" the informal (often unspoken) rules of the workplace. Coops and internships give students firsthand experience in the work environment, which helps them transition more smoothly from college life to the working world.

Ability to apply training to workplace. There is no substitute for actual job experience in helping students to apply what they have learned to the workplace. A good coop or internship will show them the applied side of the theory they learned in their course work. One employer said that she gets consistent feedback from managers that undergraduates "lack the ability to look at the problem and create the appropriate application from all their theoretical knowledge."

Basic Skills

When employers referred to "basic skills," they included oral and written communication skills, reading, simple mathematics skills, and rudimentary computer skills. Many employers that recruit from comprehensive and research universities assume that, with the exception of communication skills, candidates possess such basic skills. Basic skills seemed to be more of an issue for employers who recruit from two-year colleges. Communication skills include oral and written communication, public speaking, and listening skills.

Other employers mentioned the necessity of basic math skills and basic computer skills, as the following quotes illustrate:

> *Cathy, regarding a comprehensive college*: "I think math [is important] – I mean being able to do the metric math, especially in the medical fields, if you can't do the metric math you are going to kill somebody – bottom line!"
>
> *Dennis, regarding a research university*: "Oh, I think math is essential! I think – I mean, employers today are looking for people who can do the basics, and...you would like to assume that people coming out of college could do that. So, math and speaking ability and listening ability are very important."
>
> *Cecil, regarding a historically black liberal arts college*: "Everyone is going to need to know something about computers. ... learn a software program. Learn [a leading word processing system] or *anything.*"

Diversity Issues Considered by Employers

Many of the employers in the focus groups noted that they considered diversity when recruiting graduates. Some employers focused their recruitment on colleges and universities with relatively high proportions of minority students and females, especially in the technical fields. Other employers were more proactive in looking for underrepresented graduates and had put in place collaborative programs with particular colleges/universities to ensure diversity in their hiring. Other employers were not as concerned about bringing in underrepresented candidates, but they had programs in place to support them once they were hired.

Several employers discussed issues that they ran up against in their efforts to recruit a diverse workforce. One problem was obtaining the appropriate legal clearance to use foreign-born graduates at the bachelor's level because, compared with those who had advanced degrees, it was harder to make an argument that there were no available U.S. citizens with the required skill set. Another problem employers ran into related to poor English-speaking ability among foreign-born graduates and the lack of other essential workplace skills.

Quality of SME&T Preparation

In general, employers were satisfied with the technical preparation of graduates of liberal arts colleges, comprehensive colleges, and research universities. They were less satisfied with the job readiness of candidates and noted that they often lacked good communication skills. Employers who dealt with two-year colleges had mixed opinions about the technical skills of graduates; some thought they were adequate, while others did not. Many had serious complaints regarding these students' readiness for employment.

Depth versus breadth of SME&T preparation. Employers at all levels generally favored breadth over depth, but they were sensitive to the fact that breadth often meant limiting technical competence in a specific area. Employers recognized the advantages of a liberal arts education that naturally included more breadth.

Current Technology. With respect to the status of technology at the undergraduate level, most employers felt that it was not up-to-date (especially at two-year colleges) but that this did not represent a critical problem for them. They expected to have to train graduates in whatever technology they used. As long as the student had some interest and understanding of technology, they were not concerned. At the rate that technology is changing, they felt that it was unrealistic to expect colleges and universities to keep pace.

Need for Collaboration between Higher Education and Industry

Employers were in agreement that higher-education/industry collaboration was needed and that an active role on the part of employers was appropriate. Two aspects of collaboration were addressed in the focus groups: work opportunities for students and higher-education/industry partnerships.

Coops, Internships, Summer Work Opportunities. As mentioned earlier, work opportunities take a variety of forms and vary from company to company and from university to university. Employers concurred that work opportunities of any type had benefits, not just for students (see work experience section above) but for employers also. A principal benefit was cost savings in the hiring process. Work experiences gave employers a chance to try out students as potential employees and lowered the risk that the new employee would leave or be asked to leave after a short time because of misperceptions about the nature of the job. As noted above, one employer said that her high-tech firm uses the coop program as a feeder program and subsequently hires half or more of coop students. Employers pointed out that there were costs associated with sponsoring work opportunities in terms of additional time and effort on the part of employers.

Higher-Education/Industry Partnerships

All employers who participated in the focus groups recognized the value of building stronger higher-education/industry partnerships and the value of more frequent communication between the sectors. Among the many advantages of partnerships, the following were brought up most frequently:

- keeping the university in touch with industry and in touch with the workforce;
- keeping universities technology focused;
- providing more opportunities for students in terms of donated state-of-the-art instruments and computers; and
- facilitating work opportunities for students.

Several of the participants in our employer groups had direct experience working with university staff and faculty. Some arranged for equipment to be donated. A recruiter who sought out underrepresented students worked with heads of departments at Historically Black Institutions and gave them continuing feedback regarding how they need to strengthen the preparation of their students. Another employer was on an academic advisory board at the local university that included both people from academia and industry. Their charge was to outline needs for new course work, lab work, and internships. This individual noted, "You know, it takes time and resources to go out and make those connections, do the networking, set up the liaisons and arrangements and working relationships." Another participant was a member of a panel of employers that talked to classes of graduating seniors about their organizations and career opportunities. Other participants took the initiative in contacting universities and volunteered to give talks to classes and various student groups. One participant invites students and faculty to come to the company and have lunch with employees who were graduates of the same school and talk about their experiences with the company. They follow the lunch with a tour of the company.

Summary of Teacher Preparation Focus Groups

Forty-four participants were included in the eight teacher preparation focus groups (three were teacher employer groups, and five were recent teacher graduate groups). Participants in the teacher employer groups included district administrators (e.g., an assistant superintendent for human resources, a curriculum director, a director of human resources) and school principals; participants in the teacher groups were mainly elementary and high school teachers, with lower representation of preschool and middle school teachers.

This section summarizes participants' input related to the supply and demand for K-12 SME&T teachers, attributes/skills sought by K-12 employers, and teacher preparation.

SME&T Teacher Supply and Demand

K-12 employers noted a critical shortage of SME&T teachers, particularly in the physical sciences at the middle and high school levels. As one Western administrator who recruits from a research university said, "There simply is a higher demand for physical science, chemistry, and physics than there is a supply." Employers of K-12 teachers were frustrated with this situation, also noting that there is a pool of potential SME&T teachers in industry that cannot be used because of credential requirements.

These administrators recognized that the shortage of SME&T teachers is in some part due to the fact that promising SME&T students, particularly minorities and females, are discouraged from pursuing teaching careers by well-intended SME&T faculty. Not surprisingly, administrators bemoaned the shortage of female and minority SME&T teachers who could serve as role models for future female and/or minority scientists, mathematicians, and engineers. One participant remarked that talented individuals from underrepresented groups "just have a lot of other options now." Participants also stressed the need for male SME&T teachers.

From the students' perspective, money is also an issue, in terms of both the additional cost of a two-year master's program (required to teach at the secondary level in some states), which keeps them out of the workforce, and teachers' relatively low salaries compared with those in industry.

In keeping with the current trend of high attrition in the first five years of teaching, some of the recent teacher graduates we spoke with said that they did not plan to remain in teaching for long. They cited the low pay and the lack of resources and supplies. Despite their frustrations, nearly all expressed an attitude of "loving teaching."

Administrators also discussed the problem of high attrition of beginning teachers. One pointed out that the common practice of giving new teachers the most difficult assignments (e.g., remedial classes, heavy course loads, extracurricular duties) is one thing the profession could change to limit attrition.

Skills and Attributes Needed by Teacher Employers

K-12 teacher employers articulated a wide range of attributes and skills they look for in hiring new teachers for SME&T teaching assignments. This summary first addresses characteristics specifically related to SME&T and then covers characteristics desired for all types of teachers, including those who teach SME&T subjects.

Attributes/Skills Specific to SME&T Teachers

School administrators sought teachers who had a strong grasp of SME&T content, both in depth and in breadth. When asked to describe attributes and skills of ideal science and mathematics teachers, they stressed the importance of a solid academic background in math and science, as indicated by grades and the number of SME&T courses on the applicant's transcript. Elementary teachers were viewed as far more deficient in SME&T areas than were high school teachers.

The issue of depth versus breadth was seen as particularly relevant at the high school level. Single-subject majors with a rich background in a particular SME&T field generally do very well teaching in their field of specialization, according to participants, but are often out of their element when required to teach out of field (which many are). The importance of breadth is illustrated in the following comment by a biology major with a master's degree in education:

> *Beth, teacher, about her student experiences in a research university*: "I think the area I wasn't prepared for was earth science. In biology, I'm perfectly fine, but when I started teaching environmental science, I hadn't had a geology course or an earth science course since high school. And, yet I had to teach this stuff; so right before I have to teach it, I have to learn it. And that's where I did not have a very strong confidence level. Because I have to learn this stuff and then I have to turn around and teach it! I definitely think I was not prepared to teach that course at all."

On the other hand, participants felt that depth is still critical for top-notch teaching in a subject area. A teacher with a physics major and master's degrees in both mathematics and education had this to offer:

> *Lawrence, teacher, about his student experiences in a research university*: "Obviously, you want as much depth as possible in the subject you're going to teach, because you start seeing new connections that way and you start saying, 'Well, oh, I see what this thing is good for.'… I know in my own teaching of the kids, seniors who are going to be college students next year, if you cover something superficially, their ideas that they come out with are mush. So trying to get that breadth really doesn't work unless you go into some detail that sort of solidifies it in their mind or links it to something. Otherwise, it's just—you might as well not teach it at all."

Despite the fact that a solid background in SME&T was viewed as extremely important by K-12 teacher employers and teacher graduates alike, other skills and attributes were seen as just as important, if not more important. This finding parallels that of the general employer group, that technical skills are important, but relatively less so than interpersonal skills.

General Teacher Attributes/Skills

K-12 employers discussed many different skills and personality characteristics as desirable in a teacher candidate. Those discussed most often were:

- Ability to relate to students
- innovative teaching
- classroom management skills
- technology skills
- willingness to learn
- ability to apply knowledge/skills in the classroom
- communication skills.

Ability to relate to students. In the educational context, being able to relate to people means relating to students – a wide diversity of students – and to their parents. This was the most frequently discussed "desired attribute" across the K-12 teacher employer groups and prompted many participants to speak up in favor of teacher preparation programs that introduce prospective teachers to the classroom as early as their freshman year, to ensure that they have adequate exposure to children and to what school settings are like today. K-12 teacher employers recognized the value of experience working with children from urban as well as suburban settings, being familiar with cultural factors that could influence teaching and learning styles, and feeling comfortable in school settings that include highly diverse student populations.

Innovative teaching. K-12 teacher employers were interested in teachers who were prepared to teach in innovative ways, such as using hands-on experiences in instruction, differentiating instruction to fit the diverse needs of learners, teaching and encouraging critical thinking, and using an interdisciplinary approach.

Classroom management skills. K-12 teacher employers pointed out that new teacher graduates are generally unprepared in classroom management.

K-12 teacher employers blamed teacher preparation programs for not addressing classroom management more directly. As a middle school principal put it, "I will say unequivocally, education courses do a miserable job in behavior management for teachers." This issue is addressed further in the section below on teacher preparation programs.

Technology skills. For the most part, K-12 teacher employers felt comfortable with new teachers' technology skills and ability to integrate technology into instruction. With very few exceptions, the teacher graduates we spoke with felt well prepared in technology and ways to integrate technology in instruction, but they noted that they were generally the exceptions in their schools. Many experienced teachers apparently either do not use technology at all, or use it for classroom management tasks, such as keeping track of students' grades.

One of the participants graduated from a master's program that specialized in educational technology. She noted that she was considered an expert in her own school, where she now teaches high school biology and math. She said: "I think not only is it being comfortable with computers, but it's having a certain attitude that you're not afraid to not know everything, because the students know more than you do. The students know more about computers than I do, than I think probably all of us." Technology changes teachers' roles in a number of ways – they have less traditional "control" of the classroom, they act in the role of facilitator more than information provider, and they must often defer to students' more advanced technological skills.

One administrator pointed out the importance of not only being "technology literate" but being familiar with a range of technology and software, including the use of multimedia technology.

Willingness to learn. Given that students, schools, theories of learning, teaching strategies, and technology are rapidly changing, administrators looked for evidence that teacher candidates would be willing to learn and have the flexibility to respond to ever-changing situations and demands.

Ability to apply knowledge/skills in the classroom. K-12 teacher employers, particularly for SME&T teachers noted this as a problem.

Communication skills. K-12 teacher employers agreed with SME&T and non-SME&T employers that communication skills were critical for the teaching profession. Administrators and principals frequently use teacher applicants' résumés to evaluate their writing skills and the job interview to gauge their communication skills. The following story is a sad testimonial on the lack of good communication skills among some teacher candidates:

> *Rick, administrator, regarding an historically black liberal arts college*: "[Here is] one of the things that bothered me this past summer when I needed a teacher: I went to the personnel file and checked the references of persons, and...then I went to the personnel file and pulled out the applications and I ... read over the applications. I was extremely disappointed because the [written responses to] questions ... – the manner in which they expressed themselves – ..., the written communication skills – were very disappointing, and I said to myself, how could that person have received a degree and not know how important the application was ... . And I was very disappointed, because I wanted to hire those persons."

Quality of Teacher Preparation

Inputs regarding the preparation of preservice teachers are organized in four sections: preservice training, student teaching, beginning teacher support, and higher-education/K-12 collaboration. This organization flowed naturally from participants' comments.

Preservice Training

K-12 teacher employers felt that preservice teachers are generally being adequately prepared in the SME&T content areas but not adequately prepared for what they face in the classroom. Recent graduates, too, generally felt well prepared, with the exception of those single-subject teachers who were required to teach out-of-field at the high school level.

The key shortcoming of teacher preparation programs from the perspective of both K-12 employers and teacher graduates was that they do not give preservice teachers practical skills to apply to classroom teaching. Participants suggested that teacher preparation programs should focus more on application in the classroom – relating subject matter content to teaching, and focusing more on teaching methods than educational theory.

With respect to general teaching methods, classroom management was singled out as an area in particular need of an applied approach. An elementary school principal recommended that preservice teachers should have "more experience with classroom management techniques and not just from a textbook ... Because it is real different, and ... new teachers have said that when they get in the classroom, things that they thought would work, often do not. They need experiences with children to know what works and how to manage a classroom."

Participants recommended that teacher preparation programs put more emphasis on dealing with diversity in the classroom and on urban school issues.

Student Teaching

Recent teacher graduates' student teaching experiences varied from very useful to horrific! The two excerpts below illustrate the range of the continuum from positive to negative.

> *Stacy, teacher, regarding teaching experiences in a comprehensive college program*: "Well, I had a really good [student teaching experience]. I had the [sixth grade] math teacher, and she had

her room set up into groups. She had great kids. It was great! She wrote me notes all of the time. We had a ... journal book where we would write notes back and forth to each other. We would sit down during planning time, and she would always check and see what I wanted to do and what I was doing and stuff like that. The kids were very well behaved. I had a great experience, and my supervisor was also real supportive and really good, and they actually hooked up, and they got along real well, so it was kind of like a threesome and everything just tied in. I wish I had them still!"

Jerry, teacher, regarding teaching experiences in the same comprehensive college program:
"My cooperating teacher was, at the time, 4 or 5 years from retirement, and he gave me classes two days. The third day I was there, he gave me all of his classes and he would sit in the back of the room and start snoring.... I am the student teacher trying to explain balancing equations and I hear this snoring. He would write me up for something when he wasn't even there and I did it, or when he was asleep, so it was interesting. I wanted to get somebody who could do cooperative learning, and he says he does cooperative learning, but it is more: 'Here is the book, here is the thing; now you guys go and teach yourself how to do it,' instead of a designed kind of thing. In middle school, you can either do cooperative learning well or really bad. It is very little in the middle, and I was very interested in that. I could do what I wanted; it was a lot of work and it turned out well; it's just that I received very little feedback. I latched on to another teacher who was there who seemed interested, and she helped me a lot."

As indicated in the excerpts above, the value of the student teaching experience is related to the quality of involvement and feedback on the part of the cooperating (or master) teacher. The match between the teaching methods the student is learning (and wants to practice) and the way the cooperating teacher teaches, and the extent to which university supervision is integrated and consistent with input from the cooperating teacher. Some administrators felt that universities did not make enough effort to place their students with good cooperating teachers.

Two other factors were discussed as integral to the value of the student teaching experience: the amount of time spent student teaching and the diversity of placements. Both recent teacher graduates and K-12 teacher employers discussed the need for longer student teaching experiences. Preservice teachers need time to put into practice what they have been taught.

The participating administrators believed that not only should preservice teachers spend more time student teaching, but also they should be exposed to children and schools much earlier in their programs. They noted that this would not necessarily mean student teaching; it could be time spent observing classrooms and being around children, perhaps in the context of one-on-one projects with children. Administrators generally supported the move toward five-year programs because they give students the opportunities to student teach for a full year. From their point of view, students with more student teaching experience "tended to be stronger." Commenting on a program that put students in the classroom for two years (first observing, then teaching), an administrator noted: "The difference in their ability to go in and take over a classroom is remarkable."

The second factor that affected the value of student teaching was the diversity of placements. Students who had had two different placements valued both their experiences. As noted in the above section, exposing student teachers to students from diverse backgrounds makes them more attractive new hires. An elementary school principal stressed the value of having students placed in both an inner-city school and a suburban school.

Beginning Teacher Support

Teacher graduates' descriptions of their first day of teaching would make good material for a new sitcom. Nearly all of our participants had not only a bad first day, but also a very difficult first year of teaching. These new teachers' experiences were typical:

> *Stacy, teacher, and graduate of a historically black liberal arts college*: "And in this particular classroom the students were wild, I mean, they were *wild*, because so many substitute teachers were in and out. I started right after winter break in January. I didn't have anything prepared, of course. My room was not decorated, and I was not happy about that, and because the kids were not in a stable [environment] they were behind their work, so I was hysterical. I do agree with her [another participant's horror story]. I feel like I got a very good education here at [name of program], and I really feel they prepared us for the classroom. However, once you walk into the classroom, it's a totally different ball game."

> *Jerry, teacher, graduate of a comprehensive college*: "My favorite expression that really helped me relax in my first year of teaching was from the department head who came in – saw I was really worried about something – I don't know what it was – and said, 'Don't worry about it; your first year is a waste anyway. We don't expect you to do anything.' Just learn how to teach during your first year, and in your second year, you better know what you are doing … [another participant interjects: "Survival."] Yes. It's like she just said, 'Hang on and do the best that you can and don't worry about it.' Everyone knows your first year [can be problematic] – you will do great sometimes, and then sometimes you just go flop, and you just get used to it."

K-12 teacher employers pointed out that their districts were aware of the need for beginning teacher support. They described a range of support programs, structured mentor programs that paired beginning teachers with experienced teachers for both instructional and moral support, regular support meetings for new teachers that provided opportunities to share experiences and discuss problems, and new-teacher orientations that gave beginning teachers a "head start" on the school year and an introduction to the school's procedures. The various support programs described received mixed reviews from both teacher graduates and administrators, although the majority of both believed that such support programs were valuable.

Higher-Education/K-12 Collaboration

Throughout discussions of teacher preparation, administrators consistently pointed out the need for more dialogue and sharing between the faculty of teacher preparation programs and K-12 school staff. None of the administrators felt that the current level of interaction between their districts and local teacher preparation programs was adequate. Administrators and teacher graduates also voiced the need for teacher preparation faculty to spend more time in schools.

Summary of Student Focus Groups

Nine student focus groups were conducted at seven different institutions across the country[2]. This section summarizes the perceptions of 69 students with respect to different aspects of their SME&T courses, SME&T laboratories, the value of work experience, and diversity issues in SME&T preparation.

SME&T Courses

Introductory Versus Advanced Courses. Both SME&T and non-SME&T students often targeted introductory SME&T courses as a major barrier. They discussed problems with their difficulty level (too easy or too hard); their traditional lectures format, and disengaged instructors.

Introductory SME&T courses for nonmajors were generally perceived as "watered-down science." As one student put it, "It's frustrating because in high school, even if it was hard, at least it was interesting. Here, it's really easy, but it's really boring." Introductory SME&T courses for majors were viewed as very challenging, often serving to "weed out" less capable and/or less prepared students. Non-SME&T students at a large research institution recognized the need for intermediate-level courses targeted somewhere between these two extremes.

Students from two-year colleges and comprehensive universities brought up problems related to the way introductory SME&T courses were taught to accommodate the wide range of student abilities represented in their diverse student populations.

> *Toby, enrolled in a two-year college*: "I know there's a lot of people in the class; I mean…there's such a mixture of types…from just straight out of high school to those with two or three previous science courses. And I know the instructor is trying to teach [to] the middle or the lower middle, but sometimes it just gets so slow! … I would have the instructors go down to a high school to see what they teach, and then don't teach that again. See their labs at high school, but don't do those labs again."

Attrition rate estimates among potential SME&T students soared at one research university, mainly because of the introductory courses. Students there estimated that at least 80 percent of potential SME&T majors either change their major or decide to leave their course of SME&T study in the first couple of years of school. At one of the two-year institutions, many advanced courses were reported to have a 50 percent dropout rate. Some students believed that the system was designed that way to eliminate some of the SME&T students. They agreed that "you have to be really motivated to stay in a science major."

Both SME&T and non-SME&T students objected to the large lecture format often used in introductory courses. In worst-case scenarios, some of the introductory courses disintegrated into video presentations of material. One introductory chemistry class reportedly had an enrollment of approximately 600 students and was described as a "horrendous experience."

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[2] One of the student groups consisted of chemistry majors who had participated in the Discovery Chemistry Program, an innovative, NSF-funded chemistry program at a northeastern college.

A frequent student perception was that professors did not want to, or had been forced into, teaching introductory SME&T courses. Students imagined certain faculty members saying, "Oh God, I have to go teach this 101 course now."

Students from both comprehensive universities and two-year colleges recognized that part-time instructors taught many of the introductory courses. These instructors are often brought in at the last minute by administrators to fill a course request. Some students were critical of many of these instructors; other students preferred part-time instructors, especially if they were from local firms.

SME&T students frequently praised upper-level classes as wonderful alternatives to the stressful, less personal introductory classes. They found the pedagogy, content, and format of advanced courses to be stimulating and reinforcing. These courses had a strong conceptual emphasis, had smaller class sizes, and promoted more interactions among students and between students and the instructor. In general, students recommended that this approach be used in introductory courses whenever possible.

Older SME&T students in the focus groups often reassured younger students that there would indeed come a day when it all would make sense. In a number of different instances, students told stories in which "light bulbs" went on inside their heads and much of the SME&T material that they had been studying for years really began to make sense.

Quality of Instruction/Assessment

There was consensus among students that the quality of instruction, not the subject matter, usually determined the value of a particular course. In general, students in two-year, comprehensive, and liberal arts institutions had slightly more positive attitudes about the quality of SME&T instruction than did students in research universities.

Students discussed many different skills and attributes as desirable in a teacher, but three characteristics came up in nearly every student focus group. The abilities most sought in a professor (and some examples) were:

- Tailoring instruction to the learner
- Making connections to the real world and other disciplines
- Being accessible and caring

Common complaints about "bad instructors," especially from students in research universities, were that they knew their subject matter but did not know *how* to teach and/or that they were difficult to understand because English was not their first language. Many students, especially those from research institutions, asked for more frequent and varied types of assessment to better determine students' understanding and to help students stay on top of material.

Group work was often a popular element of both SME&T and non-SME&T courses. It tends to work best when responsibility is built in for all involved partners. Otherwise, according to students, group work can disintegrate if each person involved does not have a specific role, or if the method is used too frequently.

Technology/Technical Currency

The state of technology varied widely across campuses. Research universities and one of the liberal arts institutions had good access to the Internet and e-mail. "Chat rooms," a new resource at one research university was very popular among SME&T students, especially as a way of sharing information about courses and instructors. Two students gave their impressions of this new technology:

> *Betty, from a research university*: "We used the computer [connections] ... you can go to a computer anywhere and you can see what the professor talked about in the lecture, and you can post notes; he can post old exams everybody can look at."

> *Sue, from a research university*: "... and you can be sitting there and it's like, oh, there's another student on the program, too. Do you want to talk to them? And you can talk to them. And you can rag on the professor and..."

Other students were excited about new technology being used in their SME&T courses, realizing that exposure to technology would help them in the job market and lack of exposure would hurt them. On the other hand, some computer science majors complained that they would probably be hurt in the job market because they had not learned current programming languages (e.g., C, C++).

Unfortunately, several of the student groups noted that their institutions lacked resources to keep technology up-to-date or to purchase enough hardware or software to serve students adequately.

Competitiveness in SME&T Preparation

Some students said that the structure of SME&T programs and SME&T courses fostered competitiveness among students, especially at the introductory level. They viewed this as a barrier to learning and a negative aspect of the SME&T experience. This competitiveness was most apparent at research universities, where admittance to higher-level SME&T courses was contingent on high grades in introductory courses. Students also felt pressure to compete for limited openings in medical schools and other types of SME&T graduate programs, and noted that SME&T programs tended to be less competitive at the advanced stages.

SME&T Labs

Most students criticized SME&T labs as being mechanical, predictable exercises that lacked meaning or connections to science concepts. They often felt frustrated because there was no instructor or informed TA to answer questions during the labs. Students felt that their creativity was being stifled when they were forced to follow a "cookbook" type of lab.

Students noted that labs improved in their more advanced courses. Aspects they valued in a lab were teamwork, real-world scenarios, freedom in design, and interesting analysis.

> *Nancy, from a comprehensive college*: "But in upper-level courses it is [much better]. … In advanced organic, in the lab, we had certain problems that we had to find solutions for, and we were in groups. Like, one group was the spectroscopy group; one group was the wet chemistry group, so we would have to go and get another group to do certain things if we didn't have the time to do it. ... That is the real world, and that was a phenomenal experience. And then the other lab that I really got a lot out of...was a 6-hour lab, and you decided what you wanted to make, how you wanted to make it. You went in there and you made sure earlier in the week that the chemicals you needed were available, and you synthesized your own reactions and it was good."

One SME&T laboratory program that addresses the problems noted above and promotes student learning in ways generally associated only with advanced SME&T courses is NSF-sponsored *Discovery Chemistry Program*, which was the topic of a special student focus group.

Work Experience

Coops, Internships, or Current Work Experience. All SME&T students recognized the value of work experience such as coops or internships during their schooling. They noted that such experience helped them to better understand their SME&T material/course work and/or helped bridge the technology gap between university and the workplace.

Future Job/Graduate School/Transfer Prospects. Most SME&T students appeared comfortable about their impending job or graduate school search. The two-year students were fairly confident that they could either find work or transfer to four-year institutions. Although they believed that work experience would help with any type of transition, students especially hoped it would facilitate an easier transition to graduate school or the work world.

Diversity Issues in SME&T Preparation

Students at institutions with diverse populations viewed diversity as a positive aspect of their experience. Some minority students reported involvement in minority alliances and targeted programs as helpful. Others were frustrated by their institution's lack of commitment to diversity. Most students acknowledged that women and minorities face more barriers than do men or non-minorities in pursuing SME&T. Students discussed three types of bias: ethnic/racial bias, gender bias, and age-related bias.

Responding to a point made by fellow students that Black students tended to drop out of SME&T programs, a Black female student responded this way:

> *Annabelle, regarding a Midwestern research university*: "It's a mentality and, like I said, a lot of it starts before college. ... I'm still dealing with it – I can't think of an appropriate word for it, but, I mean, as an African-American woman and as a female, I'm always told that, "You're going to get lower scores and you're not as capable as a white male". It's like a self-fulfilling prophecy, if you let it be. I vehemently struggled with my freshman and sophomore year. I remember this summer; I was presenting research at a conference; I was presenting my research ... And, I mean, for the first time, ever, I wasn't the only Black person in the room, and more importantly; I met another Black woman who was brought in there, but she didn't want to talk to me. [Laughter] But I saw her, and it was so shocking. I mean, I went and I called my mother from a pay phone... I mean, when people are coming up to you [at the conference and saying], 'Oh, I'm so impressed. I'm so impressed.' Okay, are you impressed because I'm first author on this? Are you impressed because of my research? Are you impressed because you don't ever see Black women in chemistry? And it's just something that you deal with each and every day."

Students who had chosen to attend an Historically Black Institution generally felt that they had made the right decision, but almost all were ready to move out of the all-Black environment by the end of their schooling.

One woman was angry about the loss of a talented female professor at her institution and felt that it reflected poorly on the program:

> *Paula, regarding a research university*: "As of last spring, one of them [a female professor] left, and the reason was she wanted to spend more time with her kids and they wouldn't let her teach part-time. Now, when they lost her, I lost a lot of respect for that department, a whole lot of respect. Because, you know, they keep trying to encourage us, you know, to get more women into the field, yet... they pull this kind of crap, you know, and it makes me mad."

Other students, mostly those at the two-year colleges and comprehensive universities, accused some SME&T professors of "age bias" (i.e., favoring older students). At these institutions, it is not rare for 18-year-olds to be mixed with reentry students who are sometimes over 50 years of age.

Summary of Recent Graduate Focus Groups

Six focus groups of recent graduates were conducted, which included a diverse mix of 36 individuals who had completed their undergraduate education within the last three years. Recent graduates had much to say about their experiences in SME&T courses as undergraduates, transition to the workplace, the value of SME&T preparation, skills and attributes needed by employers, and diversity issues in SME&T preparation and the workplace.

SME&T Courses

The findings on SME&T courses are divided into four sections: introductory vs. advanced courses, quality of instruction/assessment, technology/technical currency, and competitiveness.

Introductory Versus Advanced Courses. Recent graduates agreed with current students that introductory SME&T courses were problematic. Their main concern centered on the large sizes of these courses, as well as the lecture format. Graduates who had taken SME&T courses with smaller class sizes (i.e., students in two-year colleges, liberal arts colleges, and comprehensive universities) usually had better early SME&T experiences. They did not "have to go through those large, weed-out courses that will kill you," as one graduate put it. To these students, a very important feature of smaller courses was the opportunity to have a more personal relationship with the professor. Two graduates compared the quality of instruction in small versus large classes, in this case—courses at comprehensive colleges versus courses at research universities:

> *Roger, regarding experiences at a comprehensive college*: "... and at [name of larger research university], Physical Chemistry was the weed-out class ... and he [the professor] was having 55 to 60 students in a class, and half of the class was failing and that sort of thing. Here [at the college] we had seven or eight students who were very, very supportive, [and the professor was] holding your hand the whole way through it and she said 'I want you to learn this ...'"

> *Katherine, regarding experiences at a comprehensive college*: "But I think they kept the classes small enough where they could really concentrate on the personal problems, issues, concerns, whatever it might be. That is one thing, whether it be computers or history or economics, whatever it was, the class was never too large where you really got consumed by a bunch of people around you.... It was really personal – a personalized approach, and I think that is what makes this college more successful than, say, a [larger, nearby research institution] in a big lecture hall. With this one, you can go right up to the teacher, and you know where they are."

Like current students, recent graduates also enjoyed their advanced courses more than their introductory courses. Two-year graduates were very pleased with the practical applications provided in much of their second-year course work, and research graduates said that the advanced courses were excellent because they emphasized the understanding of concepts more than memorization of facts. Advanced SME&T courses were described as more intensive, directed, personal, group oriented, challenging, and tailored to the learners.

Graduates of liberal arts colleges noted a special problem pertaining to the availability of advanced SME&T courses. Some graduates of two-year and comprehensive universities also remarked that the availability of certain courses had been a problem during their course of study, especially if a required or prerequisite course was offered every other year. In one extreme instance, a graduate felt that it had cost her dearly:

> *Rhiannon, regarding experiences at a comprehensive college*: "... that was a requirement, not an elective that I had a choice with, and it was actually a prerequisite to other things, which was a problem for me. I graduated a year later than I really had to because they only offered certain courses every other year.

Quality of Instruction/Assessment

Graduates seemed relatively pleased with the quality of instruction they received, even though most of their courses had been lecture based. The types of professors that SME&T graduates valued most were approachable, affable, helpful, familiar with their students' knowledge base, and willing to let them make mistakes in order to learn.

According to recent graduates, students can (and do) play active roles in ensuring that they get top-notch instruction by talking with other students about their experiences with particular instructors. Graduates had complaints about some SME&T instructors who did not seem to care about teaching. Faculty tenure systems were discussed as one reason why professors do not focus more of their time and energy on teaching. Some of the more savvy graduates realized those tenure systems usually reward research over teaching ability. One graduate of a comprehensive institution, where teaching is supposed to be more of a focus, remarked that professors should be treated "like teachers, not publishers."

Recent graduates also complained about foreign-born teachers or teachers who had problems with English. They said SME&T courses were difficult enough without language barriers. Graduates had mixed responses concerning the types of assessment they encountered in their SME&T courses. Some thought they should have had more regular and varied assessments to keep them up-to-date in their studies (as did current students); others thought that it was the responsibility of the student to stay on top of the material.

Technology/Technical Currency

Like current SME&T students, graduates reported that technology often helped them better understand certain concepts in the laboratory. One student said that the lab techniques he had been using at his liberal arts college were so up-to-date that he was using some of them in his current research:

> *Elvis, regarding his experiences at a liberal arts college*: "A lot of the techniques that I used in the labs are the techniques that I use to do the research now."

However, some two-year college and liberal arts college graduates complained that instructors needed to better integrate technology into their classrooms and make more of an effort to keep up with the rapid changes in technology. There was general agreement that many instructors were often "behind the times." Some graduates also complained about a lack of computer hardware at their schools.

Some graduates echoed current students' concerns about not being as marketable because they had not been exposed to the latest computer languages (they mentioned C and C++ specifically). These graduates had completed their schooling a few years ago without learning either language. They considered taking the languages in their spare time away from their jobs, but thought their colleges should have made these languages a requirement for majors. These same graduates also recommended that colleges provide courses on computer hardware with "real-life applications."

Competitiveness

Unlike current students, graduates reported little competitiveness among classmates during their SME&T preparation. It may be that they remember their more recent years of college better, when, according to current students, there tends to be less competition.

Transition to the Workplace

Recent graduates recognized the value of coops or internships in helping them find jobs after graduation, often with the company they worked for during their coop or internship. Graduates also said that work experiences helped them define what it was that they wanted to do. Other students noted the "catch 22" that without any job experience, it was difficult to find a job.

Some graduates did have problems finding jobs. Graduates from comprehensive institutions reported the most difficult time with their transitions and remarked that they did not receive help from their career placement centers or school-sponsored job fairs.

Graduates believed that more industry/higher-education partnerships would help student's transition from school to the workplace. Such partnerships could also potentially enhance the undergraduate experience by bringing employers into the classroom.

Value of SME&T Preparation

In general, recent graduates were quite pleased with the value of the education they had received. Many graduates (especially research university and liberal arts college graduates) agreed that one of the best qualities of a SME&T education is that "it teaches you to think in a certain way." The following comments were in response to a question asking graduates whether they would recommend SME&T study to an incoming student:

> *Christina, regarding a research university*: "As far as the technical area [goes], I'd definitely do it because I think your job prospects are almost unlimited when you have a technical degree, compared to some other nontechnical degrees."

> *Nicole, regarding a research university*: "I also know employers, I think, look at you with more respect if you have that background, because they know it's not an easy program, and they also know, whether or not you realize it, [that] you have that very logical thought process that you use every single day ... It's a very solid background."

> *Keith, regarding a research university*: "– the whole beauty of the SME&T education is being able to learn how to logically solve a problem. The logical pursuit of answers."

> *David, regarding a liberal arts college*: "I consider [it] in more of laying a foundation in your mind – how to think logically and attack problems."

Other graduates believed that the SME&T preparation they had received was valuable despite the fact that "what you really need to know you will learn on the job." They believed that it is critical for graduates to bring basic scientific abilities to the job.

Some graduates noted that there was a "ceiling" on the value of an undergraduate SME&T degree, as these comments by students with engineering degrees indicate:

> *Keith, regarding a research university*: "If you want to live in the United States, you can't really make a very good living as an engineer because businesses don't respect engineers. It's more or less, you get out as an engineer and then you'll make—you'll get raises up to about the $50,000-a-year level and you'll stay there."

> *Christina, regarding a research university*: "When you look at the starting salary for engineers compared to other folks…it's wonderful, but within a couple of years, there really is not that much growth."

Another graduate agreed that technical careers do flatten out and felt that if he wanted to advance, he would have to develop his business skills.

Skills and Attributes Needed by Employers

Recent graduates thought that the following skills were most desired by employers: technical competence in a subject area, writing and communication skills, flexibility (e.g., a willingness to turn to management and other areas for advancement), and business skills. Like employers themselves, graduates repeatedly commented that employers were looking for well-rounded individuals who would fit well into their work climate. Liberal arts graduates felt particularly well prepared in terms of breadth and were satisfied with their choice of undergraduate institution. Graduates of research universities generally did not feel as broadly prepared and faulted their SME&T programs for not giving them much flexibility in selecting courses and for not requiring language arts courses.

One research university graduate disagreed that SME&T preparation should focus on breadth, such as courses in teamwork or communications skills, versus depth in SME&T preparation:

> *Nicole, regarding a research university*: "Employers, I think, need to be careful. You can teach someone in a seminar better speaking skills. You can't send someone to a weeklong seminar in physics. You [the student] are paying a lot of money. We have a great amount of expertise; [I would rather they] teach me the engineering skills. Also, just on a personality level, if someone is extremely introverted, you can send them to three different classes but – guess what? – they are not going to be an inspirational speaker. So, it is good to round yourself out, but I think there are other ways you can do it, rather than spending your tuition dollars in your very short time here in developing those skills."

Most recent graduates agreed that, although it might be good to have a broad/general undergraduate degree, it is better to be prepared in some sort of SME&T specialty, if possible. The liberal arts graduates knew they were at a distinct disadvantage due to the limitations of their course offerings.

Diversity Issues in the Workplace

All recent graduates agreed that women and minorities need more role models in science and that there are far too many obstacles in the way of underrepresented students who want to succeed in SME&T. One young woman's experience demonstrates the persistence of gender bias and the lack of role models in SME&T fields:

> *Nicole, regarding a research university*: "I was in a facilities and services department, comprised predominantly of engineers. The only female role model we had, did very well for herself, she was the director of HR. What I have also seen are some women who are doing very well. Their

> careers are undermined, because their competition is thinking, 'She got the job because she is female, not because she had the same skill set and just beat me out, or she had the same skill set and they were looking at numbers, so she inched me out.'"

She went on to say:

> [When] "you graduate as a female with an engineering degree, entry-level opportunities are there. ... When you get into the working world, senior management is making decisions on your career, and they are older, they don't have exposure to female engineers, and it is a very difficult concept for them … it is a culture change for them …"

Other recent graduates related stories of female SME&T graduates not getting certain jobs or promotions that they deserved. Males, who generally agreed that women had a tougher time of it at work, reported many of these anecdotes. Some of the graduates worked for government subcontractors who were forced to consider diversity in hiring to meet certain quotas. Often, this resulted in overworking the limited number of female employees, who commonly were assigned to multiple projects.

Some underrepresented graduates said that they benefited from both formal and informal mentoring programs sponsored by their employers. Female graduates felt that having a mentor was important for a successful professional life.

Summary of Parent Focus Groups

Composition of Groups

Thirteen parents participated in the focus groups. The parents tended to focus on aspects of college life that were important to them as parents (e.g., safety, living arrangements, and peer support for academic success). For example, when asked to make recommendations about how to improve the quality of the program at her daughter's institution, one parent said:

> *Michael, whose daughter attended a comprehensive college*: "I cannot really tell them how to improve, because I am satisfied and I am not in a position, really, because I was too much removed from her experience here to really honestly answer that question – except more parking, parking, parking!"

Parents were also less informed than other focus group participants regarding the quality of SME&T education. Thus, the number of parent groups was reduced from the planned number, and the number of other groups increased to maximize the cost-effectiveness of the study.

Quality of SME&T Preparation

With just a few exceptions, most parents were very pleased with the quality of the general preparation their sons and daughters received at the undergraduate level. However, they had little to say about SME&T preparation specifically. Their impressions of quality were based primarily on the reputation of the institution as a whole. Parents could offer very little feedback with respect to whether an institution's technology was up-to-date. When asked about quality, parents had this to say:

> *Dawn and James, regarding a research university*: "So far, I think [the quality of education] is good. We have had other relatives who've gone here before, so, based on that we're seeing quality that has lasted over 20 years. My brother went here, and he's now a physician and he's doing quite well."

> *Carlette, regarding a research university*: [Name of school] "Engineering has an excellent record, good reputations of different professors. At my daughter's graduation speech (she was salutatorian), a couple of faculty came up to her and said 'That's a top program over there at [Name of school].'"

> *Laura, regarding a research university*: "People will ask where my son went to school, and I will say he goes to [name of school], the cash signs go into their eyes. I keep telling my son that if you walk out of the [name of school] campus with a degree in engineering, you are going to be making such and such. The outside world is telling them, if you get a degree from [name of school], you are going to make mega bucks!

Transitions

Unlike other groups, parents tended to discuss "transitions" in terms of the move from high school to higher education, rather than the move from higher education to employment. In the former case, they expressed a general concern (not focused on SME&T) that colleges should do more to facilitate the transition from high school to college (e.g., special summer programs to teach “survival skills” to underrepresented entering freshmen).

> *Nancy, regarding a comprehensive college*: [With respect to transition from high school to college] “It is a form of orientation, but it is more of a career orientation … It helps you decide where you are going and what you are doing and why you are doing it. Everyone is required to take it.”

Parents in both groups strongly supported work experience opportunities because they believed that SME&T education should be linked to the application of knowledge (this was their one criticism of SME&T preparation). They also felt that work experience increased their students’ chances of finding a job and being successful in the work environment.

Section V:

Background Data and Information Influencing the Conclusions and Recommendations of *Shaping the Future*

by Staff of the Division of Undergraduate Education

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Numerous changes of some significance have occurred, since 1980, in the fabric of influences affecting higher education. The cumulative impact of these changes has important implications for undergraduate education. Attention has been focused on entering students, mission priorities, faculty practices, technology, and needed skills.

I. Overview of Developments

A number of key concerns and promising developments were identified in the first volume of this report, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139), influencing its recommendations. In this overview, these are summarized briefly. In the following section, each of the points listed under A and B are discussed and some of the data and information are provided in summary form (often in charts and graphs).

<u>A. Education Concerns</u>

1. Over the past 20 years, evidence has mounted that public, K-12, mathematics and science education in the U.S. is far from the best in the world. (In particular, see the next three items.)
2. Too many K-12 teachers are inadequately prepared in mathematics and science to properly teach these subjects.
3. Measured educational progress of 8^{th} grade and 12^{th} grade students indicates a decline over the high school years in the fraction who can perform at least at basic levels of proficiency in mathematics and science. It also indicates that only a small fraction of 12^{th} grade students are fully prepared to undertake college level studies in mathematics and science.
4. Measured educational progress, in mathematics and science, by underrepresented minority students in the 8^{th} and 12^{th} grades is often significantly below average.
5. Nevertheless, there has been a steadily rising percentage of high school graduates entering undergraduate programs; more than 60 percent of high school graduates were entering college in the early 1990s.
6. The situation described above has fueled a growing awareness of the importance and enormity of the task of recruiting and educating future K-12 teachers in mathematics and the sciences.
7. Focus groups have indicated that the majority of undergraduates in the early to mid 1990s were often dissatisfied with their experiences in lower division courses in the sciences, mathematics, engineering, and technology (SME&T).
8. Following the peak reached in 1986, a declining percentage (and number) of students were earning bachelor's degrees in many disciplines in the natural sciences, engineering, and technology.

The evidence also supports the claim that improvements have been achieved in our educational system. The following kinds of improvement were examined during the review of undergraduate education that preceded the drafting of Volume I of *Shaping the Future.*

Improvements at the K-12 Level

1. On average, more course work in grades 9-12 is now taking place in subjects that constitute important building blocks for college studies, including mathematics and science. Advanced placement courses have become increasingly widespread. These data were reviewed in Volume I of *Shaping the Future.*
2. Average student achievement levels in mathematics and science in the 4th, 8th, and 12th grade have been improving since the late 1970s, particularly among African American and Hispanic students.
3. A number of standards have been developed for mathematics and science learning during the K-12 years, including those of the National Council for Teachers of Mathematics, the National Research Council, the National Science Teachers Association, and the American Association for the Advancement of Science. These help to focus attention on needed minimum levels of achievement and help guide educators in incorporating new course materials and laboratory approaches to meet those standards.
4. A growing number of states have instituted higher standards for high school graduation.
5. Within the U.S., some states were achieving high levels of performance on the National Assessment of Educational Progress in 1992 [on par with the best foreign nations]. This fact informs us that there are high achieving school systems to examine, replicate, or improve upon for implementation in other settings.
6. The inflation adjusted pay of teachers and faculty has been improving since 1980, thereby aiding the effort to attract good students to teaching careers.
7. Attention to needed improvements in the preparation of K-12 teachers of mathematics and science has grown considerably in the 1990s.

Improvements at the Undergraduate Level

1. A large portfolio of highly promising educational practices and materials has been developed for undergraduate education over the past decade. These practices and materials were discussed in a generic way in Volume I of *Shaping the Future.* Some of these approaches are now starting to spread into wider use.
2. Faculty and college and university administrators have become ever more aware that there are a variety of pedagogical practices that can yield improved student learning.
3. Federal agencies have increased their support of innovative activities aimed at improving undergraduate education in SME&T disciplines. They often play the role of "venture capitalists," financing new national models of learning that are too expensive for individual schools, school districts, colleges, and universities to develop.
4. Systemic efforts to improve K-12 school systems are helping us to understand the challenges and potential in adapting comprehensive approaches to reforming education in institutions of higher education. NSF is starting to assist model institutions to develop comprehensive improvements.
5. Educational technology promises to provide attractive learning dividends when it is developed and applied correctly.

B. Important Changes in the Social, Economic, Political, and Technical Environment

1. There are pressures on colleges and universities to reconsider their mission priorities following the declining military imperative for scientific research and the rising tide of criticism about the cost and quality of undergraduate education.
2. The status accorded to teaching and student advising by faculty at many colleges and universities is increasingly perceived as being low.

3. Because a college education now confers a major advantage in lifetime earnings, there are some public officials who think that public subsidies of higher education should not grow.
4. However, there is growing pressure on family budgets as a consequence of rising levels of tuition (in response to the rising costs of higher education).
5. Institutional differences in resource expenditures per undergraduate student have grown considerably in recent years.
6. Public higher education competes for funds with public K-12 education and other demands for state resources. The increased expenditure of state-level resources on K-12 education during the 1980s has tightly constrained most states' capacity to fund transitional resource needs in higher education to accelerate their adaptation of new practices and educational technology.
7. Federal funding for science and engineering education, research, and facilities are concentrated in the hands of a relatively small number of institutions, while the distributions of SME&T majors and other students taking SME&T courses are widely spread over a large number of institutions differentiated by size and type.
8. The type and size of SME&T classes appear to be influenced by type of institution and discipline, suggesting that there is a need for a variety of approaches to improved undergraduate instruction.
9. There are a variety of faculty practices that would assist students in mastering basic concepts and materials. However, the extent of their use is often far from universal, indicating that more needs to be done to encourage faculty to adopt or adapt improved teaching practices.
10. A number of large employers have voiced dissatisfaction, in recent years, about the lack of broad skills evidenced by many recent college graduates in certain key areas. Improvements in curriculum and pedagogy would help to develop many of these skills.
11. The rising tide of educational and learning technologies threatens legions of faculty and students who are not familiar with much of it.

II. A Look at Some Basic Data and Information

A. Education Concerns

1. Student Achievement - International Perspective. Some of the latest data on comparative achievement in mathematics and science in the U.S. (including the state level) and foreign nations can be found in *The Learning Curve; What We are Discovering About U.S. Science and Mathematics Education* (NSF 96-53, January, 1996). This report shows, for example, that the Plains states of Iowa, North Dakota, and Minnesota had mathematics achievement scores for eighth grade students, on the National Assessment of Educational Progress in 1992, on par with the 13-year olds in the highest scoring other nations (Taiwan, Korea, The Soviet Union, and Switzerland). (See page 9.) However, the U.S. as a whole ranked substantially below these four nations and nine others on this test of proficiency.

2. Teacher Preparation in Mathematics and Science. Secondary teachers active in teaching mathematics and science are under-prepared in these disciplines. Consider the education credentials in academic year 1990-91 of those public secondary school teachers whose main teaching assignment was mathematics or science. Only 52 percent of those teaching biology, 35 percent teaching chemistry, 26 percent of those teaching physics, and 23 percent teaching mathematics had earned a baccalaureate (or higher) in the **corresponding** science discipline. Minors in the same discipline were earned by another 13 percent teaching biology, 25 percent teaching chemistry, 15 percent teaching physics, and 7 percent teaching mathematics. [Source: *1990-91 Schools and Staffing Survey*, as reported in U.S. Department of Education, National

Center for Education Statistics, *The Condition of Education 1995*, NCES 95-273, pages 419-422.]

In 1993, 72 percent of the science teachers had science baccalaureates (or higher) as measured by the less strict credential of counting *any* field of science, including science education. Similarly, 63 percent of the mathematics teachers had baccalaureates (or higher) as measured by the standard of mathematics or mathematics education. [Source: I.R. Weiss, M.C. Matti, and P.S. Smith, *Report of the 1993 National Survey of Science and Mathematics Education,* Chapel Hill, NC: Horizon Research, Inc.] For elementary teachers with teaching assignments in science and mathematics, typical preparation is still overwhelmingly in pedagogy rather than subject fields. (The importance of this fact is discussed in number 5 below.) There has been modest improvement in teacher credentials during the past 10 years.

<u>3. Educational Progress in High School</u> This progress has continued over the past decade, but evidence suggests that substantial additional progress is vital. One source of evidence for basic achievement in mathematics and science of 13-year olds (typically 8^{th} grade students) and 17-year olds (typically 12^{th} grade students) is the test known as the National Assessment of Educational Progress (NAEP). The "anchor point" of basic proficiency for 13-year olds is a NAEP score of 250. Proficiency at this level in mathematics means that students have an initial understanding of the four basic operations. They are able to add and subtract whole numbers in one-step word problems and money situations. They can find the multiplication product of a 2- and 1-digit number. They can also compare information from graphs and charts. [See: US Department of Education, National Center for Education Statistics, *National Assessment of Educational Progress, Trends in Academic Progress: Achievement of U.S. Students in Science, 1969 to1992; Mathematics, 1973 to 1992; Reading 1971 to 1992; Writing, 1984 to 1994*.] However, fully successful 13-year old achievement in mathematics would be reflected in a score of 300 or higher, the anchor point level of basic proficiency for 17-year olds.

At the 300 level, students can compute with decimals, fractions, and percents. They can identify geometric figures, measure angles, calculate areas of rectangles, interpret simple inequalities, and solve simple linear equations. However, students taking mathematics each year have been exposed to most of this knowledge by the 9^{th} grade, and full mathematics proficiency for 17-year olds planning on earning baccalaureates and studying mathematics (and other quantitative subjects) for another year in college would be demonstrated by a NAEP score of 350 or higher. At this level, students can solve a variety of two-step problems using variables, identify equivalent algebraic expressions, and solve linear equations and inequalities. They are developing an understanding of functions and coordinate systems.

The achievement data in the table below indicates several trends. The good trend is that in all cases, the fraction of students demonstrating achievement at the 250, 300, or 350 level has been rising. The negative trend is a little more difficult to see. In both mathematics and science, the fraction of 17-year olds scoring 300 or higher (or 350 or higher) is less than the fraction of 13-year olds scoring 250 or higher (or 300 or higher) in the same discipline four years earlier. In this sense of maintaining measured progress, students appear to be losing ground during the high school years. The amount of ground lost appears to be greater in mathematics, where there is more ground to lose because the fractions of 13-year olds scoring 250 or higher is greater than the counterpart fraction in science.

Fractions of a National Sample of Students Scoring Above Key Anchor Points in Mathematics and Science on the National Assessment of Educational Progress [NAEP]

13-year Olds	Percent in 1986	Percent in 1990	Percent in 1992
250 or higher in math	73%	75%	78%
300 or higher in math	15%	17%	19%
250 or higher in science	53%	57%	61%
300 or higher in science	9%	11%	12%

17-year Olds	Percent in 1986	Percent in 1990	Percent in 1992
300 or higher in math	52%	56%	59%
350 or higher in math	6%	7%	7%
300 or higher in science	41%	43%	47%
350 or higher in science	8%	9%	10%

A key observation is that only small percentages of 12th grade students score 350 or higher (7 percent in mathematics and 10 percent in science in 1992). Yet more than one-half of these students will shortly enter college.

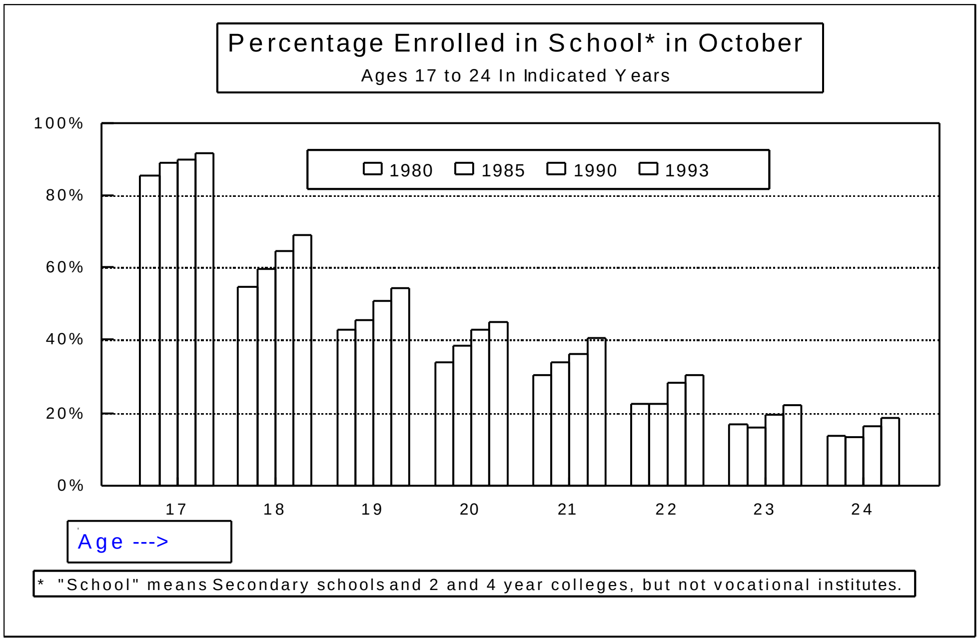
4. Minority Achievement Although minority achievement has improved for years, it has far to go. Using the anchor points for basic achievement on the NAEP test in 1992, 85 percent of eighth grade white (non Hispanic) students scored 250 or higher in mathematics, compared to 63 percent of Hispanic and 51 percent of African American students. [US Dept. of Education, National Center for Education Statistics, *The Condition of Education 1995*, NCES 95-273, pages 216-218.]

At the 12th grade level, 66 percent of twelfth grade white students scored 300 or higher in mathematics, compared to 39 percent of Hispanic and 30 percent of African American students. In comparing basic achievement in mathematics in the 8th grade and 12th grade, we see not only the decline in the percentage of students in each demographic category able to achieve minimum basic proficiency for their age level, but also a growing **relative** gap on the basis of race and ethnicity. The fraction who demonstrated at least basic proficiency in mathematics declined from the 8th to the 12th grade by 22 percent for white (non Hispanic) students, 38 percent for Hispanic students, and 41 percent for African American students. The pattern of NAEP scores in science is similar.

5. Rising Rate of College Attendance The percentage of students continuing their schooling after high school has risen steadily. Undergraduate enrollments rose throughout the 1980s, and continued to rise in the 1990s through 1992, along with the annual expenses paid by students to attend college, indicating a strong growth in demand for college education after 1980. One important indicator of this rising demand is the growing percentage of high school graduates entering four-year institutions without interruption (e.g., June graduates entering college in August or September). The percentage of female high school graduates attending four-year institutions within a few months of graduation rose from 33 percent in the early 1980s to 41 percent in early 1990s. Similarly, the percentage of male graduates rose from 31 percent in the first half of the 1980s to 38 percent in the second half of the 1980s, fluctuating slightly after 1990 in the 35 to 38 percent range. Including matriculation in two-year colleges, nearly 67 percent of female high school graduates and nearly 60 percent of male high school graduates entered post secondary education within a few months of graduation in 1992. Another 10 to 15 percent will enter college a

few years after graduating from high school, or after leaving high school and earning their general equivalency diploma. College attendance has become a nearly universal rite of passage into the workforce in the 1990s.

Another perspective is provided by the rise in percentage of U.S. residents of college age enrolled in school in October of selected years. As the following chart indicates, at each age in the span from 17 to 24 years old, this fraction has risen since 1980. This fact has had a large impact on undergraduate enrollments, which have continued to rise through 1992 despite a drop in the number of high school graduates after 1988.



Source: US Department of Commerce, Bureau of the Census, October Current Population Surveys.

6. Importance of Recruiting and Preparing K-12 Math & Science Teachers. Starting at least with *A Nation at Risk* (National Commission on Excellence in Education, 1983), educators and policy makers began to give teacher preparation high priority, particularly after the decline in the quality of K-12 schools was linked to declining economic productivity in *Time for Results* (National Governors' Association, 1986), and we collectively began to realize that school reform would not succeed without programs to improve the quality of teacher education. [See, for example, *The Preparation of Teachers: An Unstudied Problem in Education* (Sarason, Davidson, and Blatt, 1986).]

The evidence of need for improvement has grown considerably, and the total body of evidence now indicates that it would be hard to overstate the size of this problem. In his study, *Teachers for our Nations Schools* (1990), Goodlad measured the magnitude of the problem of achieving meaningful reform and explained the need and value of **systemic** approaches — an approach that is now embodied in NSF's State, Urban, and Rural Systemic Initiatives for K-12 education, Comprehensive Partnerships for Mathematics and Science Achievement, and the Collaboratives for Excellence in Teacher Preparation Program.

Researchers and educators believe the most effective teachers are those who (1) are lifelong learners who regularly update their subject and pedagogical knowledge; (2) are willing to learn from others, including students; (3) have a vision of how they want to change, spend time reflecting on their own teaching strategies, and devise strategies that are effective in addressing the diverse learning styles that their students exhibit (which they comprehend through skillful observation of student's learning processes).

Increasingly, we want that knowledge to include a knowledge of — and a comfort with — mathematics and science. Even though, as a nation, we are making progress, elementary teacher candidates can still receive a bachelor's degree without ever learning content approaching the depth of understanding expected of mathematics and science majors. Instead, subject matter knowledge is transmitted through mathematics and science courses tailored to education majors. Some states do not require elementary majors to have taken any mathematics or science content courses.

What does the evidence indicate about the value of subject matter training in mathematics and science? Evidence from the National Education Longitudinal Study of 1988 (NELS:88), a national study of 24,599 students in the eighth grade and their teachers, indicates that students of those teachers who majored or minored in science and mathematics performed significantly better on achievement tests. The following summary deals with direct effects only, leaving out indirect effects and associative effects (such as giving the best teachers the best students). The results are reproduced below in Panel A (mathematics teachers) and Panel B (science teachers).

Student achievement scores rise for each descending step in each column:

A. Mathematics

Teachers Mathematics Preparation
No courses in math (low frequency)
Math at calculus level or lower; no math education
Math at calculus level or lower and math education
Math above calculus level; no math education
Math above calculus level and math education

and

Teachers Math GPA
2.5 or lower
2.5+ to 3.0
Above 3.0

B. Science

Teachers Science Preparation
No science courses, or sci. ed. only (low frequency)
Science and sci. ed. courses (< 41 credits)
Science courses only (< 41 credits)
Science and sci. ed. courses (> 40 credits)
Science courses only (> 40 credits)

and

Teachers Science GPA
2.5 or lower
2.5+ to 3.0
Above 3.0

A brief summary of the impact of teacher preparation in subject area and pedagogy on student test scores indicates that:

- There is no pattern based on teachers' highest academic degrees.
- Mathematics scores are higher if teachers majored in mathematics.
- Science scores are higher if teachers majored or minored in science, and somewhat higher yet if teachers majored in science as graduate students.
- Training in pedagogy helped only if the teacher had training in subject area too.

7. Student Dissatisfaction with Lower Division SME&T Courses Seymour and Hewitt's large study, *Talking About Leaving* (1994), produced findings that are very critical of faculty teaching practices. They conducted a large ethnographic study over a three-year period (1990-93) with 335 students, majoring in the natural sciences and engineering (NS&E), drawn from seven campuses that were among the most productive contributors to the nation's flow of new baccalaureates in these fields. Most data were gathered by personal interview. Some data were obtained in focus groups of three to five students. An additional 125 students took part in focus group discussions on six other campuses. One-half of the students were in the biological sciences, physical sciences, and mathematics. The other half were in engineering. All of the students had SAT mathematics scores above 649 and, thus, were prepared to undertake NS&E studies in college. The student sample was designed to include slightly more students leaving (55 percent, all juniors or seniors) than remaining in NS&E majors (45 percent, all of whom were seniors). Underrepresented groups were over sampled.

Generally poor teaching by the science and engineering faculty was by far the most common complaint of able students. Nine out of ten one-time NS&E majors who switched to a non-NS&E major, and three out of 4 who persevered, described the quality of teaching as poor overall. The next most frequent complaint of non-switchers was inadequate advising by the faculty, mentioned by more than one-half of these successful majors.

Students were very clear about what was wrong with the teaching they had experienced. They strongly believed that faculty do not like to teach (especially lower division courses), that faculty do not value teaching as a professional activity, and that they lack incentive to improve. In their explanations for the poor teaching they had experienced, students constantly referenced faculty preoccupation with research as the overt reason for the failure of faculty to pay serious attention to the teaching of undergraduates and for specific inadequacies in attitude or technique. (Student perceptions of faculty research activities changed considerably, however, when students were allowed to observe or participate in that research. The few students who had this experience were pleased with the pleasant and open way in which faculty treated undergraduates in a research relationship, compared with their apparent indifference to them in a teaching context.)

The perceived dislike displayed by the NS&E faculty for pedagogical contact with students cannot be simply explained by a greater interest in research, or by the bias of departmental rewards systems, according to Seymour and Hewitt. Students offered many examples of non-NS&E faculty who evidently enjoyed teaching, saw it as an integral part of their work, and took the trouble to do it well. Important elements in what students saw as good teaching were openness, respect for students, the encouragement of discussion, and the sense of discovering things together. Student comparisons of NS&E teaching styles with those in other classes are permeated with strong contrasts including:

- coldness versus warmth,
- elitism versus democracy,
- aloofness versus openness, and
- rejection versus support.

The distancing of the NS&E faculty from students was sometimes increased by sarcasm and ridicule, which created an atmosphere of intimidation and had the effect of discouraging voluntary student participation in classroom discussions.

The focus of student criticisms were the following:

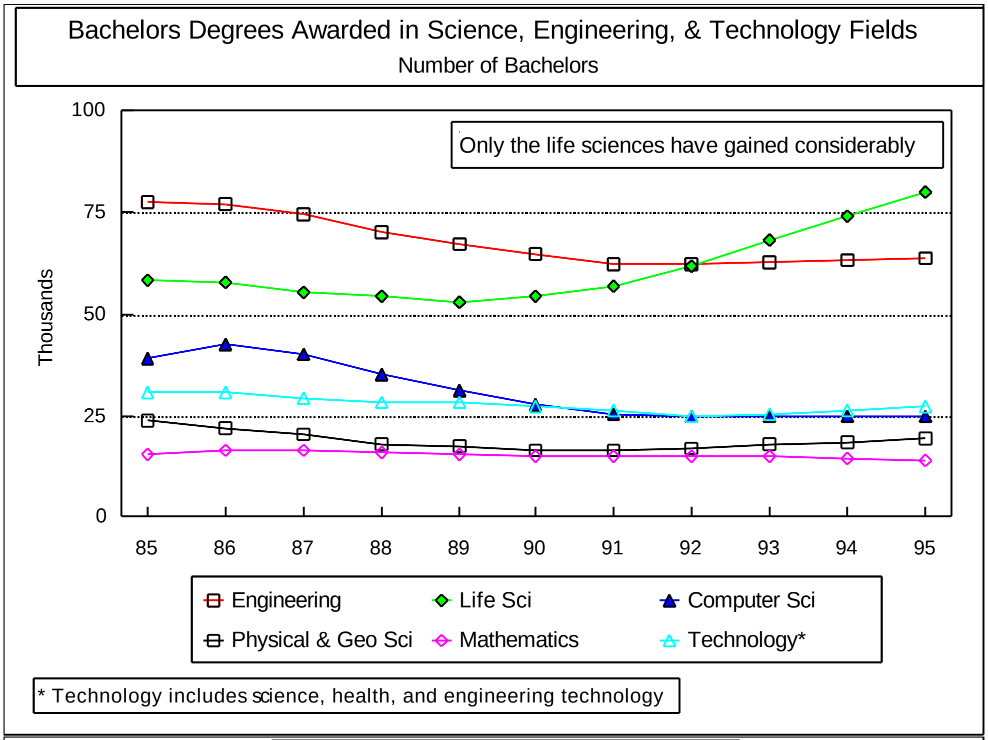
- There was a lack of student-teacher dialogue, which was also thought to reflect faculty indifference. Classes like this were one-way lectures and contrasted poorly to the high school experiences of many students, where there was considerable dialogue.
- Faculty were evidently poorly prepared for lectures, indicating to students that faculty were disinterested in student learning. Students were particularly frustrated by faculty who seemed unable to explain their ideas sequentially or coherently.
- Students also wanted (but typically did not find) many illustrations, applications, and discussions of implications. Nevertheless, students did not believe there was anything intrinsically dull about any NS&E class material, even though student interest in many classes began to flag when faculty failed to present material in a stimulating way. Many students made reference to the "monotone" voices and dry recitations of their instructors' lecturing.
- Class tedium grew in instances where faculty were "over-focused" on getting students to memorize material.

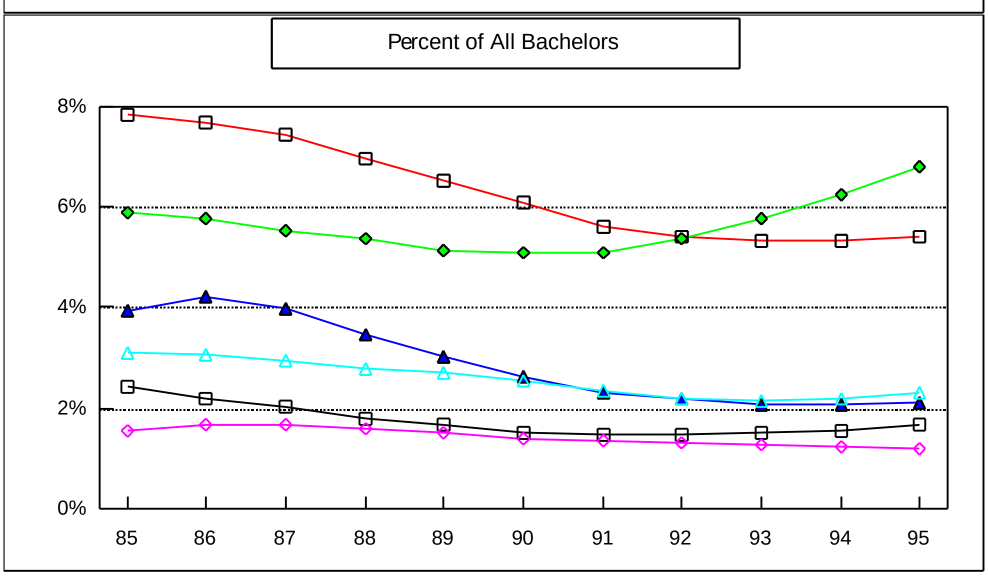
Turning briefly to the findings derived from focus groups of students convened for this study, covering a broader cross section of undergraduates than those participating in *Talking About Leaving*, it is noteworthy that the students' opinions about introductory courses are similar. (These findings are reviewed in substantially greater detail in Section IV of Volume II, pages 243 to 270.) In the focus groups for this study, students identified introductory SME&T courses as a major barrier. Many students majoring in other fields who were interested in improving their competence in SME&T fields were discouraged (or screened out) from pursuing further studies. SME&T majors found their introductory courses very challenging and often described them as "weed-out" courses.

All types of students objected to the large lecture format often used in these courses. Students from two-year colleges, Historically Black colleges, and comprehensive masters institutions were not as negative about these courses as those from research and doctoral universities, which have the largest classes. Even the recent graduates had no difficulty recalling the generally unpleasant experiences they had in introductory courses. In particular, students singled-out the practice in some large lecture classes of using television monitors in separate rooms to serve students who could not fit into the lecture hall as being very discouraging. The perception of many students was that the faculty did not want to teach these courses. In addition, a significant number of students objected to the competitive atmosphere in introductory SME&T courses, calling it a barrier to learning. Students also found considerable fault with introductory lab courses and sections. Some found them to be mechanical exercises that were seemingly unconnected to concepts of science. Lack of faculty or teaching assistant expertise on site in the labs was cited as another weakness.

<u>8. Declining Baccalaureate Degrees in SME&T Disciplines</u> Starting pay for graduates in engineering, the computer sciences, the mathematical sciences, economics, and the physical and environmental sciences has remained higher than in the social and behavioral sciences, the biological sciences, and most other non-SME&T fields. (The exceptions are accounting, finance, and a few other fields.) Yet, students have tended increasingly to major and earn bachelor's degrees in these lower-paying fields. The higher-paying SME&T fields jointly accounted for 19 percent of all bachelors in 1985, but bachelor's degrees awarded in this group fell by nearly 20 percent during 1985-1993, while total bachelor's awarded in *all* fields rose by almost 20 percent (reducing the proportion of bachelor's in the high-paying fields to 13 percent during 1993 - 95).

In the more frequently used subtotal of NS&E, degree awards have declined from 215,000 in 1986 (21 percent of total bachelor's) to 175,000 in 1991 (15 percent of total bachelor's), recovering thereafter to 201,000 in 1995 (16.5 percent of total bachelor's) due to growing interest in the life sciences. Changing student interest in the life sciences accounted for only about 5 percent of the decline in NS&E bachelor's awards during 1986-91, but more than 90 percent of the rise in these awards during 1991-95. Associate of Arts degrees in these same disciplines exhibited the same pattern to a more limited extent. These trends are shown in the following charts.

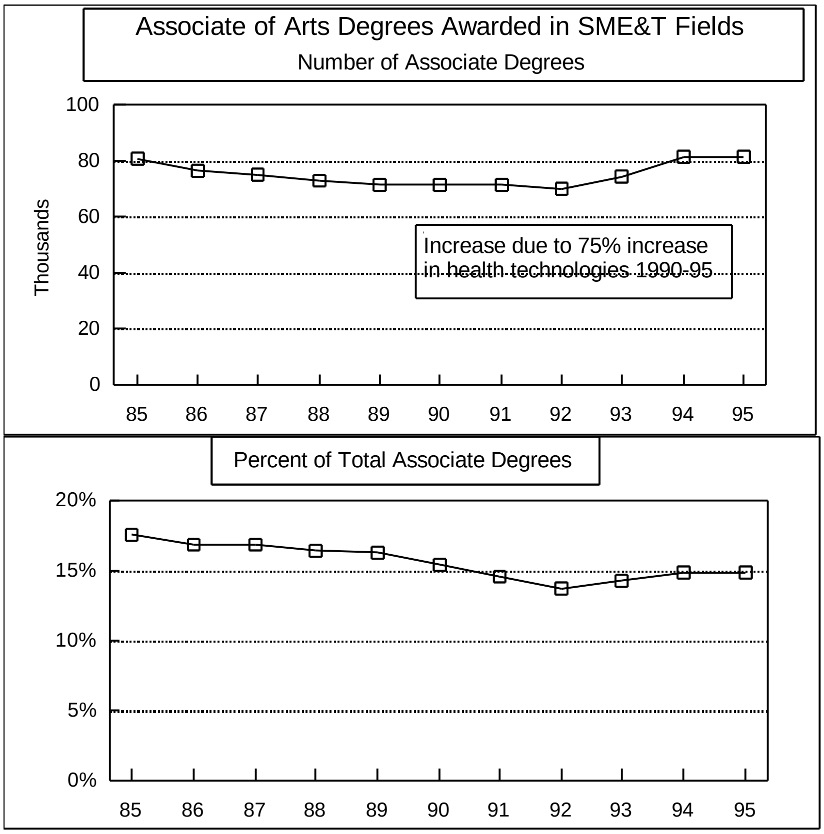




Source: U.S. Department of Education, National Center for Education Statistics, IPEDS (Integrated Postsecondary Education Data System) and HEGIS (Higher Education General Information Surveys) surveys of U.S. postsecondary institutions.

One concern that derives from these trends is that there may be similar declines at other levels of learning in the SME&T disciplines, such as a reduced number of minors elected in NS&E, or reduced percentages of students taking introductory courses in these fields. Unfortunately, national time series data to track these concerns are not available.

There are a variety of hypotheses for the decline in "popularity" of SME&T majors. One is the poor preparation of many high school graduates to succeed in NS&E courses. Although this is still a sizable problem, it is important to observe that, by all national quantitative measures, it has diminished during 1985-95.



Source: U.S. Department of Education, National Center for Education Statistics, IPEDS (Integrated Postsecondary Education Data System) and HEGIS (Higher Education General Information Surveys) surveys of U.S. postsecondary institutions.

It is possible that the growing number of older and part-time students include many whose mathematics skills and basic science preparation have become rusty from disuse, precluding the choice of an NS&E major. For example, data from the High School and Beyond panel surveys indicate that, from the perspective of 1993, nearly all of the baccalaureates in NS&E earned by students who were high school sophomores or seniors in 1980 were earned within six years by students who persisted with, at most, relatively short periods of absence from their studies.

B. Important Changes in the Social, Political, and Technical Environment for Higher Education

1. Pressures on Public Institutions to Reexamine Their Priorities. The Pew Higher Education Roundtable ("To Dance with Change," *Policy Perspectives*, Vol. 5, No. 3, Section A, April, 1994)

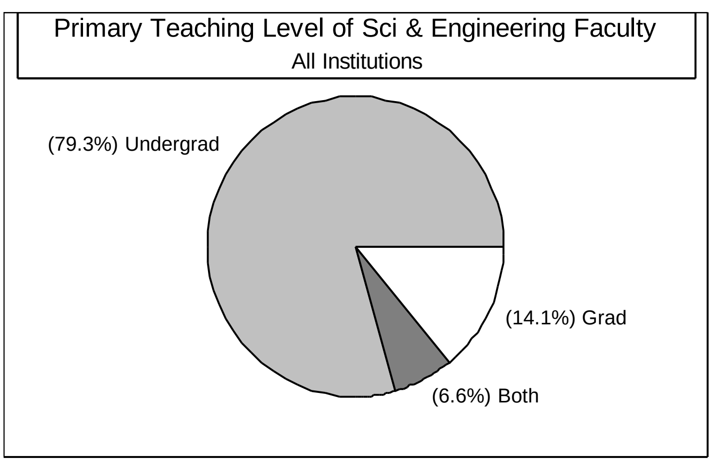
found that:

> *There is less inclination to trust government to establish public services or define public priorities. It is part and parcel of the general inclination to resist new taxes from the conviction that individual consumers make better and more appropriate choices than any government can* (page 5A); … *There is real anger at higher education ... from the makers and shapers of public policy — governors, legislators, regulators, heads of public agencies, and surprisingly, an increasing number from the world of private philanthropy. ... Many ... believe that colleges and universities have become too isolated from the economic pressures that are forcing most other American enterprises to rethink purpose and mission ...* (page 6A).

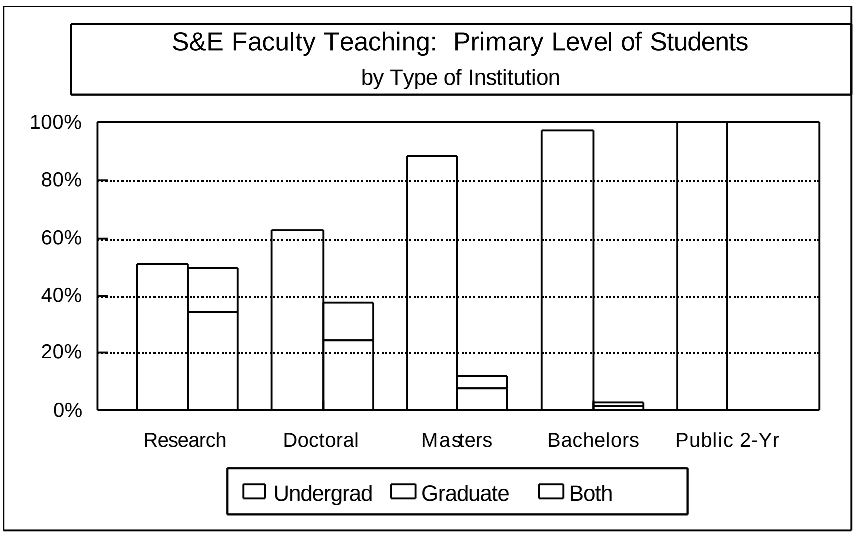
The Pew Roundtable traces this anger to two concerns, both of which are central to this Review. The first is the growing unease in recognizing that higher education has far to go before it fulfills the promises that have often been the implicit basis of its funding, namely the creation of a skilled citizenry, buttressed by the improved access of underrepresented minorities, leading the way to economic development for states and regions. The Roundtable claims that there is a growing sense that too many institutions frequently confer academic degrees on students who have not demonstrated sufficient skills to be effective workers or informed citizens. The best graduates are often seen as "exhibiting a self-centered aggressiveness rendering them incapable of working with others." [Page 6A] This situation is seen as the consequence of excessive academic competition for the best students and competition within classes.

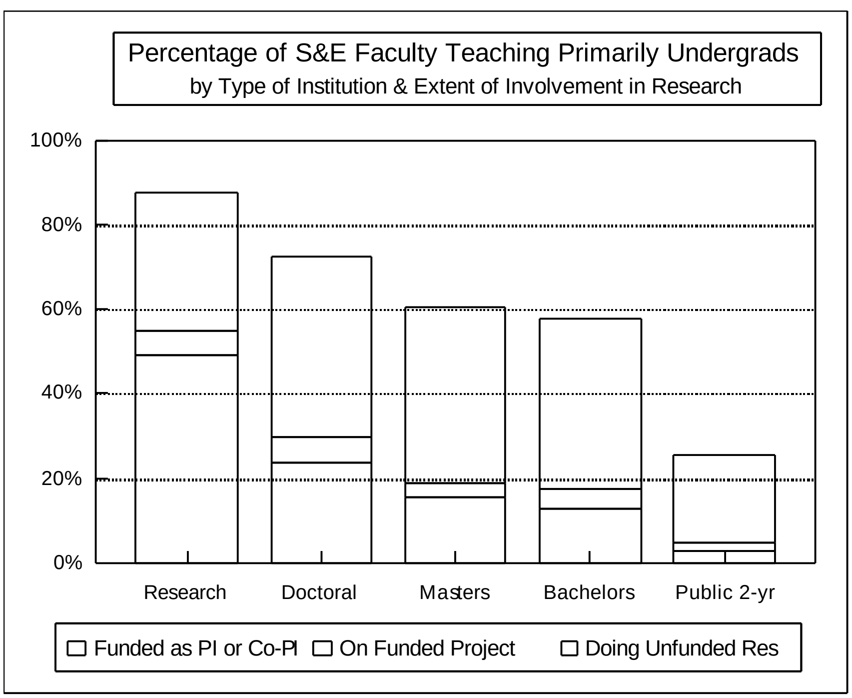
2. Status of Faculty Teaching and Advising. The Pew Roundtable (in the same 1994 publication) also reported a public perception that academic institutions "have become havens for a privileged class." [Page 6A] Some states are actively pursuing (and others are considering) legislatively mandated requirements to increase faculty teaching. Statements, from state officials, that the principal job of the faculty is to teach students are increasingly common in the news media. Now, let us examine the faculty perspective.

Data on faculty teaching and research activities, taken from the *1993 National Survey of Postsecondary Faculty* (NSOPF-93; US Department of Education, National Center for Education Statistics), indicate that most faculty must teach. Nearly 80 percent of these taught primarily undergraduates in 1992, with another 6 percent teaching both undergraduates and graduate students. Even in Research Universities, 50 percent of the teaching faculty taught primarily undergraduates, with another 16 percent teaching at both the undergraduate and graduate level.

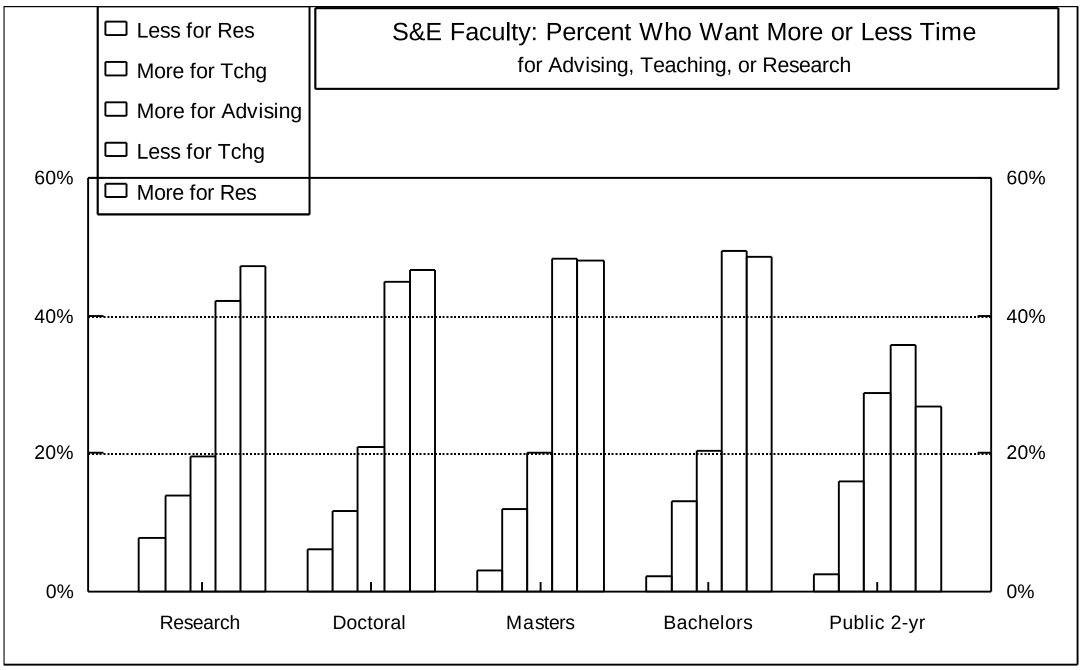


Not surprisingly, the fraction of faculty teaching primarily undergraduates rises as the research intensity of the institution drops. [See the following two charts.] A less obvious fact is that sizable proportions of the faculty who teach primarily undergraduates are also engaged in research. More than 50 percent of the "undergraduate" faculty in Research universities (and nearly 30 percent of the undergraduate faculty in Doctoral universities) are principal or co-principal investigators or included on externally funded research projects. These data suggest that student perceptions that faculty attention may often be focused on their research may be on target, but they also indicate the high potential for allowing students to observe or participate in faculty research.





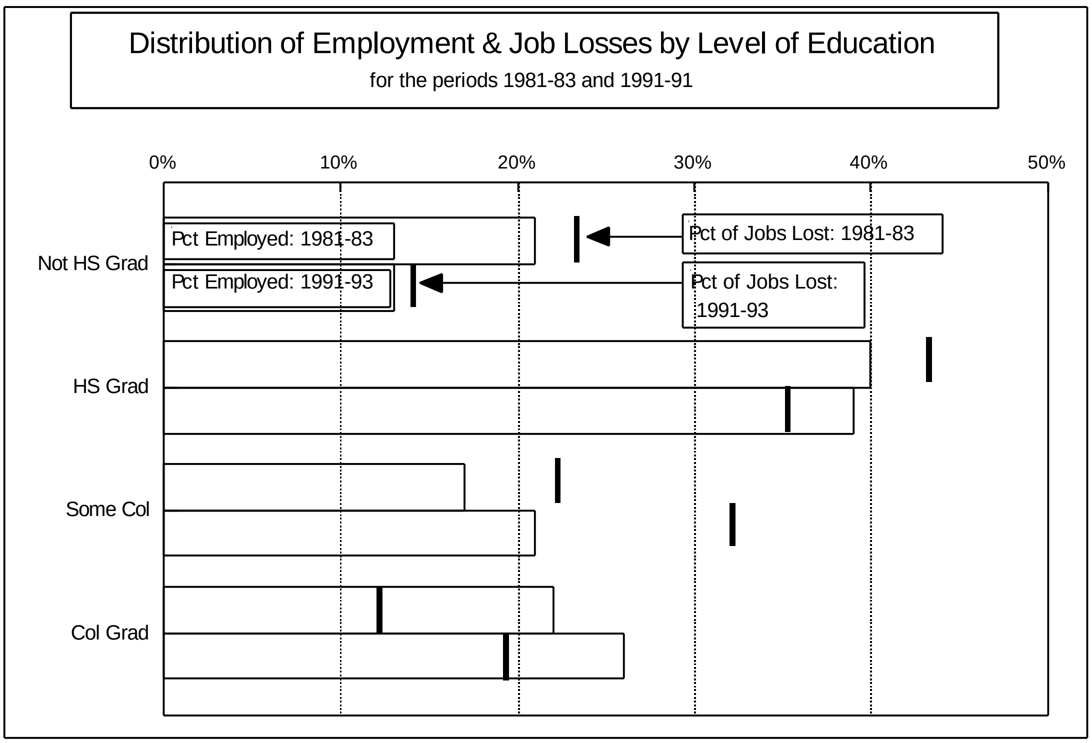
What were the faculty preferences for altering the distribution of their 1992 work efforts in teaching, student advising, and research? This is, in a sense, the faculty side of Seymour and Hewitt's profile of SME&T education. In every type of four-year institution, much greater percentages of faculty want to devote *less* time to teaching (40 to 50 percent) and *more* time to research (again, 40 to 50 percent) than would prefer spending more time engaged in teaching activities (10 to 15 percent) or less time doing research (8 percent or less). Despite widespread dissatisfaction of students with the quality of faculty advising, only 20 to 25 percent of the undergraduate faculty said they were somewhat or very dissatisfied with the (little) time available for student advising. The reasons faculty expressed these preferences are not available. One may speculate whether the reasons include a dislike for teaching by those who are not very good at it, ignorance of students' preferences due to inadequate contact between students and faculty, or a reward system that frequently favors successful research over successful teaching.



<u>3. Public Attitudes About Public Subsidies</u>. Among the sources of revenue for undergraduate education, public (chiefly state-level) sources have collectively been the most important. However, the share of total cost derived from this sector may be in long-term decline. According to the Pew Higher Education Roundtable (1994), a major force reshaping American higher education is the increased substitution of market revenues for public funds:

> *Having heard the message that a college degree translates into the higher earnings that come with a good job, the conclusion being drawn is that a college education in fact contributes more to individual advancement than to the nation's social fabric. The result is that students at public institutions everywhere are being asked to pay for an ever greater share of the costs of their higher education* (page 4A); ... *There are new adherents to the proposition that appropriations for public higher education, particularly at flagship institutions, amount to a public tax for the benefit of the economically advantaged, whose children neither need nor deserve such subsidy for their college education.* (page 5A)

Turning to data on the sources of employment growth and the effect of education on unemployment, there is ample evidence that college does confer important advantages on job holders and seekers. In the early 1980s, the following chart (based on employment data published on the Web Page of the Bureau of Labor Statistics (BLS) of the U.S. Department of Labor) indicates that job losses were occurring disproportionately among those who were not college graduates (in each of three separate categories). By the early 1990s, employment of workers with less than high school diplomas had shrunk from 21 to 13 percent of the total, and employment of those with some college and a college degree each rose by 4 percentage points of the total. The growth in the pool of workers with "some college" and with college degrees was evidently large enough that job losses in the early 1990s were disproportionately higher among workers with *some* college than among those with less than a high school education. Workers with college degrees were still experiencing the lowest frequency of job losses.

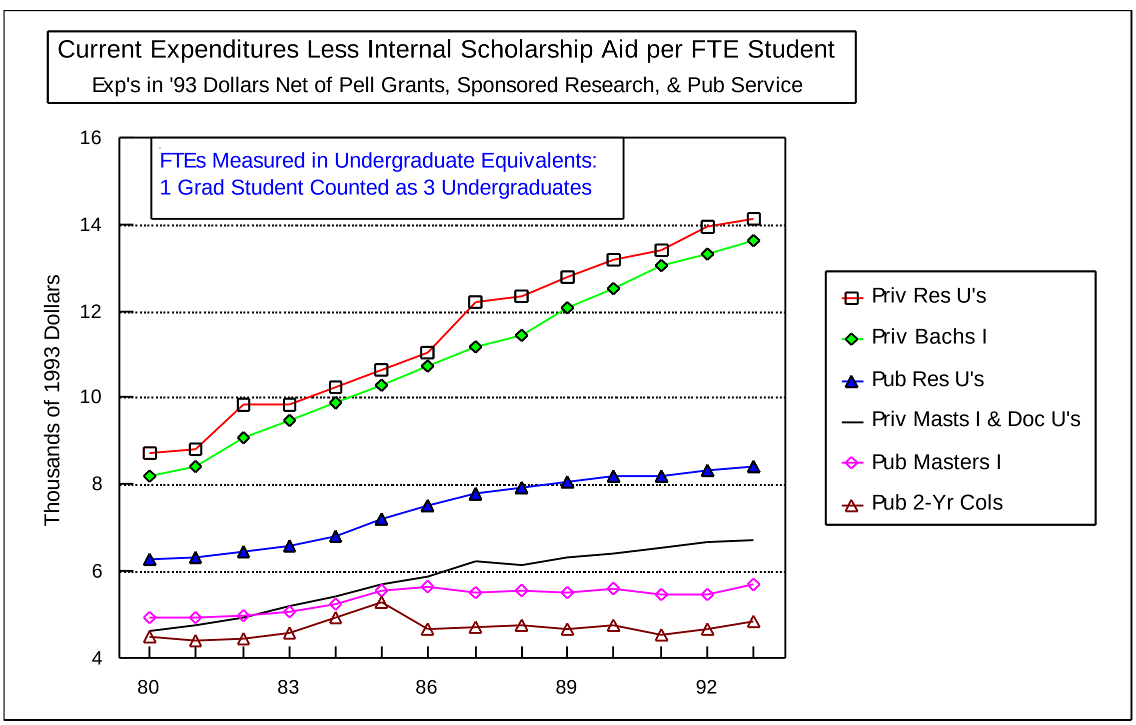


Source: U.S. Department of Labor, Bureau of Labor Statistics data reported in the *New York Times* on March 3, 1996, page 27.

4. Rising Per-Student Costs in Higher Education. Undergraduate education is part of the academic enterprise which spans graduate and professional education, research, and service to the community. Expenditures by this combined academic enterprise have grown rapidly for decades, funded by revenues from a variety of sources. Even though precise estimates of expenditures by type of activity (e.g., undergraduate education) are lacking because key resources (e.g., faculty) are shared by multiple activities, we can still infer valuable information from examining expenditures data. Because academic institutions are nonprofit organizations, trends in expenditures approximate trends in resource costs.

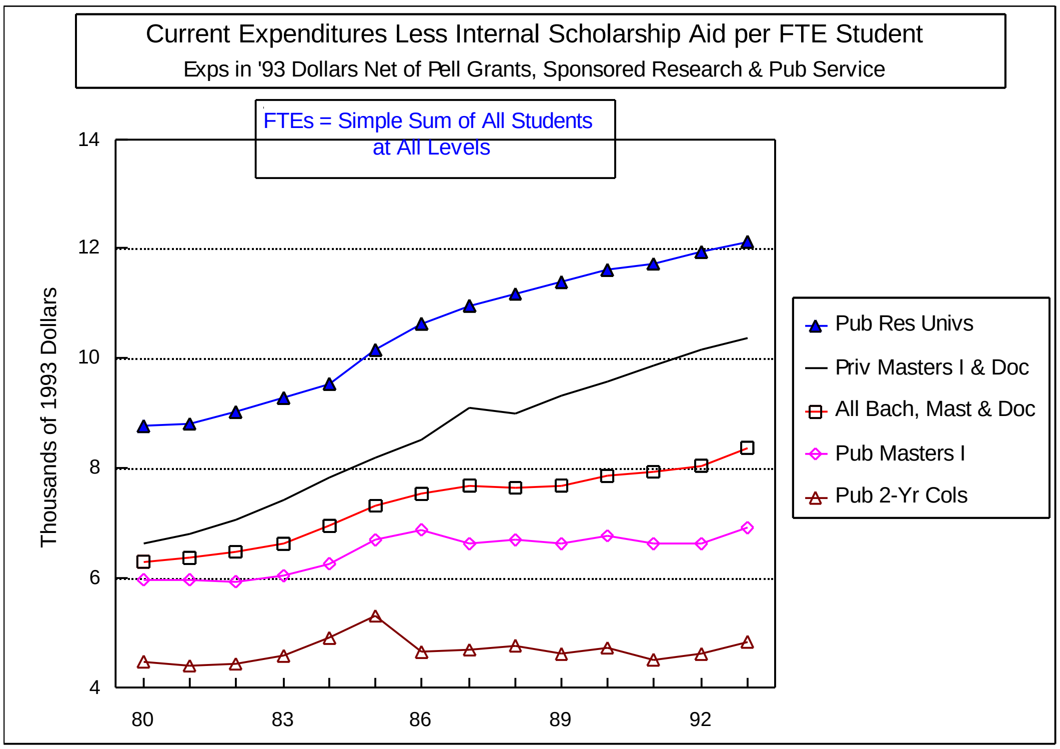
The unit costs of undergraduate education have been rising, at least since 1980, although it is hard to measure these costs with precision. An explanation is offered in the following text box. National estimates depend on financial data from the HEGIS and IPEDS surveys conducted by the U.S. Department of Education, National Center for Education Statistics. (Extensive documentation is available at http://www.ws.gov.edu/NCES/...) The following chart indicates that the unit costs of education rose during 1980-85 in each type of institution represented, but that thereafter they leveled off in public two-year colleges and public Masters I institutions. (This chart does not cover all types of institutions, but the included types cover the entire range of unit costs.) The high level of expenditure in the highly selective private Research I and Bachelors I — formerly known as Liberal Arts I — institutions is due in large measure to higher resource levels per student. These greater resources include substantially larger expenditures on "student services."

How do you measure the unit cost of undergraduate education? Estimates of the "educational and general expenditures" per undergraduate student full-time equivalent require some understanding of differences in education costs by level, because these expenditures are reported for undergraduate, graduate, and professional students combined. If all post-secondary education students are counted equally and total instructional costs are divided by the sum of all FTE students, the resulting calculated unit cost would overstate the *level* of expenditure per undergraduate in Research and Doctoral institutions and also the *increase* in this unit cost (because graduate and professional enrollments have been rising more rapidly than undergraduate enrollments). We do not know the exact nationwide "weights" to give graduate and professional students compared to undergraduates. However, specialized studies of individual institutions and programs have shown that graduate or professional students require at least twice (and often much more) the value of resources used to instruct undergraduates. In the fourth chart, unit undergraduate costs have been estimated, counting graduate and professional students as three times as costly to educate as undergraduates. This ratio was selected because it is representative of cost studies and brings the unit costs in private research universities into close proximity with unit costs in Bachelor's I institutions (formerly called selective Liberal Arts Institutions).



Also note that the rate of increase in unit costs in public Research and private Doctoral and Masters I universities slowed appreciably after 1986. Also a factor in explaining the higher level of unit costs in these two groups and in public Research universities ("flagship public institutions") is the much higher average compensation of their faculty. In fact, growing faculty compensation during the 1980s is the most important cause of growth in resources expenditures per student in academic institutions during that period. For example, according to Getz & Siegfried (1991, page 300), the rapidly rising prices of instructional inputs accounted for about 75 percent of the 2.7 percent per year increase in academic "education and general" expenditures per student *over and above* the general rate of price increase of GNP during the 1980s.

The values in the previous chart should be compared to those in the chart below to illustrate the point that the rise in costs per student (unadjusted for the mix of student types) was partly a consequence of growing proportions of graduate students in research and doctoral institutions. In particular, the large and growing difference in unit student costs by type of institution is partly a result of the growing proportions of graduate students.



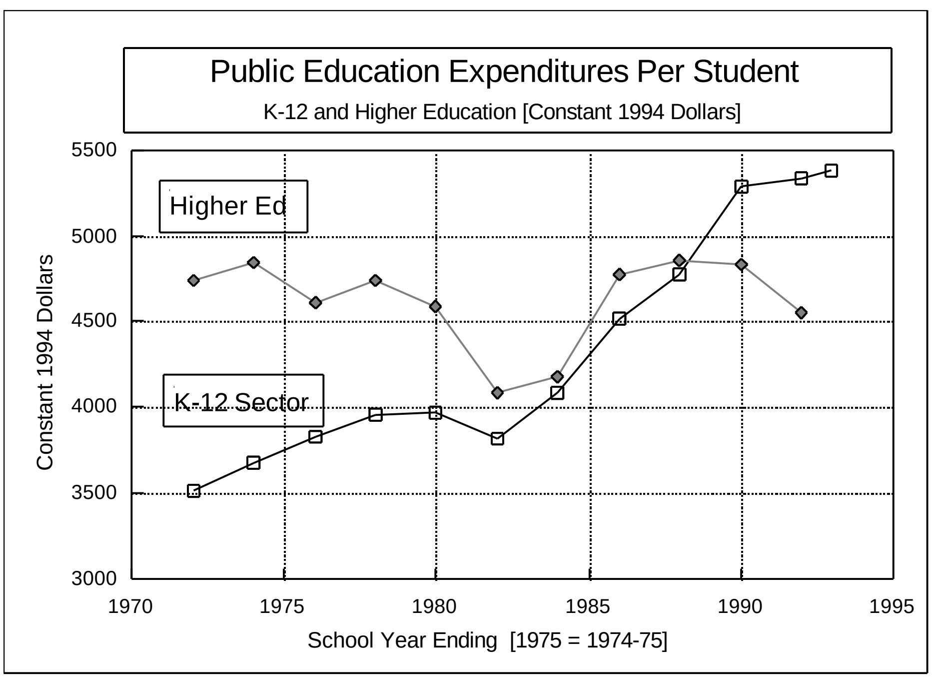
These estimated costs per student, unadjusted for the mix of undergraduate and graduate students, indicate a widening of unit costs in different types of institutions that took place during the 1980s and the early 1990s.

5. Impact of Growing Differences in Per-Student Costs. The cessation of growth in externally sponsored support, in combination with reduced or tightening state budgetary support (which is discussed in the next section) has likely had some impact on lower-division courses in NS&E within universities with externally supported research faculty and doctoral students. The replacement of retiring faculty has not been complete during the 1990s. Faculty retirements are often being used as a source of academic downsizing, which puts increasing pressure on existing

faculty to raise external grant funds and teach more students. These reductions in faculty resources for instruction have created pressures within undergraduate courses — larger classes, less variety, more incentive for hiring inexpensive teaching assistants or part-time adjunct faculty. Average class size rose throughout the 1980s (Getz & Siegfried, 1991, page 391). These developments may have reduced the opportunity to try innovative approaches to offering courses and curricula in these institutions at the same time that it has increased the need for productivity enhancing improvements.

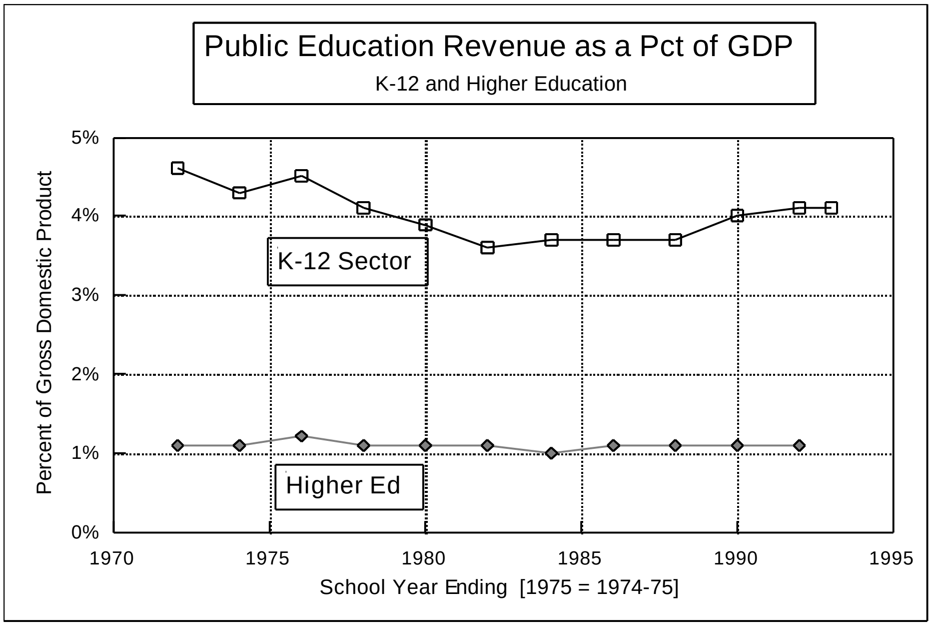
However, it is also important to realize that these data indicate a wide difference in institutional capacity to finance faculty release time. Such release time is valuable because it allows older faculty to engage in teaching enhancement workshops and seminars and to retool their teaching skills by studying the growing body of material and approaches to successful undergraduate education (and adapting those that best fit their needs). For national programs focused on improving the quality of undergraduate education, such as those found in NSF's Directorate for Education and Human Resources or in the Department of Education's Fund for the Improvement of Postsecondary Education (FIPSE), the challenge and need are to ensure that all types of institutions participate in these programs.

6. Pressures on Sources of Revenues. Public expenditures per pupil in grades K-12 began to rise shortly after the publication of *A Nation at Risk* (National Commission on Excellence in Education, 1983). This increase is likely to have resulted from a growing awareness generated by this and other studies of the need for substantial improvements in quality — a conscious parallelism of action by many groups. The following chart indicates that the cumulative rise during 1983-1993 was large.

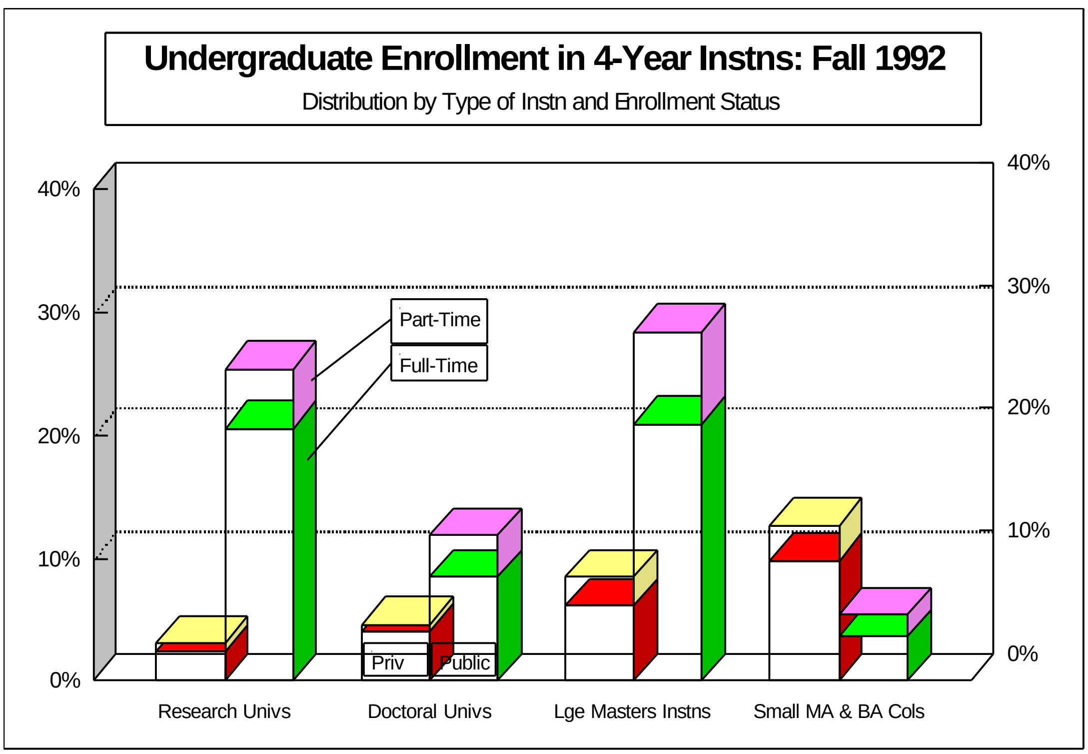


Source: U.S. Department of Education, National Center for Education Statistics, *The Condition of Education 1994*, NCES 94-149 pp. 148, 149, 325 - 328.

There has been a growing fiscal reliance on state governments to fund public education in grades K-12 during 1970-1990, as real expenditures per pupil were rising. This has constrained state-level funds for higher education. States provided 40 percent of public revenues for K-12 in 1970, 47 percent in 1980, and nearly 50 percent in the second half of the 1980s. During this period, public expenditure per student in the higher education sector did not grow in real dollars, although it has remained a constant 1 percent of Gross Domestic Product (GDP). (See the following chart.)



Source: U.S. Department of Education, National Center for Education Statistics, *The Condition of Education 1994*, NCES 94-149 pp. 148, 149, 325-328.

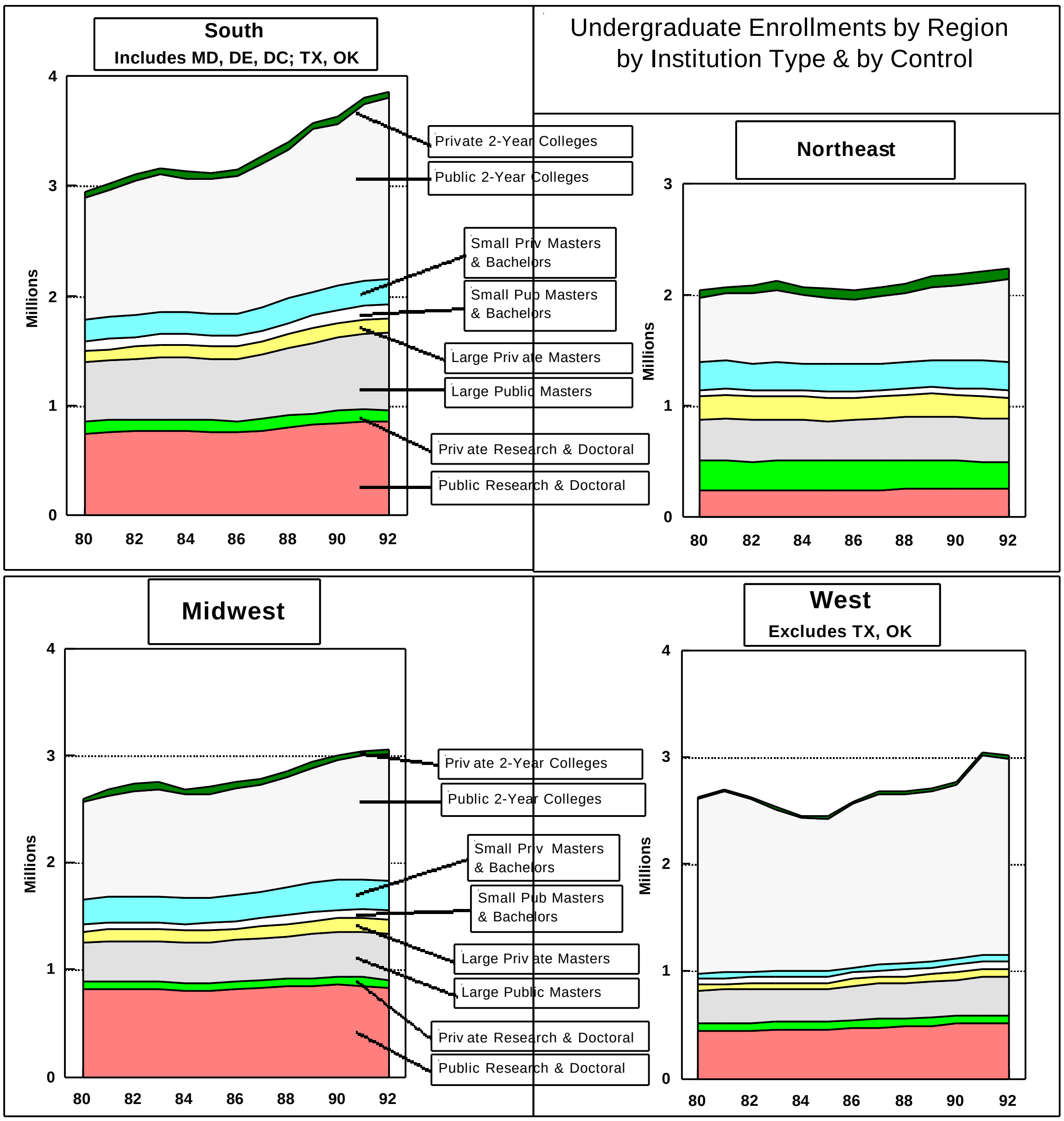


Source: U.S. Department of Education, National Center for Education Statistics, *Enrollment in Higher Education:*

Fall 1994, NCES 96-440 and detailed data runs using the NSF CASPAR data system. Enrollment data are collected as part of the IPEDS and HEGIS surveys.

And, as was discussed in Sections 4 and 5 above, graduate student enrollment in Research and Doctoral universities was increasing more rapidly than total undergraduate enrollment during this period, so public funds available for undergraduate students were declining in real dollars.

Public expenditure per undergraduate and graduate student dropped briefly during the 1978-1983 period as the rate of growth in undergraduate enrollments finally dropped after several decades of high levels. As it increased once again, it coincided with (and helped to cause) an increase in the inflation-adjusted compensation of the faculty, noted above in section 4, which experienced a cumulative growth of about 25 percent during 1980-1992.



7a. Distribution of Undergraduates and SME&T Courses. In this section, we examine the distribution of undergraduate students and SME&T courses and the headcount of undergraduates enrolled in those SME&T courses. Undergraduates are found in a large variety of institutions. Within four-year institutions in 1992, about 37 percent were enrolled in Large Masters Institutions (more than 2,000 undergraduates), compared to 29 percent in Research universities, 18 percent in small Masters and Bachelors colleges, and 16 percent in Doctoral universities. This distribution does not include other four-year institutions, such as Religious colleges, Business schools, and Art institutes, which were excluded from the chart because they do not have science and engineering degree programs.

Two-year institutions accounted for 46 percent of all undergraduates, counting part-time and full-time students equally, and the excluded four-year institutions would add about another 5 percent to the 4-year total. As the set of four regional enrollment charts indicates, community colleges are even more important as educators of high school graduates in the West and South. Large public Masters institutions are well-represented in all four regions, but most prominently in the Northeast. Large private Masters enroll considerably more students in the Northeast than in any other region. And, in general, all types of private institutions are proportionately most prominent in the Northeast and least prominent in the West. Finally, public Research and Doctoral universities enroll more undergraduates in the Midwest and the South.

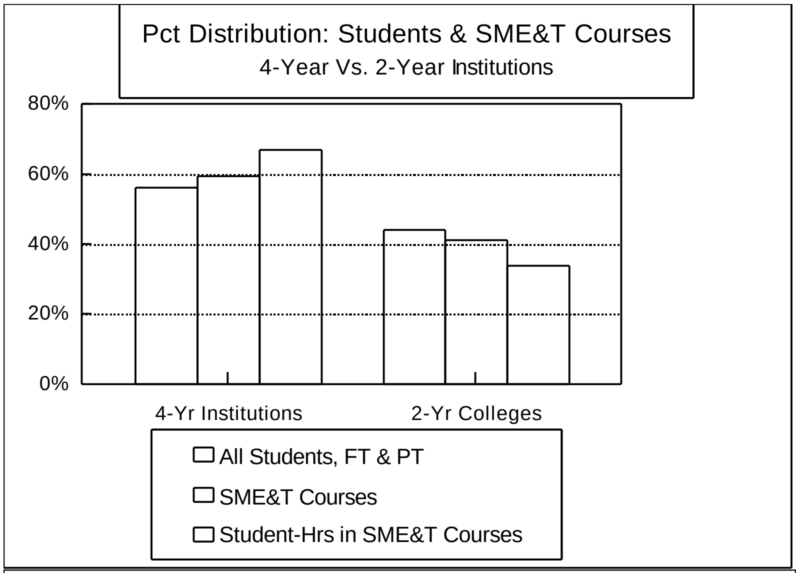
[These data were obtained from the NSF CASPAR data system, now available to the general public from a web site supported by the NSF: http://caspar.qrc.com. This system obtains its data from the U.S. Department of Education surveys known as HEGIS (or Higher Education General Information Surveys) and its successor IPEDS (Integrated Postsecondary Education Data System). Special tabulations were made because the standard tabulations available in *Enrollment in Higher Education: Fall 1994*, NCES 96-440 do not use the same institutional categories.]

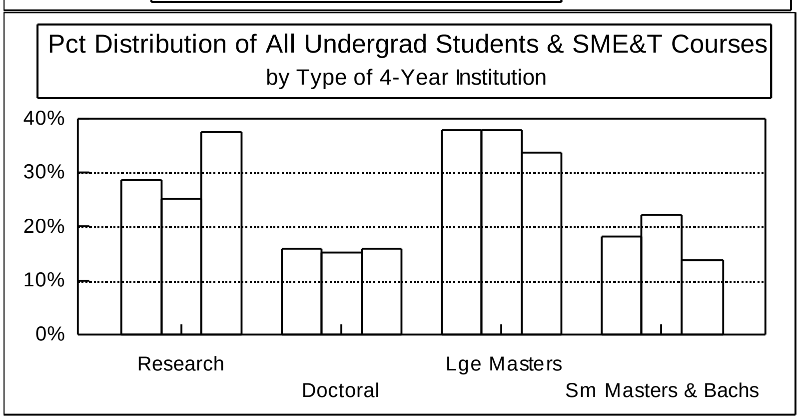
Compared to two-year institutions, four-year institutions have a larger share of SME&T courses than total undergraduates. [The information about SME&T courses was derived from data collected through the *1993 National Survey of Postsecondary Faculty*, NSOPF-93; US Department of Education, National Center for Education Statistics.] (See the charts on the following page.) But within four-year institutions, the distribution of SME&T courses is moderately less concentrated in Research and Doctoral universities than the distribution of undergraduate enrollment. Compared to these distributions of SME&T courses by type of institution, the distribution of students enrolled in SME&T courses is moderately more concentrated in four-year institutions than in two-year colleges, and — within 4-year institution groups — more concentrated in Research universities than in Masters and Bachelors institutions.

Overall, about 500,000 SME&T courses were taught for credit and about 17,000,000 students were enrolled in these courses. (Many students were enrolled in two or more courses.) On average, the enrollment in SME&T courses averaged 1.3 courses per undergraduate student.

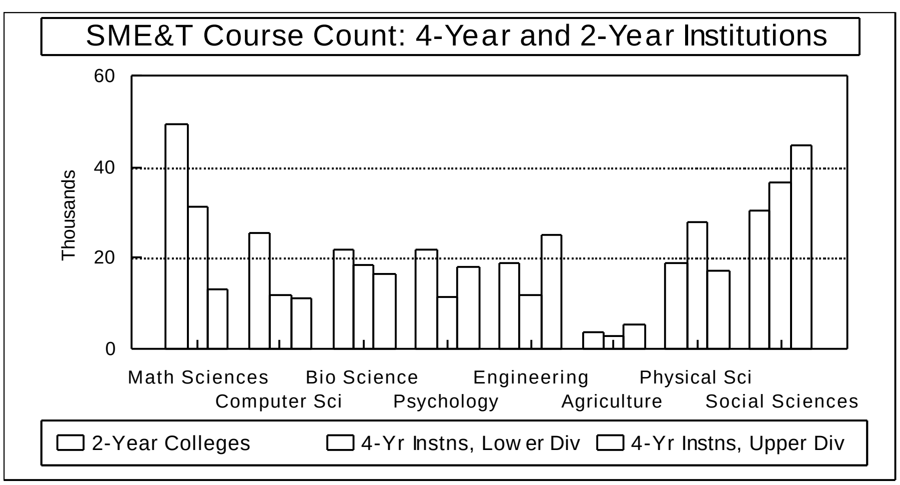
In a number of disciplines at the lower-division level (freshman and sophomore level), more courses were taught in two-year colleges than in four-year institutions. In descending order, these disciplines were the mathematical sciences, computer and information sciences, engineering (including engineering technologies), psychology, agriculture, and the biological sciences. In mathematics, computer science, and psychology, there were also a larger number of enrolled students in two-year colleges compared to lower-division students in four-year institutions.

In the aggregate, including all disciplines and institutions, there were more than twice as many lower-division courses as upper-division courses, and almost three times the number of students

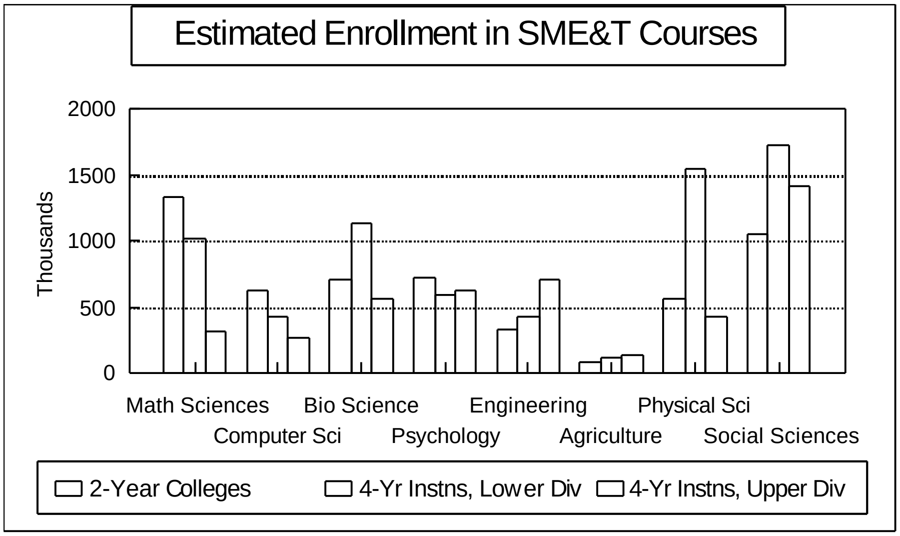




enrolled for credit in the lower-division courses. Mathematics is the discipline most oriented towards lower-division courses and students, followed by the physical sciences and the biological

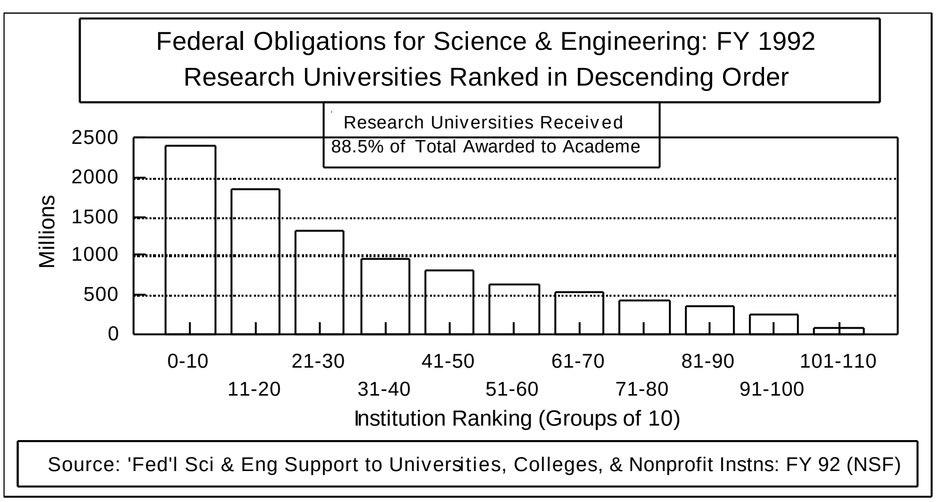


sciences. Engineering is the most oriented towards upper-division courses. This pattern of enrollment indicates the importance and strategic value of ensuring that students in lower-division courses are served with effective course designs and good teaching practices and ensuring that two-year colleges are included whenever possible in efforts to improve student learning in SME&T.



Finally, we turn to the distribution of Federal funds for Science and Engineering (S&E) in academic institutions, a category of Federal support that includes research and development (the largest category), equipment and facilities for S&E (the second largest), and education and training in S&E (the smallest). The Federal Government (which includes NSF) is by far the largest external sponsor of academic S&E.

7b. Distribution of Federal Obligations for Science and Engineering Federal funds are highly concentrated in a number of ways. First, within each institutional category, research funds are highly concentrated. Second, funds are also highly concentrated across classes of institutions. The following chart shows the distribution of S&E funds among all 125 Research universities. (The



distribution in other classes of institutions was similar.) Research universities received 88.5 percent of total Federal obligations for science and engineering in FY 1992 and are clearly in a class of their own. In contrast, all 111 Doctoral universities received only 6.2 percent of total Federal S&E obligations. The top 10 Doctoral universities received slightly less than the ten Research universities ranked 91-100. Other categories receiving significant funds include the top 200 Masters I institutions (with 4.2 percent of the total), the top 100 Bachelors colleges (with 0.7 percent of the total), and the top 50 two-year colleges (with 0.2 percent). Funding is also very highly concentrated within the Doctoral and Masters subgroups: the top 12 Doctorals and 25 Masters received more than 50 percent of the funds in their subgroups.

The following table shows a ranking of these 575 institutions. They are shown in groups of 50 (except for the third group of 25 of Research universities) in descending order based on Federal S&E funding received in 1992. The table demonstrates the highly concentrated nature of these

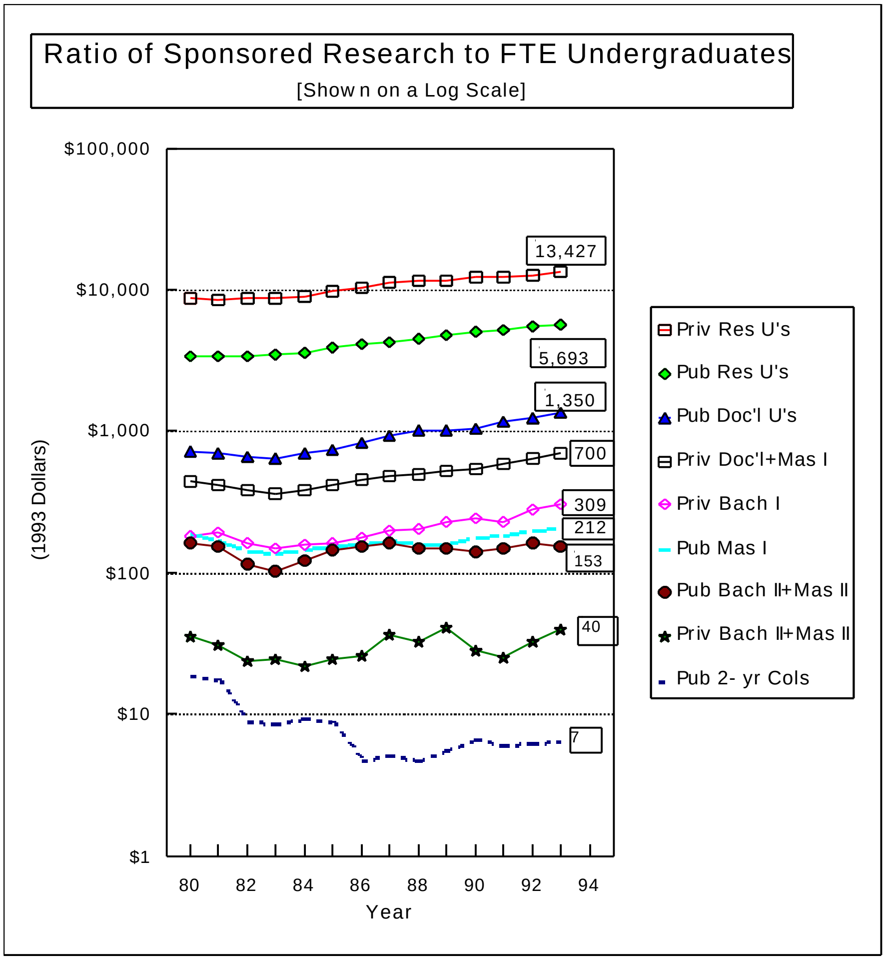
Distribution of Federal Funds for Science & Engineering in FY 1992

Categories of Institutions in Descending Order:	Federal S&E *Per Institution*	FTE Undergrads *Per Institution*
Research Univs Ranked 1-50	147,835,000	15,620
Research Univs Ranked 51-100	46,148,000	14,028
Research Univs Ranked 101-125	15,867,000	12,754
Doctoral Univs Ranked 1- 50	11,784,000	8,330
Masters Instns Ranked 1- 50	7,126,000	6,230
Doctoral Univs Ranked 51- 100	2,131,000	7,606
Masters Instns Ranked 51- 100	1,540,000	7,867
Bachelors Cols Ranked 1- 50	1,160,000	2,186
Masters Instns Ranked 101- 150	645,000	5,318
Masters Instns Ranked 151- 200	355,000	5,010
Bachelors Cols Ranked 51- 100	339,000	1,929

Source: *Federal Science & Engineering Support to Universities, Colleges, and Nonprofit Institutions: FY 1992* (NSF, Division of Science Resources Studies), and U.S. Department of Education, NCES, the IPEDS/ HEGIS surveys of students enrolled. FTE (=full-time equivalent) enrollment was calculated as full-time + 40% of part-time enrollment.

funds. The average enrollment level is provided to give a sense of difference in average size among these groups of institutions. The next chart provides additional perspective, illustrating institutional differences in the ratio of Federal S&E funds per FTE undergraduate, and how these have changed (primarily risen) since 1980.

Within NSF, the distribution of S&E funds is less concentrated than overall Federal funds, partly because of the broad base of institutions participating in the programs of its Directorate for Education and Human Resources (EHR). The awards made by EHR have both expanded the number of institutions receiving NSF funds (from 578 to 828 in FY 1994) and reduced the concentration of funds in the hands of the top 20, 50, 100 (etc.) institutions. It is still the case that institutions receiving the most funds from NSF *research* programs also tend to receive the largest amounts of *education* funds. As the next table indicates, it is also the case that about one-half of all undergraduates were enrolled in institutions that received no NSF funds in FY 1992.



Source: These data were calculated from data obtained from the U.S. Department of Education, National Center for Education Statistics surveys: HEGIS (Higher Education General Information Surveys) and the replacement IPEDS (Integrated Postsecondary Education Data System). Extensive documentation is available at http://www.ws.gov.edu /NCES/. FTE (=full-time equivalent) enrollment was calculated as full-time + 40% of part-time enrollment.

Distribution of Undergraduate Students in 4- and 2-year Institutions by Level of NSF Funding in FY 1992 (Each Row Sums to 100%)

NSF funds = f:	f=$0	f<$100K	$99<f<$250K	$249<f<$500K	f>$499K
1. Undergraduates Counted on an FTE Basis.					
4-Yr Institutions	23%	14%	9%	7%	47%
2-Yr Colleges	87%	10%	2.3%	0.3%	0.3%
All Institutions	49%	13%	6%	4%	28%
2. Full-Time & Part-Time Undergraduates Counted Equally.					
4-Yr Institutions	24%	14%	9%	7%	46%
2-Yr Colleges	87%	10%	2.3%	0.3%	0.3%
All Institutions	53%	12%	6%	4%	25%

Source: NSF funding for all science and engineering was taken from *Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions: FY 1992* (NSF, Division of Science Resources Studies). Enrollment data were taken from the IPEDS/ HEGIS surveys of the U.S. Department of Education, NCES.

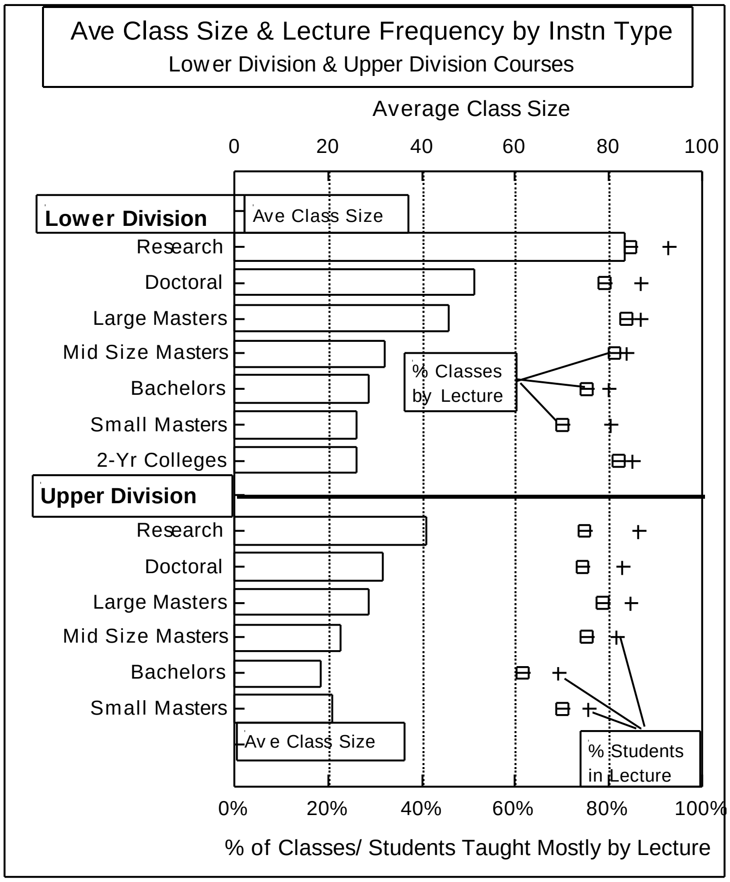
These patterns suggest that we will often find faculty in research intensive institutions developing innovative approaches to teaching and learning in a variety of SME&T disciplines, but that NSF has also helped increase the pace of innovation in undergraduate education by making education awards to a larger base of institutions. In order to maximize the impact of NSF funding, it is important to ensure that promising innovations used initially only by their developers are made accessible to other faculty in other institutions. Making NSF program funds accessible to faculty (in institutions where there is little current award activity) in order to adopt and adapt innovations developed elsewhere is one direct way to accomplish this.

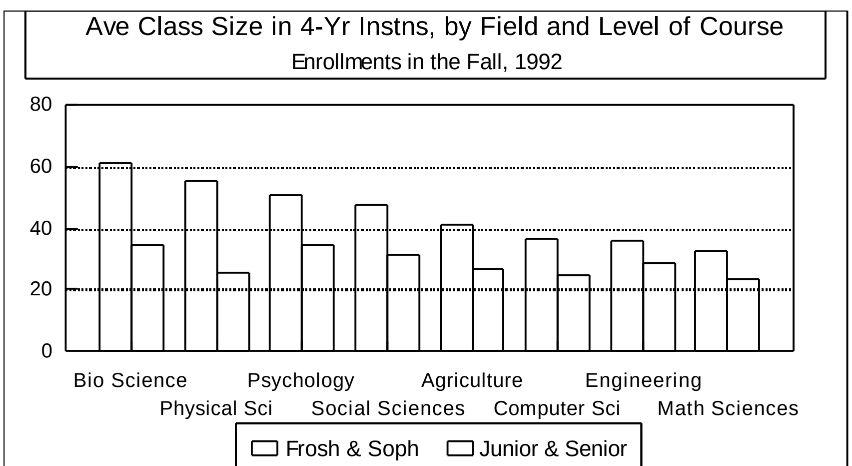
8. Institution Type, Class Size, and Choice of Teaching Methods. The information in this section and the following Section 9 was derived from data collected through the *1993 National Survey of Postsecondary Faculty* (NSOPF-92; U.S. Department of Education, National Center for Education Statistics). There are both institutional and disciplinary differences in average class size. These differences are shown in the next pair of charts, which reflect average teaching practice in the Fall of 1992. Lower-division SME&T courses tended to be the largest (by a considerable margin) in Research universities, and the smallest in Bachelors, small Masters, and two-year colleges. (They averaged 83 in Research universities and 26 in small Masters institutions.) The same ordering was also found in upper-division courses, but the differences were less pronounced. In four-year institutions, the average size of lower-division SME&T classes appears to have had some influence on the percentage of those courses and students taught primarily by lectures. (This influence is also apparent in upper-division courses.)

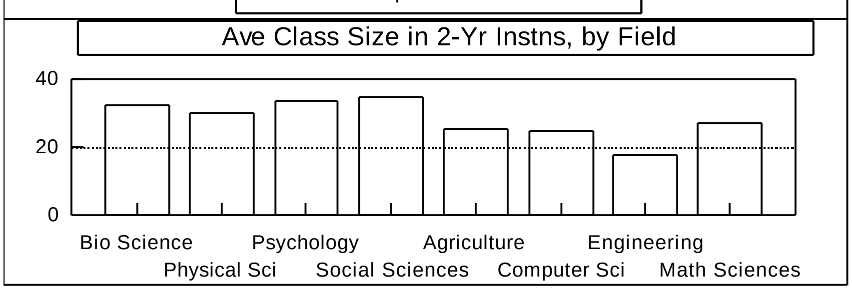
The much larger class sizes in lower-division courses in Research and Doctoral universities were supported in part by a much heavier reliance on teaching assistants. Lower-division classes averaged 1.5 teaching assistants per course in Research universities, and 0.5 in Doctoral universities, but no higher than 0.25 in other institutions. Upper-division classes averaged 0.6 teaching assistants per class in Research universities, but under 0.3 in Doctoral universities and well under 0.2 in other institutions.

Recall that estimated costs per FTE undergraduate (in all fields) were highest in research universities and next highest in doctoral universities despite the larger class sizes and greater reliance on teaching assistants. Clearly, the higher costs in these universities were due to other factors and held partially in check by resorting to large class sizes.

The reliance on lectures is striking. About 80 percent of lower-division courses in large four-year institutions and all two-year colleges were taught primarily by lecture, and about 70 percent of classes in small four-year colleges relied on lectures. Large enrollment courses tend more often to be taught by lecture, with the consequence that about 93 percent of students enrolled in lower-division SME&T courses in Research universities were taught by lecture (87 percent in Doctoral and large Masters universities, and 80 percent in small four-year colleges). The situation was somewhat better in upper-division SME&T courses, but even there more than 80 percent of enrolled students from large institutions were in lecture courses. Only in Bachelors colleges were less than 70 percent of students taking SME&T courses in those taught primarily by lecture.


Ave Class Size & Lecture Frequency by Instn Type
Lower Division & Upper Division Courses
Average Class Size
0
20
40
60
80
100
Lower Division
Ave Class Size
Research
Doctoral
Large Masters
Mid Size Masters
Bachelors
Small Masters
2-Yr Colleges
% Classes by Lecture
Upper Division
Research
Doctoral
Large Masters
Mid Size Masters
Bachelors
Small Masters
Ave Class Size
% Students in Lecture
0%
20%
40%
60%
80%
100%
% of Classes/ Students Taught Mostly by Lecture

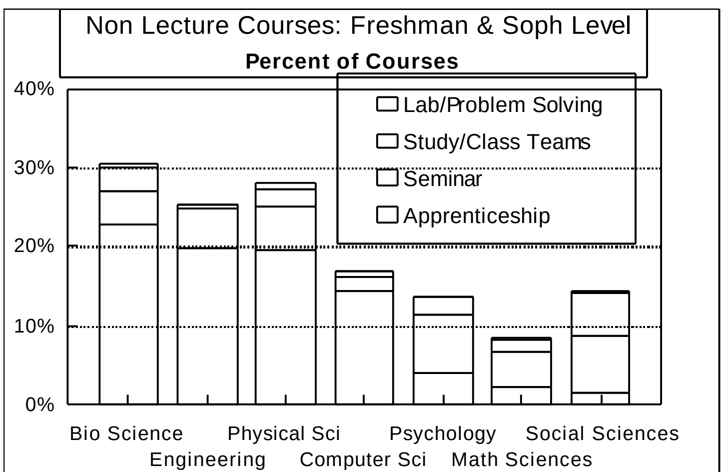

Ave Class Size in 4-Yr Instns, by Field and Level of Course
Enrollments in the Fall, 1992
80
60
40
20
0
Bio Science
Physical Sci
Psychology
Social Sciences
Agriculture
Computer Sci
Engineering
Math Sciences
Frosh & Soph
Junior & Senior

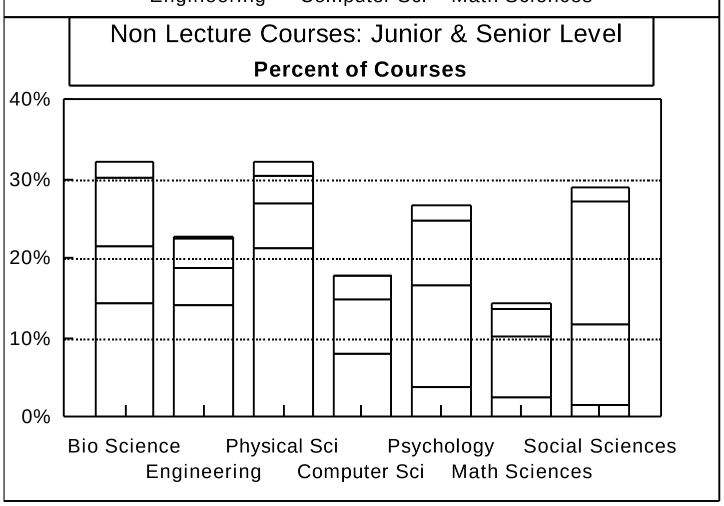

Ave Class Size in 2-Yr Instns, by Field
40
20
0
Bio Science
Physical Sci
Psychology
Social Sciences
Agriculture
Computer Sci
Engineering
Math Sciences

In four-year institutions, average class size at the lower-division level in different fields varied considerably, ranging from over 61 in the biological sciences to 33 in the mathematical sciences. At the discipline level, average class size seems to have had only a small effect on the choice of the lecture method of instruction. In two-year institutions, in every discipline, the average class size was smaller than in four-year institutions. And, although the ordering of size by discipline is not the same (see the last bar graph on the previous page), average class in the first four disciplines was higher (with a range of 30 to 34) than in the last four disciplines (with a range of 18 to 27).

In those courses not relying on lectures, the second most common instructional method used was a laboratory (problemsolving or clinical) approach, followed by "group" approaches to learning (i.e., cooperative learning groups, group projects, class discussion groups, class presentations, and role playing and simulation in class). The frequency of these approaches is illustrated in the two charts at the bottom of this page. A few courses were essentially apprenticeships or internships. These were much more common at the upper-division level.

These more active and interactive modes of instruction were more typically used in small classes, with the result that the percentage of students enrolled in these courses was considerably less than the percentage of courses employing these methods as their primary instructional technique. The high reliance on lectures has been addressed in a number of studies as well as in many published opinions. Consider, for example, the informed opinion published recently by the president of a





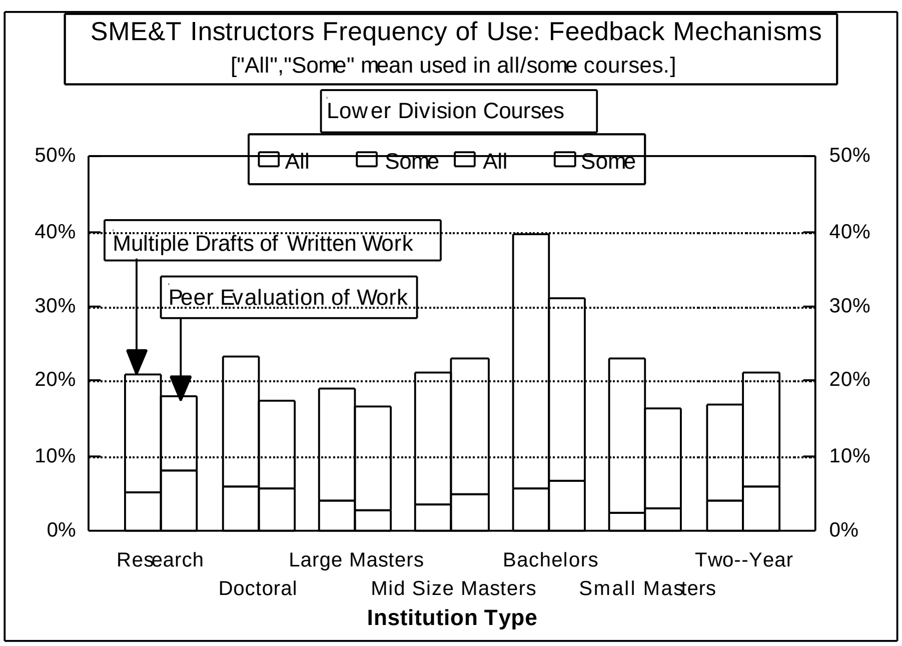
community college, observing that the "instruction paradigm" is still the dominant model for community colleges (Boggs, 1995/96, page 26):

> *Under the instruction paradigm, community colleges are responsible only for providing instruction, not for student learning. Responsibility for learning is the student's. ... Under [this] paradigm, faculty are primarily lecturers. Students are often competitive and individualistic. Faculty members carry out their functions independently of one another. Teachers classify, sort, and grade students.*

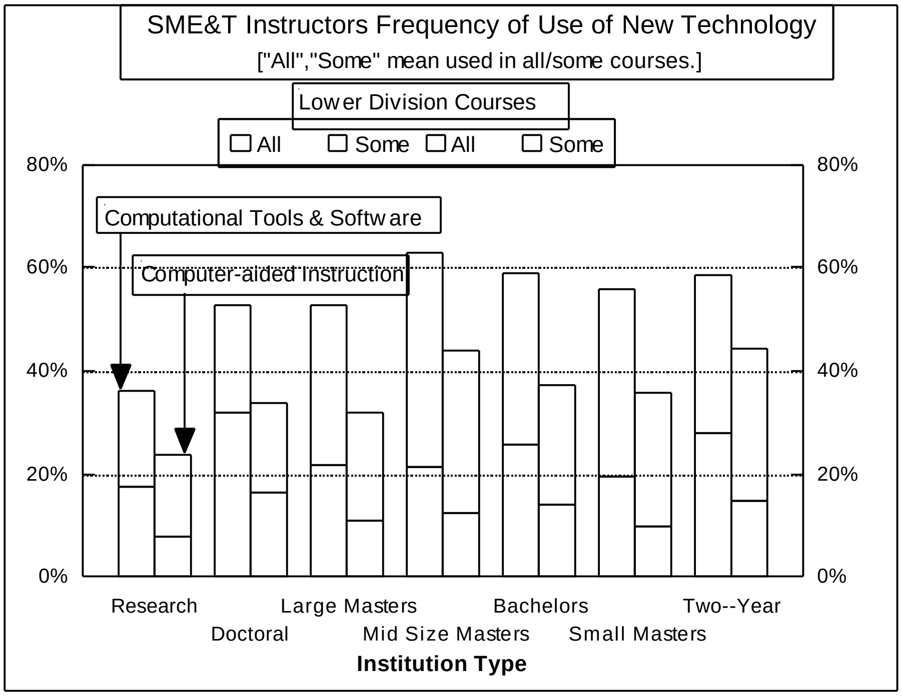
Data obtained from ethnographic studies and from focus groups of students support the hypothesis that most students learn most when reliance on lecturing is reduced. Boggs' careful statement is that he prefers "the learning paradigm," where colleges, as well as students, are responsible for student learning. In this paradigm:

> *...faculty are primarily designers of learning methods and environments. They are ... facilitators of student learning in much the same way as a coach facilitates the best performance of an athlete. They and their students work in teams with each other and with other college staff. ... The learning paradigm does not automatically define the lecture method as bad, ... [but it] will require that lectures prove their value in promoting student learning against other methods. ... Already there is a lot of research to indicate that more active methods of learning are usually more effective.*

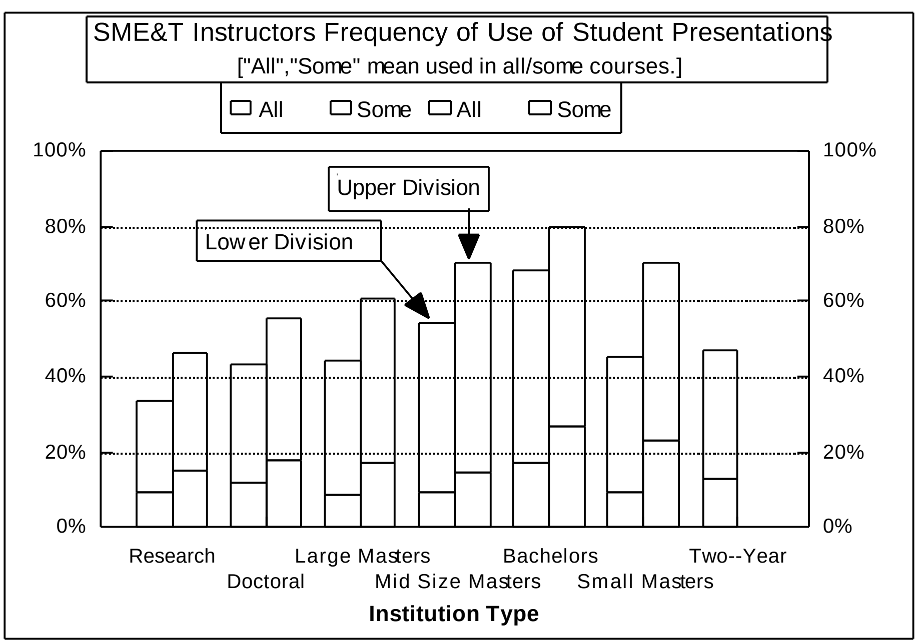
9. Faculty Practices that May Influence SME&T Course-Taking and Student Learning. The ethnographic studies of Seymour and our own focus groups indicate the importance of student access to teachers, teaching assistants, and themselves as peer learners. Even though the lecture format predominates in undergraduate education, it is still possible to improve the learning



environment considerably by employing techniques that ensure more frequent and helpful feedback on student learning. In the first two charts, the reported frequency of some such techniques in

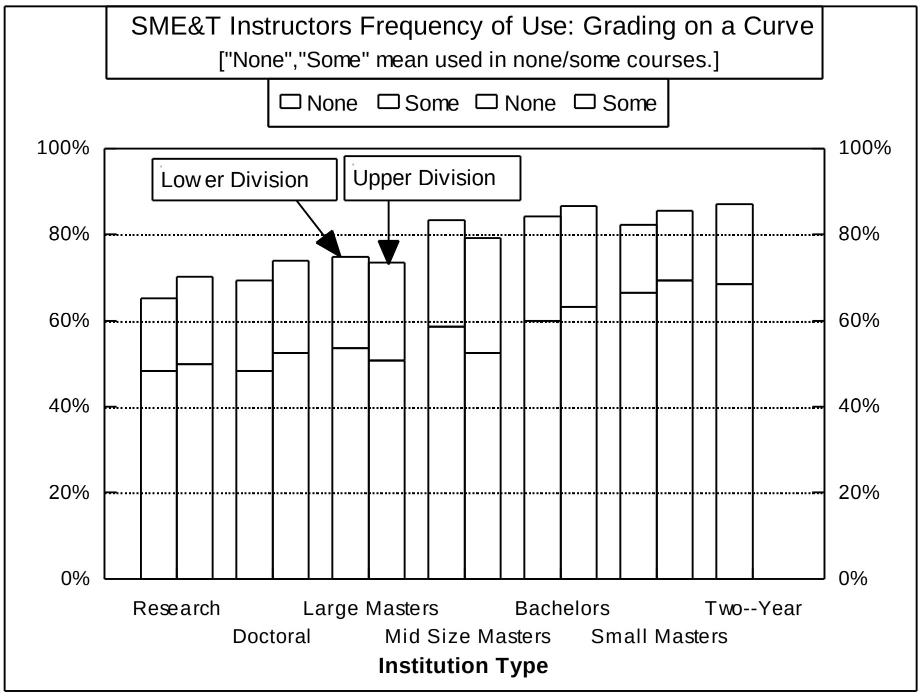


lower-division courses are illustrated from the 1993 Survey of Post-secondary Faculty. These charts illustrate that these techniques were used widely enough during the Fall of 1992 to be familiar at some level of detail to most SME&T faculty. However, teaching practices in SME&T courses taught during that Fall semester more frequently did not employ these methods.



This was particularly true in Research Universities, and also to a large extent in Doctoral and large Masters institutions. Only the use of computational tools and software could be called widespread.

The final two charts examine other good practices in both lower-division and upper-division courses taught by the SME&T faculty. The use of student presentations was most widespread in Bachelors colleges and was also found more frequently in upper-division than in lower-division courses. Grading on the curve, a practice associated with so called "weed-out" courses, is now absent in the majority of SME&T courses. So is the practice of basing grades on multiple choice examinations, particularly in Research universities and Bachelors colleges. This suggests that faculty practices are beginning to change for the better.



10. Employer Perspectives on Desirable Outcomes from Undergraduate Study. Employers today are seeking entry-level employees at the associate or baccalaureate degree level who can demonstrate solid basic (disciplinary) skills *and* a full complement of other skills. These other skills make the recently acquired specialized knowledge more valuable to the organization, which increasingly seeks to combine diverse areas of expertise embodied in individual employees by bringing them together to work in teams. Private firms have become more demanding and cautious in screening potential new employees, and increasingly require a full complement of skills in their new hires.

Statements made by employers about their needs and preferences have been growing in number during the 1990s. Yet these show a remarkable degree of consistency in identifying the skills sought from college educated, entry-level employees. (These skills are described in a subsection below.) Employers' preferences have also had a noticeable influence on undergraduates' strengthened sense of purpose.

Many employers also agree that the *growth* in skills needed to fulfill many jobs — including many professional occupations — has been rapid, and seems to have outstripped the capacity of many undergraduate institutions and their programs to keep pace. This is because most undergraduate programs are not specifically designed to help students develop these skills directly.

The deficits in skills identified most frequently by employers are usually not defined in terms of the disciplinary knowledge of recent graduates. In fact, employers of SME&T graduates have often indicated their basic satisfaction about the specific knowledge that recent graduates with good grades bring from most academic institutions to entry-level positions. However, while many academic SME&T departments are thought to produce able college graduates from able high school graduates, the bulk of them are often seen as not serving the needs of the remaining students to achieve a desirable level of SME&T competence or literacy, and there is growing concern about the breadth of learning of high-achieving SME&T graduates (as there is at the graduate student level).

There is also some concern about the low numbers of able graduates. Metaphors abound to convey this judgment of limited success. Faculty are advised to switch from playing the role of "filter" to being a "pump" (Steen, 1991, page 19). Departments are disparaged for conducting "weed-out" courses and employing excessively competitive grading practices (Seymour and Hewitt, 1994). Undergraduate SME&T education during the past three decades is described by Goodstein (1993) as:

> *... a mining and sorting operation, designed to cast aside most of the mass of common human debris, but at the same time to discover and rescue diamonds in the rough, that are capable of being cleaned and cut and polished into glittering gems, just like us, the existing scientists. ... [This] explains why we have the best scientists and the most poorly educated students in the world. It is because our entire system of education is designed to produce precisely that result.*

Employers are articulate in describing in general terms the types of skills that enhance the value of their employees, but they are not comfortable prescribing either methods for bringing undergraduate programs into better alignment with their stated needs or specifying actual levels of knowledge that recent graduates should have mastered in various disciplines. (See, for example, Bikson (1995), Verville (1995), Pew Higher Education Roundtable (1994), Wingspread Group on Higher Education (1993), and the National Center on Education and the Economy (1990). See also the written testimony of employers participating in a hearing at NSF on November 1, 1995, particularly the statements of Israel Galvan (GHG Corporation), Roberts Jones (National Alliance of Business), John McMasters (Boeing), Alfred Moye (HP), John Sisler (Shell Oil), and Patrick White (Bell Atlantic).

There are sound reasons for this reluctance to prescribe specific features of improved college programs. One is that the overarching need is for employees that can continuously adapt, adjust, and re-educate themselves to remain productive in a changing environment. As one employer commented to the National Academy of Sciences, "we may place a new employee in a position which exploits any special expertise [learned] in order to provide 'a soft landing,' but he or she will eventually be called upon to handle a wide range of problems that go far beyond the [formal course work] received during the completion of the Ph.D." (National Academy of Sciences, *Reshaping the Graduate Education of Scientists and Engineers*, 1995).

Another reason is that competence in mathematics, science, engineering, and technology serves a broad range of objectives, and needs vary by student major and intended career (for example, consider the literacy needs of a chemistry major, a mathematics major, and an English major). This broad range of needs is often a difficult issue for academic departments seeking to redesign their curricula. A representative minimum level of literacy was recommended by Lynn Cheney when she was Chair of the National Endowment for the Humanities (1989). She suggested a core 50-credit-hour curriculum for college students comprised of three civilization courses, a foreign language course, and a year of mathematics and science that is more than most undergraduates typically are required or elect to take. The study of mathematics would examine mathematics as a field of inquiry. The science course would cover the physical and life sciences, focusing broadly on how scientists have historically developed and validated new concepts and past concepts of matter, energy, and life.

<u>A Brief Look at Desired Workforce Competencies</u>. Jobs increasingly require basic knowledge of SME&T, as does the capability of individuals to engage in lifelong learning in broad directions. There is a growing expectation that successful students must acquire those skills that will allow them to be lifelong learners, often in non-academic settings. We are increasingly told that change itself is the *status quo*. Broadly speaking, a minimum requirement for lifelong learning is a basic grasp of mathematics and its uses, science and its methods, and technology and its effects. The expected need for this knowledge in the future is widespread among professional jobs and is spreading rapidly in so-called blue-collar occupations. Verville (1995) notes that about 65 percent of all workers in the U.S. use some type of information technology in their jobs, and this figure is anticipated to be 95 percent by the year 2000. (Recall from Section 3, Public Attitudes About Subsidies, that most of the job growth in the past decade has occurred in government, personal, and business services.)

A college graduate seeking employment must currently demonstrate the following skills in order to successfully compete for professional positions in a number of manufacturing or service firms with national or international operations. [These are borrowed from Bikson (1995).] The job seeker's academic major and associated transcript and grades open the door to job interviews, but the following skills are sought by employers to justify offers of employment:

Generic cognitive skills
- Problem solving skills
- Learning how to learn
- Decisionmaking skills

Social skills
- Communications skills
- Interpersonal skills (teamwork)

Personal traits
- Adaptability and flexibility
- Openness to new ideas, empathy for ideas of others
- Strong work ethic
- Innovative and entrepreneurial outlook

Many of these skills are seen as important because employees are more typically working together in teams comprised of demographically and functionally more diverse coworkers. Many firms are employing greater numbers of women, minority males, and employees from foreign countries, whose specialized training spans R&D, engineering, manufacturing, marketing, sales, and legal services. Compounding the challenges of diversity is the pace of technological change. Products and services are being changed rapidly under intense competitive pressure to accommodate regional preferences and to incorporate quality improvements.

Among recent baccalaureates who have demonstrated some mastery of their coursework in a college or university whose academic program is known to the potential employer, each of the above competencies was considered more important than academic achievement in predicting a job candidate's performance on the job. Some employers expect colleges and universities to inculcate these skills and traits more deliberately as part of the undergraduate learning experience. Such skills cannot be expected to develop in passive learning environments where the dominant pedagogical approach is lecturing by the faculty and note taking by the students, punctuated by cookbook laboratory exercises or, in some courses, recitation sections devoted to unimaginative sets of problems to be solved (designed to develop familiarity in using tools through repetitive practice).

These skills needs of employers can be developed as part of undergraduate studies to a much greater extent through the choice of sound pedagogical (learning-enhancing) practices and the increasing use of curricular improvements in SME&T courses. Many of these practices have been clearly identified by many contributors to this Review as more effective than traditional methods for most learners. In essence, this crucial finding is described by the following set of points:

1. Students acquire SME&T knowledge and retain it years later far more effectively when courses are designed with learning effectiveness as the highest priority, as opposed to covering a fixed body of "material."
2. Pedagogical techniques that teach teamwork and communication, sharpen cognitive skills, and help to develop openness to new ideas, adaptability, and flexibility are known to also enhance subject matter learning.
3. There should be a focus on concepts that apply across fields, and on connections across the disciplines and between science and technology, especially in basic introductory courses. At advanced levels of education, this translates as a recommendation for breadth as well as depth of learning. This is perhaps the most prescriptive recommendation for SME&T courses identified by contributors to this Review.
4. A much higher percentage of students from a given pool would be drawn to SME&T if curricular and pedagogical "best practices" were more widely employed.

<u>11. Electronic Technology and Systemic Reform</u>. The realization is growing that academic institutions no longer have a collective monopoly on knowledge, and access to that knowledge (which traditionally has been located in libraries, textbooks, and the brains of faculty). [See, for example, Noam (1995), Duderstadt (1995), Denning (October 23, 1995 NSF Hearing Testimony), Ward (October 25, 1995 NSF Hearing Testimony), and Massy and Zemsky (1995).] Noting that there are numerous examples of applications of new technology, Massy and Zemsky predict that, in most institutions, the demand for using information technology to assist teaching and learning will grow exponentially over the foreseeable future and "will change teaching and learning profoundly, no matter what the response of traditional higher education institutions." Competition from nontraditional providers of education will pressure colleges and universities to exploit these new technologies, a theme echoed by many others.

However, it is also realized that there is a lot of exploratory work to do before we can exploit the full potential of new technology (e.g.,Noam, 1995, and Vest, 1996). For example, Vest (1996, page 4) warns us that we do not yet know how best to use the new information technology for many education objectives. Massy and Zemsky agree, stating:

> *Across American higher education the lure of the new information technologies remains as uncertain as it is unsettling. While few doubt that information technology has the potential to enhance teaching and learning, there is no agreement on how that technology should be used to boost academic productivity — or whether such an increase is in itself a valid goal if its enhancement means substituting technology for the more traditional, labor intensive rhythms of higher education.*

Many believe that the opportunity to become an effective lifelong learner outside of academic settings has been improved immensely by technological improvements in personal computers, the Internet (and other computer networks), the World Wide Web, and numerous software tools. We are making increasingly sophisticated use of video and audio technology in connection with these other advances, which "softens" this technology, making it more "personable." We are on the threshold of widespread access to digital libraries, with the promise of powerful tools becoming available to individuals, which will assist them to find, extract, understand, and connect information from a variety of sources. This will form a building block for the development of "virtual universities." The opinions of many who have discussed using these technologies in undergraduate settings agree that we have only started to exploit its potential. Faculty are increasingly expected to become knowledge guides rather than center-stage actors. As the National Academy of Science stated about the future of education, the promise of these related technologies is that:

> *... all students will be held to far higher standards of learning because everyone will have to be prepared to think for a living and everyone will have to be capable of learning many new skills over the course of a lifetime. ... The timing and location of education will be more flexible ... The distinction between learning inside of school and outside of school will blur.* (*Reinventing Schools...*, 1993).

Section VI:

Contributors to the EHR Advisory Committee Review of U.S. Undergraduate Education in SME&T

Acknowledgments

Shaping the Future is the product of many people, and it is a pleasure to acknowledge their contributions to this report. My only fear is that I will overlook someone, and I hope for forgiveness if that is the case.

First, I thank Luther Williams for the idea to do the report in the first place and the unfailing support and encouragement to complete it and to implement it. To Bob Watson, Division Director for Undergraduate Education is owed an enormous debt of gratitude. Bob opened the Division to me, provided whatever I needed to get the job done, allowed me to observe and participate in many aspects of the Division's work, and gave invaluable advice and suggestions at every stage. Throughout, however, he was careful to allow me to be independent. Any lapse of objectivity is my responsibility, not his.

The staff in DUE were helpful beyond belief, though they had a full plate of responsibilities without this review! They provided information and assistance at every turn, seemingly never too busy to answer a question or offer a suggestion. They planned the conference, "Shaping the Future," in such a way as to provide a superb sendoff for our report. Thanks to all of them, who became and still are good colleagues.

Special thanks are due to Myles Boylan and Peter Yankwich, who did most of the staff work, analyzing information, commenting on early drafts, gathering data, and providing invaluable historical perspectives. Anita Broadus was our faithful secretarial support, solving all sorts of problems and providing all sorts of assistance, always with a smile. Ranetta Roseboro was always available as backup, helping me with computer or administrative problems.

Outside the NSF, I acknowledge with gratitude my colleagues at the NRC with whom we worked so closely. Thanks to Don Kennedy, who provided the overall leadership for "From Analysis to Action," along with Brad Moore, Chair of the NRC's Committee on Undergraduate Science Education, and Nancy Devino, NRC staff. They were faithful colleagues whose commitment and wisdom are reflected in many ways in *Shaping*.

The RevUE committee was wonderful. They trusted me, corrected me, improved my writing, made me think, broadened my horizons. The report would not have been nearly so complete or accurate without their invaluable help.

I thank my several institutions, who permitted me the time to work on *Shaping the Future*. I am particularly grateful to the University of Minnesota for giving me the opportunity to do the major part of this work, on an IPA with the NSF. But St. Olaf College and The University of Missouri have also generously shared me (or maybe they were glad to be rid of me!) for some of this work. I trust they will think it has been worthwhile.

Finally, I thank most sincerely all those around the country who participated in the review, through writing letters, testifying at hearings, sending information, responding to my questions, being part of the opening convocation, regional symposia, discussions at professional meetings, or the final conference itself. Your ideas, not mine, are reflected in the report. It was you who have done so much to improve SME&T undergraduate education in the past 10 years—and it is that progress that created a climate in which the vision we tried to articulate in *Shaping* could even be conceivable. Thank you, on behalf of all of our students, today and in the years to come.

Melvin D. George
Columbia, Missouri
March, 1997

Reproduction of the letter sent out by NSF Assistant Director Luther Williams to initiate discussion and commentary on the national state of undergraduate education. Respondents to Dr. Williams' letter, the various NSF and NRC steering committees, participants and contributors to the process are listed following the Description of the review.

OMB 3145-0156
EXP. DATE 12/95

June 14, 1995

Dear ____________

I seek your assistance with a comprehensive review of undergraduate education in science, mathematics, engineering, and technology (SME&T) that is being carried out by the National Science Foundation. SME&T education in the United States takes place in different types of institutions and in very diverse settings; we are seeking guidance from every major sector. At this early stage, I am soliciting the views of a small number of persons experienced and strongly interested in the subject of the review in order to identify major themes, topics, and focal points for consideration.

The attached memorandum, *NSF Review of Undergraduate Education*, describes the structure of the effort, indicates the policy context, lists the goals of the Foundation's SME&T education activities, and indicates some of the broad areas of inquiry to be studied. This solicitation of views occurs at the beginning of *Phase I*.

I invite you to participate now in the Review by writing a substantial letter based on your experience with contemporary undergraduate SME&T education and focusing on two questions:

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

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?

I hope you will use *student learning in SME&T fields* as the primary frame of reference for your remarks, and the *quality of the resulting student preparation for diverse post-matriculation pursuits* as the primary criterion for judging educational merit. Your letter (or any questions) should be addressed to "Undergraduate Review," c/o Dr. Robert F. Watson, Director, Division of Undergraduate Education, Room 835 at the above address. Your input is needed by August 1, 1995. A report summarizing the findings and recommendations of the review should be available to share with you early in 1996.

Your letter will be an important addition to the contributions you have made to undergraduate education. I thank you for it.

Sincerely,

Luther S. Williams
Assistant Director

NSF Review of Undergraduate Education: Description

The Education and Human Resources (EHR) Directorate of the National Science Foundation (NSF) is undertaking a general review of the condition and needs of undergraduate education in the United States in the areas of science, mathematics, engineering, and technology (SME&T). This review includes wide consultation with students, educators, and employers. It will produce, by late spring 1996, a set of recommendations for accelerating progress in the improvement of undergraduate education. Concurrent with the review is a national dialogue on this subject conducted by the National Research Council and following from the joint NRC-NSF *Convocation on Undergraduate Education* held in April 1995 in Washington DC. The NSF review is coordinated with this dialogue—drawing on it and on other sources of input from individuals, organizations, and groups across the country.

Acting in an advisory capacity to Luther S. Williams, Assistant Director of NSF for EHR, are members of the Subcommittee for Undergraduate Education of the directorate's Advisory Committee:

Sadie Bragg, Borough of Manhattan Community College
Denice D. Denton, University of Wisconsin - Madison
Melvin George, University of Minnesota, (Chair)
Peter Gerber, MacArthur Foundation
Mary M. Lindquist, Columbus College (Georgia)
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David Sanchez, Texas A&M University
Alfredo G. de los Santos, Jr., Maricopa Community Colleges (Arizona), and
Carolyn Meyers, North Carolina A&T State University, (Consultant)

The Foundation is undertaking this review of the central enterprise of undergraduate education at a critical moment. National efforts to improve *precollege* education in SME&T, including those of the NSF, have been extensive and have involved efforts to create both innovative local improvement and larger systemic changes. The support of such efforts at the *undergraduate* level is more recent and has emphasized innovative improvement projects at single sites. The necessity for—and possibility of—larger-scale changes in undergraduate education is the primary question the review will investigate. While the Foundation recognizes that it raises this question at a time when the nation's colleges and universities are facing unprecedented financial and programmatic challenges, it is expected that the review will reveal ways of increasing the effectiveness of these institutions in undergraduate education. The provision of excellent educational services requires a robust infrastructure whose components at all institutions include faculty, curriculum, and capabilities for teaching and scholarship. The condition and support of these components will be examined.

The goals of improved undergraduate education in SME&T are:

- citizens who are empowered to be full participants in a scientific and technological society;
- a technically well-prepared workforce that can both participate and lead in a high performance workplace employing advanced technologies;
- teachers who are solidly grounded in both science and pedagogy, and scientists and engineers who are well-prepared for their occupations; and
- young people with diverse backgrounds, reflecting the changing face of America, successfully involved in SME&T.

Consistent with its chartered responsibility to "initiate and support ... science education programs at all levels …", the NSF seeks to ascertain the extent of effective innovation in undergraduate education in SME&T, and to determine what steps, if any, should be taken next to bring about further significant improvements. The specific areas of inquiry listed below are designed to lead to implementable recommendations to universities and colleges, scientific societies, and government and private funding and credentialing agencies (including, particularly, NSF itself):

- What are the innovations in undergraduate education and what is the evidence that their adoption represents a superior practice of undergraduate education? [The areas of inquiry regarding superior practice will involve: curriculum of all types and levels, faculty maintenance and development, pedagogy, instructional technology, instrumentation and facilities, research opportunities for students and faculty, and connections of instructional programs to the world of work.]
- What are the unmet educational needs of those who are receiving and have received undergraduate SME&T instruction?
- What infrastructure needs of institutions offering undergraduate instruction must be supported for them to implement the best instructional practices and meet the needs of students and employers?

In the context of an institution's entire undergraduate enterprise, what are the problems that need to be addressed to achieve the goals of undergraduate SME&T education? What are suggested solutions to these problems? Who should do what, and how?

The effort through which the Foundation plans to address these questions will consist of three phases:

Phase I, now well advanced, involves direct, systematic investigation of the considered points of view of a broad spectrum of individuals and organizations who may be regarded as the "customers" of the diverse educational programs and institutions that deliver undergraduate education. Four major means are being employed: (a) Responses are being analyzed to letters soliciting the views of nearly 200 individuals and organizations. (b) Comments are being invited at a number of disciplinary and educational conferences. (c) Hearings were held to receive testimony from representatives of disciplinary groups, institutions of higher education, and business/industry. (d) Focus groups of students, recent graduates, parents, employers, and graduate/professional schools admission officers are being conducted. In addition, existing reports and data on undergraduate SME&T education are being analyzed.

Phase II of the review will present a summary of preliminary findings and tentative recommendations from Phase I for comment and elaboration to a large number of persons experienced in undergraduate education: individuals and organizations will be contacted, regional hearings will be held, and there will be discussions with faculty and administrators attending key professional society meetings.

In *Phase III*, the review will formulate, based on Phases I and II, specific firm recommendations in a plan for action to achieve the goals stated above for improved undergraduate education in SME&T. The report conveying the results of the review is expected to be ready in the spring of 1996 and will be disseminated first through a major event planned for July 1996 in Washington, DC.

For further information contact the Division of Undergraduate Education of EHR.

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Section VII:

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