THEN, NOW, & IN THE NEXT DECADE

The undergraduate years are critical for strengthening our nation's science and mathematics capacity. It is in college where future scientists and college faculty are recruited and prepared for graduate study; where our nation's elementary and secondary teachers, educators of America's youth, are equipped; and where tomorrow's leaders gain the background with which to make critical decisions in a world permeated by vital issues of science and technology.

A COMMENTARY ON STRENGTHENING UNDERGRADUATE SCIENCE, MATHEMATICS, ENGINEERING AND TECHNOLOGY EDUCATION

FRANK G. ROTHMAN
BROWN UNIVERSITY

JEANNE L. NARUM
PROJECT KALEIDOSCOPE

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December 1999

Dr. Norman Fortenberry, Director
Division of Undergraduate Education
Directorate for Education and Human Resources
National Science Foundation
Arlington, VA 22230

Dear Dr. Fortenberry:

On behalf of our colleagues in Project Kaleidoscope, we transmit this report, *Then, Now, & In the Next Decade: A Commentary on Strengthening Undergraduate Science, Mathematics, Engineering and Technology Education.* Our charge was to answer the questions, "Are new approaches in classroom and laboratory making a difference? To whom? How do we know?"

These are timely questions, as the past decade has been one of unparalleled attention to improving the learning environment for undergraduate students in mathematics, engineering, and the various fields of science (SME&T). Our point of departure (*then*) is the mid-1980s, when education in these fields was not perceived to be serving national needs. We contrast the circumstances of that time with those of today (*now)* and identify steps that need to be taken in the coming decade to address urgent needs of students, science and technology, and society. We have focused on five primary arenas of activity: learning and assessment, course and curriculum, facilities, technology, and faculty and scholarly networks. Attention to students is woven throughout, recognizing that the aim of reforms is to make a difference in regard to the learning of all students.

We are encouraged by the evidence of progress made since the mid-1980s in designing, understanding, and adapting new approaches in SME&T classrooms and labs, in creating spaces that accommodate these new approaches, and in changes in institutional policies and practices that ensure such approaches will have long life. But when we look at the entire undergraduate SME&T enterprise, efforts to date can only be seen as a pilot for a large-scale national effort in the coming decade. We need to press for greater support from the campuses, changing the attitudes of more presidents, deans and faculty about the urgency of this work. We need also to press the external constituency—the officials who decide funding priorities, the parents who influence their children's education, and those who hire our graduates—to recognize how an investment in undergraduate programs in science, mathematics and engineering is an investment in the future of this nation.

We believe the most recent generation of reforms has made a difference. What needs to be done in the next decade is presented in detail in these pages. We look forward to working with you and with all who share our conviction that striving together for strong undergraduate programs in mathematics, engineering, and the various fields of science is in the national interest.

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HISTORICAL OVERVIEW: 1945 - 1986

1945: Research leading to the atomic bomb increases public interest in and apprehension of applications of the physical sciences and engineering.

1945: The GI Bill opens up the possibility of college for millions of students who could otherwise not afford it, and plants the idea that all Americans should have access to a college education.

1950: The federal government creates the National Science Foundation (NSF).

1950-1970: Public higher education expands rapidly. In 1950, college enrollments total 2.3 million; approximately 50% are in private institutions. By 1970 college enrollments total 8.6 million; about 25% are in private institutions (McPherson and Schapiro, 1999).

1950-1986: With support from the federal government, universities build major scientific research programs.

1953: The Watson-Crick model for DNA structure opens up biological and medical sciences for revolutionary advances, including genetic engineering and the biotechnology industry.

1959: Launching of Sputnik leads to massive federal efforts to improve SME&T education. Leading university research scientists join in designing new high school curricula.

1960s: The Civil Rights movement results in affirmative action programs to bring underrepresented minorities into the mainstream of American higher education.

1967-75: Two-year colleges become a major component of higher education with an increase from 20% to 34% of total enrollments, serving students from diverse backgrounds and with diverse career aspirations (National Science Board, 1999).

1969: U.S. success in landing men on the moon reassures the country of our scientific and engineering future.

1970s: The Vietnam War dampens the enthusiasm of many youths for the technology that contributes to the unpopular war, resulting in a shift in enrollments from the physical to the social and biological sciences.

1970s: Increases in college enrollments level off as the last of the baby-boomers go to college. Economic rewards of a college education begin to ebb as the supply of academically-trained workers exceeds demand.

1970s: The emerging women's movement leads to many social changes, including the increase of women in higher education. Coeducation begins to bring women into 'typically-male' professions.

1970s: To meet changing student interests at a time of lagging enrollments, colleges develop undergraduate professional programs, for example, in business, computing, and nursing.

1982-1984: NSF abandons direct support of undergraduate education, which had reached annual funding as high as $43 million in the immediate post-Sputnik years.

1977-1985: Personal computers by Apple and IBM achieve wide use in academic work. In 1983, the Internet is first introduced for research communication.

MID-1980s: Various studies paint a dismal picture of the status of undergraduate SME&T programs.

1986: A National Science Board document (the 'Neal' Report) provides a blueprint for revitalizing undergraduate SME&T education and charges NSF to take a leadership role in its implementation.

EXECUTIVE SUMMARY

This Commentary focuses on reforms in undergraduate education in science, mathematics, engineering, and technology (SME&T) since 1986. We present a snapshot of what these programs are like at the end of the century and outline steps to take in the next decade. As reforms are rooted in the past, why then do we begin in 1986 rather than 1945, when demographics of undergraduate students changed dramatically with the GI Bill of Rights? Or perhaps 1959, when the launching of Sputnik galvanized attention on a strong undergraduate SME&T community to serve the national interest? We begin with 1986 because dramatic changes have occurred and something significant has emerged since that time: a successful (though fledgling) movement to transform undergraduate SME&T programs by focusing on *the learning of all students*.

From a number of developments, we can determine that new approaches are making a difference:

- In a world in which science and technology have an increasing impact on how we all live and work, a primary focus of academic planning is shifting from preparing a small number of select students for careers in SME&T fields to preparing *all* students, those from diverse backgrounds and with different career aspirations, for the kind of century that is just around the corner.
- Research in cognitive science is helping to inform us about how students learn, and thus about the advantages and disadvantages of various ways of teaching, in SME&T fields. Research which deals with effective measures of assessment is also contributing to the work of reform.
- As our understanding of ourselves and of the world in which we live is enriched daily by scientific discovery, and as business and industry press for a more technologically-sophisticated work force, a rigorous encounter with mathematics and science for all undergraduates is becoming an issue both of a liberal education for the 21st century, and of national competitiveness in a global economy. Education centered on the learner is becoming the best way to prepare *all* students, including those preparing to be the next generation of K-12 teachers. This focus on all students fosters also the entry and retention of groups currently underrepresented in these fields, a national goal which has not been served by traditional approaches.
- Rapid advances in the usability and accessibility of information technologies are providing new opportunities for faculty to transform how they teach and do research, in ways that could not have been imagined in the mid-1980s and in ways responsive to student demand. These same technologies provide means for sharing curricular and research materials and facilitate the spread of reform.

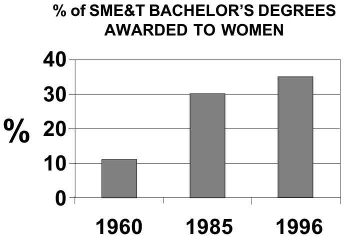
Such beachheads of reform are becoming established at hundreds of colleges and universities, yet those engaged in this effort remain a minority. Some resistance—to approaches that incorporate inquiry-based learning, greater interaction between student and instructor, collaborative learning opportunities—comes from faculty who believe there is no evidence that new ways are better than old. Others hesitate to become engaged in reform because of an institutional culture in which the faculty reward system is based more on achievements in research than in classrooms and labs with students.

Yet, from careful assessment of new approaches, there is a growing body of knowledge about what works in strengthening student learning. The challenge now is to expand current efforts making a difference into more colleges and universities across the country. To make this happen as a nation we need to:

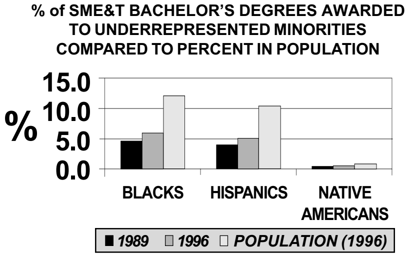
- agree on the salient features and *raison d'être* of strong undergraduate SME&T programs
- identify and support faculty, curricula and institutions with demonstrable success in attracting and sustaining interest of all students in SME&T, and facilitate widespread adaptation of best practices
- document meticulously the impact of new pedagogies, technologies and practices on student learning
- establish what it will cost, at the local and national level, to make an investment in undergraduate SME&T that will truly make a difference in the next decade.

THEN & NOW: 1986 - 1999

WOMEN:
The percentage of SME&T* bachelor degrees awarded to women has increased dramatically since 1960, but the overall percentage of 35% is still substantially below the percentage of women in the population (51%). 1996 percentages: life sciences, 50%; physical sciences, 36%; math and computer science, 34%; and engineering, 18%.



UNDERREPRESENTED MINORITIES:
In spite of modest increases, the percentage of bachelor's degrees remains well below the percentage in the population.



These groups account for less than 3.5% of doctoral candidates, unchanged since 1976.

(National Science Board, 1998; National Science Foundation, 1999)

THEN[†]	NOW[†]
LEARNING AND ASSESSMENT	
◆ Courses were generally organized around lectures to passive students; teaching was largely in the context of one discipline.	◆ Pedagogies are shifting to emphasize active student learning, informed by successful experiments in teaching and by studies in cognitive science. Students cross disciplinary boundaries in their learning.
◆ Professionals trained in cognitive aspects of assessment methods were seldom consulted by SME&T faculty.	◆ Increasingly, assessment methods measure student learning are the subject of joint research and practice by cognitive scientists and SME&T faculty.
COURSE AND CURRICULUM	
◆ Programs to increase access and retention of groups traditionally underrepresented in the study and practice of science were, by and large, not working.	◆ New pedagogical approaches that give attention to different styles of learning and career aspirations are having an impact on learning by all students. These approaches provide students firsthand experiences with design and discovery, including those that incorporate real-world problems. Marked increases in enrollments of underrepresented groups is not yet visible.
TECHNOLOGY	
◆ Computer-assisted instruction and distance learning (by correspondence and television) had little impact at the undergraduate level.	◆ Sophisticated communication technologies provide new means to connect teachers and learners within and beyond a campus. Distance learning on the Internet in a global marketplace for learners provides an attractive investment for for-profit educational entities.

[†] THEN: mid-1980s, at many institutions. NOW: mid-1990s to present, increasingly.

* Social Sciences not included.

THEN & NOW: 1986 - 1999

THEN	NOW
FACILITIES	
Most science buildings, then more than 25 years old or built in post-Sputnik haste, did not support new scientific endeavors or pedagogies; many did not comply with building codes.	A new generation of science buildings is coming on line, casting in concrete a student-centered educational philosophy. Shared, flexible facilities accommodate new disciplinary and interdisciplinary directions, as well as new technologies.
FACULTY AND SCHOLARLY NETWORKS	
American higher education was concentrated primarily at traditional colleges and universities. The two-year colleges were gaining notice as an emerging presence. Collaboration, communication and partnerships across sectors of higher education were limited.	Institutions from each sector are included in educational coalitions supported by NSF and other funders, leading to a better understanding of commonalities and differences among institutional missions.
Faculty at all career stages were rewarded primarily for research productivity. Little attention was given to preparing graduate students and early-career faculty for the broad range of responsibilities of the academic scientist (or other careers).	With a growing emphasis on students and on student learning, academic institutions, funding agencies, and disciplinary societies are defining and beginning to reward faculty careers in which research and teaching go hand-in-hand.

PROFILE OF UNDERGRADUATE EDUCATION (1996)

- **Students: 12,300,000**
- **Institutions: 4,000**
- **Percent of All Undergraduate Students Enrolled in Two-Year Colleges: 44%**
- **Students 25 Years or Older: 30%**
- **Part-time Students: 30%**
- **Percent of Total Bachelor's Degrees in SME&T: 17%**
- **Percent of SME&T Bachelor's Degrees Awarded by Schools Which Also Have Graduate Programs: 86%**

PROJECTIONS (1996 - 2006)

An increase of 44% in SME&T jobs, more than three times the 14% expected for all jobs. Three fourths of the 44% increase in SME&T jobs will occur in computer-related occupations.

(National Science Board, 1998; National Science Foundation, 1999; The Chronicle of Higher Education, 1999)

IN THE NEXT DECADE

A serious loss of talent in the service of science and society will result if current successful efforts– to give all undergraduate students access to a rigorous engagement with mathematics, technology and the various fields of sciences– are not used as the foundation for systemic reform in the next decade. Each year that passes, a significant percentage of the more than 12 million undergraduate students now enrolled in campuses across the country are being shortchanged because they do not have access to such programs. Although the recommendations on page 6 are directed primarily at academic leaders, nothing significant can happen without the informed involvement of leaders in public life, in the corporate and industrial sector, disciplinary societies and funding agencies.

IN THE NEXT DECADE: 1999 - 2009

Undergraduate education in science, mathematics, engineering, and technology is a critical determinant of our national future. The undergraduate years are the springboard to advanced education for students who choose to major and then pursue graduate work in science, mathematics, and engineering—students who will help create the world in which we all live. The undergraduate years are the last opportunity for rigorous academic study of these subjects by many of the future leaders of our society—the executives, government officers, lawyers, clergy, journalists, and others who will have to make momentous decisions that involve science and technology. Colleges and universities prepare the elementary and secondary teachers who impart lifelong knowledge and attitudes about science and technology to their students. And undergraduate institutions help to train many of the technical support personnel who will keep our technological society functioning smoothly in the years to come.

—National Research Council,
From Analysis to Action, 1996.

LEARNING AND ASSESSMENT

Colleges and universities should:

- translate goals for learning into practice, by using those goals as benchmarks against which programs (old, new, experimental) are developed, implemented and assessed.
- consider the impact of new approaches on faculty effectiveness, institutional cultures and budgets.

COURSE AND CURRICULUM

Faculty and their administrative colleagues should:

- shape courses and curriculum on the assumption that all students can learn mathematics and the various fields of science, and provide access to a rigorous and rewarding experience in these fields.
- ensure that all students experience investigative learning in SME&T classrooms and labs, including learning that connects to other fields of inquiry and that suggests practical applications to the world beyond the campus.
- ensure that students majoring in SME&T fields can move with dispatch into graduate and professional school and/or into the scientific/technological work force.

TECHNOLOGY

Colleges and universities should:

- acknowledge the dramatic impact of information technologies, developing and implementing plans for faculty development, course and curriculum development, and facilities renewal that reflect an understanding that these technologies are changing both the study and practice of science.

FACILITIES

Colleges and universities should:

- use the opportunity to shape and reshape classrooms and labs to enhance student learning and to achieve institutional distinctiveness over the long-term.

FACULTY AND SCHOLARLY NETWORKS

Colleges and universities should:

- develop and implement well-coordinated plans to invest in faculty careers at all stages, so faculty remain current in their field, are at ease with emerging technologies and pedagogies, can connect to other disciplines within and beyond SME&T, and can link their research to student learning.
- collaborate across boundaries of discipline, sector, and geography, building networks of innovators and adapters to strengthen undergraduate learning with all deliberate speed.
- insist that departments of education, mathematics, and the various fields of science to work together to improve both the content and the content-specific pedagogical knowledge of K-12 teachers.

WHY ATTENTION TO UNDERGRADUATE SME&T IS CRITICAL

Pick up the daily paper. Consider how scientific and technological issues jump out at you from every section; think about what people need to know to deal with those issues in their workaday, as well as their personal, world.

Walk into your neighborhood elementary or HIGH SCHOOL. Consider how this nation will meet the critical need for 2 million well-prepared K-12 teachers; think about what preparation is needed by the coming generation of teachers.

Access the Internet. Consider how information technologies, providing ease of access to limitless material and data, are changing our world; think about how people must learn to evaluate and use such material most productively.

Look at the listings for job openings. Consider the demand for employees who can solve problems, work both collaboratively and independently, write and speak persuasively, and handle sophisticated technologies; think about the difference between educating and training people for such a work force.

Walk down the street in a major city. Consider that more than 50% of persons under 18 years of age in America today are members of ethnic and racial minorities; think about the historic role of education in enabling past generations of ethnic (immigrant) minorities to have productive, responsible, and self-fulfilled lives.

Ponder America's past and future. Consider how our country has been shaped by the spirit of discovery and invention; think about how this nation's future is dependent upon persons who, because of their education, have the talents and energies to explore new worlds, design new tools for living and working, and understand the social relevance of science and technology in a changing world.

Building Learning Communities

***CircLES:* A Program for Entering Students at the University of Texas, El Paso (UTEP).** Located in the world's largest binational metropolitan urban center, UTEP is a recognized leader in the education of Hispanic students, both from the US and Mexico. Of students attending UTEP in 1998, 72% were Hispanic, and 3% were African-American; 55 % were first generation college students and 11% were international students (mostly from Mexico).

Several years ago, UTEP decided to confront the high attrition rate of freshmen and sophomores throughout the University. Recognizing that science, engineering, and mathematics (SEM) students had no "administrative home" in the large commuter campus, with the aid of an NSF Model Institutions for Excellence Grant, UTEP instituted the *SEM Entering Students Program* on a pilot scale in 1997, and in 1998, expanded and institutionalized it into *CircLES* (Center for Learning for Entering Students). The goal of *CircLES* is to "create a learning environment where entering students in engineering and science can be successful and develop lifelong learning habits...." The program is designed to address the whole student, and to significantly increase the retention of pre-engineering and prescience students over the next 3-5 years.

Central to achieving this goal is the creation of a learning community for entering SEM students. Following placement tests in English and mathematics, these students are assigned a peer group—their learning community—with whom they take a block of three clustered courses: mathematics, English, and a University Seminar with a science or engineering theme. The course contents are linked: for example, essays in English may involve themes encountered in the Seminar. Students and faculty engage in cooperative learning. Learning is further enhanced by interactions with mentors and self-assessment. In the Fall of 1998, the first year of full operation, 389 entering SEM students were clustered in 24 different learning communities and 66 entering SEM students were not clustered. A significantly higher percentage of the students who were fully clustered than those who were not returned in the Fall of 1999 (see chart). A similar enhancement was observed in the pilot class that entered in 1997.

"I think ultimately the reason [for higher retention] is that students become connected to the university. Students become a support group for each other since the same set of 25 students or so are taking courses together and all of the instructors are using some kind of active, team-building learning strategy. They become connected to each other, the faculty, and peer facilitators. They feel a part of the university."

—Pablo Arenaz, Associate Dean of the College of Engineering and Science.

THEN & NOW: LEARNING AND ASSESSMENT

THEN	NOW
In many courses, the material being presented was the focus of the classroom; students sat passively while being taught.	The extent to which students are learning in a course is increasingly the focus of faculty attention.
Classroom practices generally did not reflect awareness of research on learning and were not geared to the variation in students' learning styles.	Studies, such as that recently released by the National Research Council (Bransford *et al.*, 1999), are bringing issues about learning and cognition into the mainstream of discussions about curricular reform; graduate programs, at an increasing number of universities, provide opportunity for doctoral studies on research in teaching and learning from the disciplinary perspective.
Documentation about *what works* that might convince the skeptical of the efficacy of new approaches was not available.	The impact of studies on collaborative learning and the use of techniques to engage students in problem-solving is visible on a wide array of campuses; reports emerging from the major systemic initiatives in undergraduate SME&T funded by NSF and other federal agencies are documenting the value of new approaches to strengthen student understanding of science and mathematics.
Evaluation was primarily done by multiple choice exams that measured recognition, rather than the ability to recall learned material; competition for grades often shaped the environment.	Evaluation methods include more open-ended questions, essays, and design of experiments, which test for depth of understanding about process and content.
Accreditation organizations focused on the quantity of courses taken and their content.	Accreditation practices for engineering programs (beginning in 2001) will require that students can design and conduct experiments, function in multidisciplinary teams, and communicate effectively.

IN THE NEXT DECADE

Understanding how students learn must shape practice at all educational levels, recognizing that students learn in different ways, and that approaches to teaching, use of new technologies, and assessment must reflect those differences. Equally, students preparing to be K-12 teachers must be taught in the way they will be expected to teach. Undergraduate faculty incorporating such understandings into their curricular planning must be rewarded for their efforts. Skeptical faculty who demand careful documentation of the effectiveness of new approaches must set the same high standards for old ones. There should be some commonly agreed-upon national goals for student learning against which local efforts could be compared.

Learning Styles

Learning can be achieved in many ways. Students vary as to how they learn different subjects best (Hayden, 1997). Therefore, teaching to various learning styles can increase a teacher's effectiveness in promoting student learning for all students.

Differences in learning styles can be observed in each of the steps involved in the process of learning:

- receiving information, *e.g.*, preferences for seeing, hearing, doing
- learning and remembering, *e.g.*, in the type of organizational aids for learning and recall, such as outlines, sketches, and analogies
- cognition and thinking, *e.g.*, some students learn better by assembling information one piece at a time ("linearly"), while others prefer to start with the whole picture ("non-linearly"), and then dissect it into its pieces
- expression, *i.e.*, spoken, written, or acted out
- personality, *i.e.*, the context from which a learner comes influences such attributes as motivation and attention span.

By varying the modes of presentation to and evaluation of a class of learners with varying learning styles, the successful teacher maximizes the learning that can take place.

From *How People Learn*, from the National Research Council (1999):

- "Theoretical physics does not prescribe the design of a bridge, but surely it constrains the design of successful ones. Similarly, learning theory provides no simple recipe for designing effective learning environments, but it constrains the design of effective ones.
- "Effective teachers need pedagogical content knowledge—knowledge about how to teach in particular disciplines, which is different from knowledge of general teaching methods."
- "Competent learners and problem solvers monitor and regulate their own processing and change their strategies as necessary. They are able to make estimates and educated guesses."
- "Because many new technologies are interactive, it is now easier to create environments in which students can learn by doing, receive feedback, and continually refine their understanding and build new knowledge."

The Nature of Assessment

The heart of the assessment process is an attempt to determine how well the goals of a course are achieved, as well as to have both teacher and student understand the progress of the student (and the course) toward those goals. Courses in SME&T may have multiple goals relating to student learning:

- learning course content
- understanding principles well enough to apply them to new situations
- understanding methods of analysis and experimentation used in the field
- learning to do research
- relating the subject to other subjects
- expressing ideas in fluent spoken and written English.

Feedback during a course about how well students are meeting the desired goals allows for mid-course adjustments (formative evaluation). Assessments of a course when completed can be used both to evaluate the teacher and to guide revisions for the next time it is taught (summative evaluation).

How can one assess an experimental course and evaluate whether it is worse, as good as, or better than the conventional course? It is not easy. Typically the goals of the experimental course have changed from those of a conventional version. For example, consider an introductory course usually taken by 200 students at a university. Grades depend on multiple choice exams focused on the specific content of the lectures and text. In order to assess a new pedagogical approach one year, the class is divided into two sections. One, the conventional section, is taught as usual, using lectures, readings in a text, and homework assignments graded in discussion sections led by a graduate student. The other, the experimental section, is taught with a different emphasis, namely to have students apply the principles learned to solving problems in new situations. The pedagogy is quite different: instead of the conventional format, students spend time in groups of three at tables equipped with a computer, studying materials handed out and provided on-line, and solving problems either with pencil and paper or on the computer, both in and outside of class. Instructors circulate in class "coaching:" answering questions, giving help, and facilitating group discussions. Grades are based on essays and portfolios as well as exams.

How do we compare the performance of the students in the two sections? Do we give the conventional exams or develop new ones more appropriate to the goals of the experimental section? Either way will raise issues of fairness. The good news is that in many cases, students in experimental classes did at least as well on the conventional exams as students in conventional classes. The knowledge that experimental pedagogies do no harm by previous standards has served to reassure skeptics, and made innovation in both pedagogy and assessment more acceptable.

Assessment Strategies for New Approaches

1. Comparing experimental and conventional sections at the end of the course.

A recent study at the University of Wisconsin-Madison illustrates the thought and care now going into comparing experimental and conventional sections of a course (Wright *et al.*, 1998). In this study, experimental and conventional sections of an introductory analytical chemistry course were offered, with each section having about 100 students. The conventional section used lectures that encouraged student questions and participation, spreadsheets and difficult homework problems, and, in the last three weeks, independent group projects. The experimental section was characterized throughout the semester by interactive classroom settings, cooperative student assignments and examinations, and open-ended group projects and laboratory experiments. The faculty in each section had strong reputations for teaching excellence.

The novel aspect of the assessment strategy was to evaluate the students shortly before they completed the course by a process involving twenty-five university faculty from science, mathematics and engineering departments other than chemistry. (All but four of these faculty used the concepts learned in this analytical chemistry course in their own research.) Each assessor designed his or her own thirty-minute oral examination to rank student competence; each was assigned eight students (four from each section) who had performed about equally well in the internal course evaluations. The assessors were not told which students had taken which section, and were simply asked to rank the competence of "their" eight students.

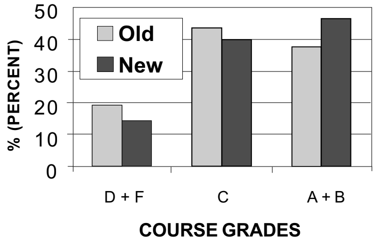
The results obtained by these independent assessors were quite striking. For 19 of the 25 assessors, the average rank of the students from the experimental section was better than that of students from the conventional section, in most cases by a sizeable margin. The criteria used were agility of thought, ability to use analogy, analytical ability, and awareness of the subject as a whole.

> ***An administrator once told me, 'Your method [of teaching] does not work because our good students no longer do well...' "Good" here means "good by the traditional standard," and this is the crux of the problem: changing the method of instruction also means changing the method of assessment. How else can one assess the change and, what is perhaps even more important, drive students to change? Changing the method of assessment, however, means giving up any meaningful correlation with previous assessments.***
>
> — Eric Mazur, Professor,
> Harvard University.

2. Comparing the impact of experimental and conventional sections on performance in subsequent courses.

A. Since educators are interested in retention of learning, some assessment studies have been designed that measure outcomes later in a student's college career. A particularly robust example comes from the United States Military Academy at West Point, where the entire entering student body of about 1000 students takes the same courses for the first two years (Gold, 1999). In the academic year 1990-91, a bold, new two-year core curriculum in mathematics integrated more technology, utilized more interactive instruction, and included more group projects. Since the use of technology and the integration of content allowed more topics to be introduced, the new curriculum also included more content. The West Point study compared performance by the first cohort taking the new curriculum to the last cohort that had taken the old curriculum. The performance assessed was not in the mathematics courses that had been changed; it was in the upper-level calculus-based physics courses and the engineering science courses subsequently taken, which had not been changed, and which use the mathematics taught in the first two years. In physics, students who had the new mathematics courses performed better than those who had the old (see graph below). The median grades in each of two upper-level courses were C for students who took the old math, and C+ for those who took the new. In four out of eight engineering courses, results similar to those in physics were obtained; in the other four engineering courses there were no significant differences. This example illustrates some potential strengths and problems encountered in designing assessment strategies. The large class size and well-established admission standards at West Point make it very likely that the two student cohorts were similar in background and preparation. On the other hand, the possibility that the different outcomes can be attributed to factors other than the math courses taken by each cohort can not be rigorously eliminated. Better performance by the experimental cohort in six of ten courses is a robust result. But content, as well as several pedagogical techniques, was changed, making it impossible to fully assess the relative contributions of each.

DISTRIBUTION OF PHYSICS GRADES AT WEST POINT



B. The effect of curricular innovation on performance in subsequent courses was also examined at North Carolina State University (Felder *et al.*, 1998). In an experimental program enrolling 95 students, five consecutive chemical engineering courses were taught by Richard Felder, making extensive use of active and cooperative learning, and a variety of other techniques designed to address different learning styles. Each class session involved a mixture of lecturing, problem solving, and a variety of group exercises. Exams were open book, taken individually. Computers were not used in class.

These students were compared to a cohort of 139 students who took the same five courses taught in a conventional manner. The entering profiles of the two cohorts were very similar in pre-college academic credentials and in demographic data, except that more of the experimental cohort had parents trained in science. At the end of five years, 85% of the experimental cohort had graduated with a chemical engineering degree, in contrast to 65% in the conventional cohort. 33% of the experimental cohort intended to pursue graduate study and/or to work in a research facility, compared to 21% of the conventional cohort.

3. Measuring learning gain from start to finish of a course.

A final exam measures only how a student performs at the end of a course, not what he or she has learned in the course. In order to measure learning achieved in the course, one can give the same exam at the beginning and end of a course, and use the difference as a measure of what has been learned. This approach has been widely used in physics. A test called the Force Concept Inventory (FCI) (Halloun and Hestenes, 1985) is often used for first-semester introductory physics. The results are measured in what is called the "normalized gain," <g>, which takes into account the fact that a student getting a higher score has fewer points left to get 100. So the score is calculated as the (posttest % - pretest %) / (100 % - pretest %). For example, for a student who received 20% on the pretest and 40% on the posttest, <g> = (40-20)/(100-20)= 0.25 (or 25%), and for a student who received 40 on the pretest and 60 on the posttest, <g> = (60-40)/(100-40) = 0.33 or 33%.

Richard Hake (1998) has gathered data from 62 introductory physics courses taught at a variety of high schools, colleges, and universities. He found that <g> = 0.23 for conventionally taught courses and <g>=0.48 for courses in which the students participate in some form of "interactive engagement." This is a very robust result.

THEN & NOW: COURSE AND CURRICULUM

THEN	NOW
What students knew about the content of science was used as the measure of good teaching.	What students understand about both process and content of science is a measure of good learning.
Lectures were the primary means of transferring information to students.	Inquiry-based undergraduate labs and the expectation that students will do research during the summer or in semester/yearlong experiences is becoming common; student research productivity is recognized through presentations at national meetings, and senior research papers.
Laboratory experiments for beginning students followed the 'cookbook' method; select majors had the opportunity for independent research.	Building a research-rich environment—from introductory courses to independent research for majors—is an aim for an increasing number of institutions.
Computers were rarely used in undergraduate classrooms or labs; attempts to use them proved to be time-consuming and rarely cost-effective.	Courses and labs across the curriculum take advantage of materials on the web; sophisticated data banks provide students with easy access to information needed for studies from introductory to advanced levels.
Courses and labs were developed and taught primarily from the perspective of a single discipline.	Real-world problems requiring multidisciplinary approaches are increasingly recognized in course and curriculum design.
Courses and curriculum were designed for students working alone, competing for grades, and anticipating graduate or medical school.	Group work is resulting in better learning for most students, particularly with regard to improving skills of problem-posing/solving and communication.
Curriculum emphasized material needed by majors.	Curriculum is designed to build communities of learners, including both majors and non-majors, serving greater numbers from groups currently underrepresented in the study of science.
Departmental sense of autonomy and insularity tended to shape decisions with regard to hires, development of program and facilities, and equipment purchases; courses and curricula were planned with little regard for linkages beyond a single department.	Collaborations within the sciences, and between SME&T and other disciplines, reflect the need to share expensive equipment, and provide opportunity to incorporate scientific findings into new interdisciplinary programs; such collaborations also address the general education needs of students.

IN THE NEXT DECADE

Increasingly, strong undergraduate programs in mathematics and the various fields of science will be recognized as primary indicators of institutional quality. Preparing students for a world that needs 'science-savvy' persons (who have a deep understanding of the role of science and technology in a contemporary society, are facile in solving problems and working in teams, and can communicate in oral and written form) must be a priority for curriculum planning. Departmental and institutional goals should reflect such priorities.

Introductory Courses

Introductory courses are arguably the most important curricular component in strengthening SME&T education for all students. Throughout the country, important innovations in introductory courses have been introduced and are being assessed. For students intending to major in an SME&T field, some new curricula (*e.g.,* at UTEP, described on p. 8, or in calculus reform, described below) emphasize connections to other fields and to real-world problems, and incorporate opportunities for strengthening communications skills. For students not planning to major in SME&T, curricula (*e.g.*, at Drury College, described below) aim for the development of math and scientific literacy, often using approaches similar to ones used for majors but with less emphasis on the content needed in majors' courses to lay groundwork for further studies.

The Calculus Reform Movement (Tucker and Leitzel, 1995; Schoenfeld, 1997; Haver, 1998). Calculus reform was developed by mathematicians as a response to the challenge posed by computer scientists for giving primacy to discrete (rather that continuous) mathematics, and was in the vanguard of curricular experimentation in the late 1980s. Funded by the NSF from 1987-95, it became a national movement involving faculty across the country. By 1994, 68% of the post-secondary institutions at which calculus was taught reported participating at least to some degree, representing more than 150,000 students. The effort was promulgated through text books: in the fall of 1994, 108,000 copies of nine leading reform texts were sold, and virtually all the traditional college-level texts had been revised to reflect the change in content and pedagogical goals of the reform movement. These included:

- extensive use of graphing calculators and computers
- more applications to everyday phenomena
- more cooperative learning, long-term projects, discovery learning and written work
- restructured content using geometric and numerical as well as analytical methods.

Assessment was not rigorously carried out in the early days, and the debate on these reformed curricula continues. There is however, agreement on two important advances:

1. The visualization afforded by use of graphing calculators and computers permits educational and research innovations of great power.
2. Many more research faculty, even among traditionalists and skeptics, are taking an active interest in pedagogy.

The Pew Learning and Technology Program. This program is an $8.8M four year effort to place the national discussion about the impact of new technologies on the nation's campuses in the context of student learning, and on ways to achieve this learning cost effectively. Its major component is *the Pew Grant Program in Course Redesign*, a three-year, $6 million program conducted by the Center for Academic Transformation at Rensselaer Polytechnic Institute with support from the Pew Charitable Trusts. The purpose of this institutional grant program is to encourage colleges and universities to redesign their instructional approaches using technology to achieve cost savings as well as to enhance quality. Redesign projects focus on introductory courses with large-enrollments, which have the potential of affecting thousands of students and generating annual cost savings in the hundreds of thousands of dollars. First round awards of $200,000 each to ten colleges and universities were announced in September, 1999.

Science for All Students

The integrated curriculum at Drury College, developed with support of an NSF Institutional Reform grant, is designed to develop scientific literacy by non-science students consists of three required courses: Math and Inquiry, Science and Inquiry, and Undergraduate Research. The curriculum emphasizes the interconnectedness of all disciplines in understanding the world, uses material that is relevant to students' lives, contains a significant integrated laboratory component, emphasizes small group projects, and engages all students in a semester of scientific research.

Innovative Approaches

Workshop Physics at Dickinson College. In Workshop Physics, at Dickinson College with Professor Priscilla Laws, calculus-based physics is taught without lectures. The following anecdote (Laws, 1991) illustrates the spirit of the course: in one of the experiments designed to introduce Newtonian mechanics, the student hits a moving bowling ball repeatedly with a baton to approximate a constant force. Beanbags are dropped to record the locations of the ball at various times, and calculations of velocity and acceleration are made from the data.

What impact does this have on student learning? A Dickinson senior woman who came as an international studies major and switched to physics reports:

"The first exam was going to be problems, and I said, 'How can I possibly take an exam which is problems when all we've been doing is playing with toys?.... Well, I got the exam, and the first problem was a rocket problem, and it had a constant wind hitting it, and you had to guess the path of the rocket. I have learned nothing about rockets and I'm not a rocket scientist, and so how am I ever going to do this problem?... All of a sudden I remembered sitting in the Kline Center with a baton and a bowling ball and hitting this bowling ball, and so if we thought this baton was the wind and the bowling ball was the rocket - wow! I did this problem and got it right.... It wasn't in a book or anything, but I saw it in my head."

Just-in-Time Teaching (JiTT). JiTT is a teaching and learning strategy to promote active learning, using two elements: classroom activities and World Wide Web components (Novak *et al.*, 1999). It has been developed at three institutions: Indiana University Purdue University at Indianapolis (IUPUI), the United States Air Force Academy, and Davidson College. The JiTT system is built around Web-based assignments, which the students complete individually at their own pace, and submit electronically a few hours before class. The faculty, in turn, then adjust and organize the upcoming classroom sessions informed by the student work. In class, the instructor leads a guided discussion that begins with the students' own preliminary understanding of the material and builds on it, which is one way people learn. JiTT incorporates experiences in teamwork, opportunities to practice written and oral communication, and provides appropriate levels of support and feedback for students at different learning levels. The JiTT strategy specifically targets obstacles facing many of today's students: low motivation to learn, weak study habits and academic backgrounds, little confidence in their ability to succeed, and time constraints.

Assessment of the JiTT two-semester course sequence for physics majors at IUPUI to date <u>shows a 40 % drop in attrition.</u> Student cognitive gains using the FCI test (described on page 12) had a value of <g> between 35 and 40%, which is in the upper range for interactive engagement courses nationally, but not at the top. The fact that JiTT is working well at three very diverse institutions suggests its potential wide applicability. It is currently in use at 16 institutions.

Underrepresented Groups

Xavier University of Louisiana. Historically Black Colleges and Universities (HBCU), founded at a time of legal segregation, have historically played the predominant role in the education of African-Americans, particularly for scientists and engineers. During the past 35 years, admission of African-American students at other colleges and universities has increased. Nevertheless, the contribution of HBCUs to bachelor's degrees in SME&T remains remarkable: in 1994, about 40% of all African-American students who received bachelor's degrees in science and math did so from HBCUs. The corresponding number for engineering was 26%. These are very high percentages considering that the number of HBCUs offering these degrees was only 7 % of the total number of institutions doing so. The figures for 1987 were not very different (NSF 99-38, 1999). These institutions are apparently unusually successful at identifying and nurturing talented students. The recent NSF award of $42 million to 14 HBCUs to support greater participation of underrepresented minority groups in SME&T will provide essential support to build on current success.

One successful HBCU in the past decade has been Xavier University of Louisiana. For each of the four years 1995-1998, Xavier has been #1 in placing African-Americans into medical school, a remarkable achievement for a liberal arts college with an enrollment of under 4000. Approximately 40% of Xavier graduates, most of whom are African-American, attend graduate or professional schools.

Xavier officials attribute this student achievement to many factors, but single out the pre-college program, Project SOAR (Stress on Analytical Reasoning). This four-week program is designed to help students develop the type of problem-solving skills needed to succeed in college-level mathematics and science courses. SOAR is one of a series of six programs which together constitute an educational pathway beginning in the 8th grade, continuing through high school, and leading into and through Xavier's science departments into science-related graduate and professional schools. Characteristic of HBCU, mentoring by concerned and accessible faculty throughout the undergraduate years plays a critical role.

One of Xavier's abiding philosophies, "success drives success," characterizes the institution today. A host of grants is providing the necessary resources to implement an excellent curriculum and a commitment to student research.

Programs to improve the climate in SME&T education for women. Although women represent slightly more than 50% of the U.S. population, and approach that proportion in the work force, they have historically been greatly underrepresented in the SME&T work force: 22% in 1995, up from 13% in 1980. The fact that women make up about a third of science students but only one-fifth of science professionals indicates a greater degree of attrition of women than men. Numerous programs have been established to help women overcome the chilly climate which has often greeted them in male-dominated scientific bastions. For example, the Association for Women in Science (AWIS), a nationwide organization with 75 local chapters, has recently completed a major mentoring project, supported by the Sloan Foundation and NSF. At each of twelve sites, mentoring programs for women students in SME&T tailored to the needs and resources of the area were developed. These programs were very well received by the participating students, faculty, and professional women. Mentoring went far beyond the traditional one-on-one relationship, which is often difficult to maintain. Small-group mentoring activities were a valuable part of the programs; larger scale get-togethers made women feel part of a substantial community and let them see the great diversity among women in science.

Research in the Undergraduate Setting

The opportunity for students to do undergraduate research has been offered for many years at select liberal arts institutions and to exceptional students at some universities. In the last decade, based on the growing conviction that introducing students to research early in their studies is an excellent way to engage their interest in science, student research programs have expanded to the junior, sophomore, and even freshman years at more and more institutions. Student responses to these programs are very favorable, and many sources of funding have become available for undergraduate research programs.

A Consortial Approach.

> *"At Keck we were out in the field working with professors with different perspectives on petrology. My experience had an impact on how I supervise students doing their senior theses today. At Keck I saw models for how different professors mentor students."*
>
> —Kim Hannula, 1989 Graduate, Carleton College, now-Assistant Professor of Geology, Middlebury College.

Since 1987, students and faculty from twelve of the country's liberal arts colleges have joined together to do original geoscience research. Each summer sophomores and juniors from consortium institutions are selected to work with faculty members at one of eight sites around the world. Students learn how to develop questions of importance, plan their time, work in teams, and communicate orally and in writing. The vast majority of the 550 students who have participated in this program go on to geoscience-related careers. The collaborative research has introduced faculty to new ideas about the geosciences and about how to teach. The Consortium, funded by the W.M. Keck Foundation, is breaking new ground both in education and research, with impact far beyond the students selected for the summer projects.

Institutionalizing Student Research. Like many colleges and universities, Brown University in the 1980s received grants from The Department of Education's Fund for the Improvement of Postsecondary Education (FIPSE), The Ford Foundation, NSF, The Andrew W. Mellon Foundation, Howard Hughes Medical Institute (HHMI), and other sources to support undergraduates as research and teaching assistants, and in the novel Odyssey Program in which undergraduates work with faculty on curriculum development. These activities were judged to be so successful for students that the University took three steps to institutionalize an undergraduate teaching and research assistantships (UTRA) program: a) building endowment for the program; b) allocating money in the annual base budget while the endowment grows; and c) requiring the faculty mentor's grants, or the home academic department, to provide 20% of the stipend as matching funds. The "buy-in" by funded research faculty is an important indicator of faculty acceptance, and the Odyssey Program is an interactive and visible way the institution demonstrates its concern with the improvement of teaching. The program has grown almost fourfold in a decade. In 1999-2000, 209 students are being funded with over $487,000, of which only 14% comes from external grants. Sixty percent of the students funded are working in SME&T fields.

A Research-Rich Environment. The unusual aspect of the Hope College student research program, begun more than 20 years ago with strong presidential leadership, is not that undergraduate research occurs, but rather that it flourishes through a true faculty-student collaboration that forms the foundation of the mission of every academic department. Summer research opportunities are supported in part by five NSF-Research Experiences for Undergraduates (REU) awards in biology, chemistry, computer science, mathematics, and physics. These grants support not only Hope students, but also those from other colleges and universities, providing a heterogeneous, intellectually stimulating environment. On average over 120 students do summer research with Hope science and mathematics faculty. Advances in the research laboratories at Hope intentionally make their way into Hope's curriculum so that there is a seamless integration of a research-based, hands-on philosophy in everything that is taught.

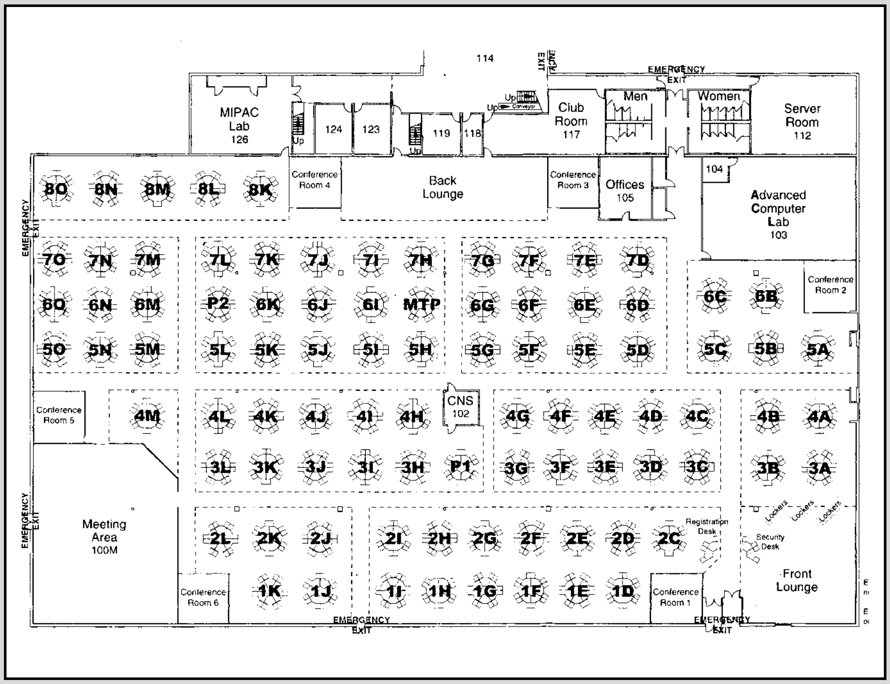
These opportunities stimulate student interest in science; many students indicate that the prospect of doing undergraduate research is the major deciding factor that helped them identify Hope College as their college choice. About 85% of Hope science

Facilities and Technology I

The Mathematics Emporium. The Mathematics Emporium at Virginia Polytechnic Institute, now beginning its third year, is a pioneering effort to use technology to create a learning laboratory that serves a wide range of student abilities. Located in a former department store near the campus, the Emporium contains 500 computer work stations attractively grouped in pods of six. Much of the space is laid out to facilitate students working in groups; other areas are designed for individual study. The Emporium is open 24 hours a day, 7 days a week. It is the classroom for some ten freshman and sophomore level courses in mathematics involving thousands of students; it is also available to students for mathematical help in other courses. Faculty, assisted by a large number of graduate students and undergraduates are present 14 hours a day for help. Technical help is available around the clock. Frequent bus service between the Emporium and the campus is available. In addition to the open-design computing areas, there are two classrooms, a lecture hall, partitioned spaces for tutorial and small group work, lounge areas, and lockers.

The Emporium program builds on several years of experience with computer technology and related innovations in courses, for which the Mathematics Department and its faculty have won numerous awards. An ongoing assessment program is in place. Evidence to date suggests that the use of the Emporium is having a positive impact on the academic performance of mathematics students in general as well as on the morale of the faculty. Many students have become more engaged in their own learning. Nevertheless, some still avoid assignments involving hands-on-work, and some would prefer more traditional instruction. Courses continue to evolve, and experimentation to find the best combination of activities continues in this novel, massive program designed to use technology effectively. It is too early to analyze the data from the ongoing longitudinal studies designed to evaluate the impact on learning of this new facility.

Measuring the cost-effectiveness of the Emporium is complex. While it represents an increase in resources, the increased success of students leads to savings due to fewer having to repeat courses. The existence of the emporium is also likely to increase demand for technological innovation in other parts of the university.



THEN & NOW: TECHNOLOGY

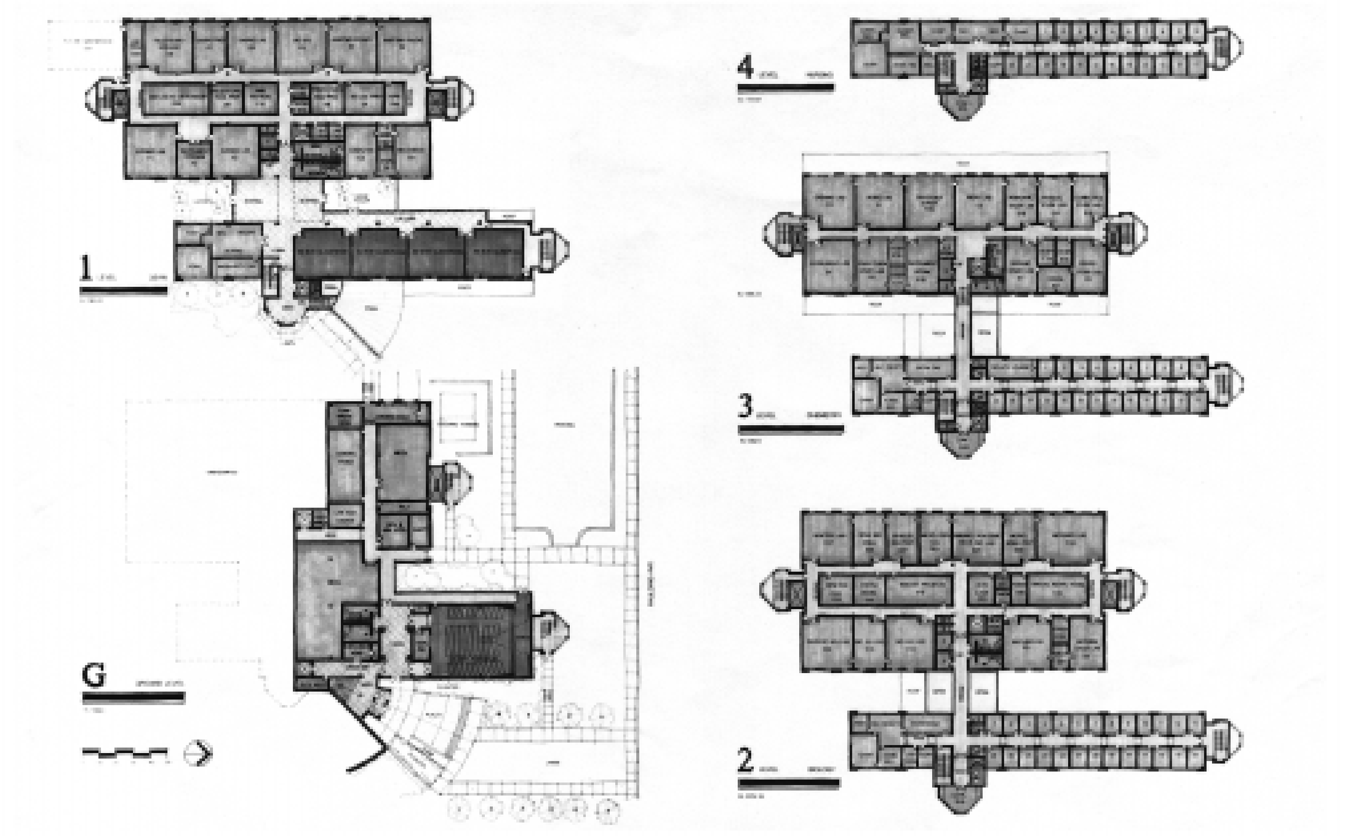
THEN	NOW
◆ Personal computers, in their infancy, were expensive, cumbersome and rarely used.	◆ Personal computers—powerful, fast, interfaced with other systems—are routinely used.
◆ Fax machines and word processors were considered revolutionary; the Internet was understood and used only by a few.	◆ The Internet is revolutionizing undergraduate teaching, learning, and research; web-based information and e-mail are used routinely.
◆ Publishers and broadcasters were the primary arbiters of information dissemination.	◆ Individual Internet users are publishers as well as consumers and critics of information, communicating with peers in all parts of the world.
◆ State-of-the-art research instrumentation for undergraduate use was available mainly at select liberal arts colleges and at universities.	◆ Technologies are permitting state-of-the-art research equipment maintained at one site to be used by faculty and student across the country—indeed, around the world.
◆ Students, particularly in introductory level courses, were not exposed to information technology.	◆ Courses and majors in information technology are introduced, and two-year colleges have become major players in equipping students to enter or advance in technical fields.
◆ ‘Off-site’ use of computers in education, including distance learning, was in its infancy; with few exceptions students went to campus to attend class and lab.	◆ Asynchronous and distance learning are changing the basic pedagogical paradigms.
	◆ The widespread access offered by information technologies to resources for reform is creating the same kind of connected community among those pursuing educational excellence as exists in the research community.
	◆ The potential capacity of digital libraries to create large databases and to store, organize and communicate such data and knowledge is becoming evident. Awareness of this capacity and of the transformative nature of such archives to the research and educational communities is leading to many innovative initiatives.

IN THE NEXT DECADE

Faculty and academic planners must respond to the reality that over 80% of entering students report using e-mail and the Web in the last year of high school (Sax *et al.*, 1998), and that such information technologies are radically changing how all Americans live, work, and interact. Undergraduates must have experience using technologies that connect them to raw data and multimedia image archives for learning and research; they must understand how to evaluate that information critically, and become adept in using current technologies to manipulate, process and communicate it. Incorporating technologies into the undergraduate environment should be seen as a means to free up faculty for engagement with students beyond the mere transferring of information. Sharing expensive technologies through electronic access is another cost-effective step. Assessment should be an integral part of the institutional plan to enhance the technological capacity of the campus.

Facilities and Technology II

The Science Building at Kennesaw State University. In recent years, many new buildings for undergraduate science have been built that accommodate curricular and technological innovations and provide flexibility for the future (Project Kaleidoscope, 1995). One example is at Kennesaw State University (KSU). Located 30 miles northwest of downtown Atlanta and serving students in its vicinity and northwest Georgia, KSU grew very rapidly in the past decade. The diverse student body, all of whom are commuters, includes 40% part-time students, and many who have resumed their education after being in the work force. The Science Building, opened in 1996, has provided critical expansion space for classrooms and laboratory facilities, created space for student-faculty projects and directed research, and is setting a campus-wide example for the use of computer and audiovisual technology in teaching. Adaptability, accessibility, and accommodating technology were all important design considerations. For example, each room is equipped with a media-control system which allows faculty to retrieve media from satellite or reproduction equipment located in the main control room in the building. Laboratories were designed to be “generic” facilities so that either biology or chemistry could use them. The layout of the lab wing floors provides an “O” corridor with labs on the outside, instrumentation rooms, special preparation rooms, and project rooms on the inside. Dedicated space for student research projects has allowed for a robust implementation of the college’s mission to train students in applied sciences. An attractive atrium connecting the office and laboratory wings of the building acts as a magnet for interactions among faculty and students. The Science Building has become the centerpiece of campus tours and a major factor in student recruitment and satisfaction.



THEN & NOW: FACILITIES

THEN	NOW
◆ Facilities, particularly those built before or with haste during the Sputnik era, were manifestly obsolete.	◆ Over $2 billion is being invested annually in planning and construction for facilities for instruction and research in SME&T fields.
◆ Classrooms and laboratories with fixed furniture were designed for a teacher-centered environment.	◆ Careful campus planning links the relationship between renewal of program and renewal of space, with the renewal of program driving most major facilities projects.
◆ Sophisticated technologies were not easily accommodated.	◆ In new facilities, laboratories and offices, classrooms and communal spaces are wired so that computers can easily be used as a tool for learning and research.
◆ Spaces limited opportunities for undergraduate and faculty research, especially in interdisciplinary fields.	◆ Research by students and faculty, individually or in teams, is easily accommodated, often in settings that model real-world research laboratories.
◆ Facilities were problematic in meeting code requirements and could not accommodate sophisticated instrumentation.	◆ New spaces and structures for science meet government regulations for accessibility and animal care; they are equipped with mechanical/electrical systems that are designed for safety, economy, long-life, and state-of-the-art equipment.
	◆ Creative collaborations between campus leaders and architects, laboratory designers, and campus planners are resulting in a generation of spaces that contribute both to the long-term excellence of the research and instructional program and to the humanity of the campus.
	◆ Improved spaces have significant impact on campuses; they enhance efforts to attract strong students and recruit and keep first-rate faculty, as well as enable the integration of research and education and the cross-disciplinary pursuits that are hallmarks of contemporary practice in research and education.

IN THE NEXT DECADE

Data must be gathered as to the adequacy, limitations, and constraints of present spaces used for instruction and research in the undergraduate setting, updating similar surveys from the late 1980s and expanding current surveys focused primarily on research spaces. These data should then inform a national discussion about the costs of bringing facilities on-line to serve present and future needs of students and science, as well as the roles and responsibilities of public and private funders in meeting those costs. The goal of this national discussion should be the development of a wider range of funding opportunities for facilities construction and renewal, with a coordinated ten-year plan among federal, state, and private funding agencies.

Facilities and Technology III

The Studio Classroom.

> *"Student chairs are comfortable and equipped with casters - the greatest boon to science reform."*
>
> — G. Doyle Daves, Interim Provost, Renssalaer Polytechnic Institute.

The introduction of "Studio" courses at Renssalaer Polytechnic Institute (RPI) illustrates how design of pedagogy drives design of spaces. These RPI courses are based on the premise that, in all aspects of the course, students learn more by "talking about and doing" than by "listening and watching." Courses formerly presented to hundreds of students in large lecture halls are taught to groups of 60 in "studio" classrooms, equipped with tables at which two to four students work together. The workstations on each table are arranged so that the students can turn to face the instructor's podium or turn to work in teams. Teachers can lecture for part of the twice weekly two hour periods, but more often act as coaches, roaming around the room interacting with groups of students as mentors, guides, and advisors. The "wet" sciences use both the studio classrooms and adjacent laboratories in each two-hour class period.

Student and faculty satisfaction is very high. Attendance has increased to an unprecedented 90%, compared to nationwide figures as low as 50% in large lecture courses. Students perform at least as well as students in traditionally taught courses in spite of the one-third reduction in class contact time. A detailed program of assessment of learning outcomes is in progress. The Studio courses are cost effective, primarily because of reduced demands for teaching assistants. Today the Studio model is used throughout RPI in mathematics, science and engineering courses.

RPI has made the institutional transformation to the Studio model while maintaining its traditional strengths. One science department chair reported an increase of over 33% in research grants from external sources during the three years that conversion to studio teaching was taking place. While the increase may have been due to other factors, work involved in the conversion does not seem to have had a deleterious effect on research productivity of faculty.

Studio Physics: It's the Pedagogy That Counts. In a recent study, Professor Karen Cummings and her colleagues (1999) showed that the pedagogy is what counts to achieve a significant gain in learning in a studio classroom. Student learning in the earlier version of Studio Physics at RPI was found to be the same as in the traditionally taught course, as measured by the Force Concept Inventory (FCI) (described on page 12) to measure conceptual gains. However, when two well-developed modes of interactive techniques, Interactive Lecture Demonstrations and Cooperative Group Solving, were incorporated into Studio Physics, there were substantial gains using both FCI and a second test system.

THEN & NOW: FACULTY AND SCHOLARLY NETWORKS

THEN	NOW
◆ Faculty interested in reform often worked in isolation—within a department, division, or institution.	◆ Increasingly, interest in new approaches is percolating through departments and across campuses as networks of reformers are visible nationally.
◆ Skeptical faculty responded “it won’t work here” to new ideas, and saw no need to try something different.	◆ There is a growing savviness about the work of reform: take small steps, get local teams to work together, secure support from the institutional leadership, take advantage of plentiful funding opportunities.
◆ There was little recognition or reward of the scholarly activities of faculty beyond their research productivity.	◆ Quality teaching is required and rewarded at more and more institutions
◆ Research in how to teach a discipline was not valued.	◆ Some institutions are assigning tenure-track positions in SME&T departments to faculty doing research in how to teach their discipline.
◆ Institutions in different sectors (e.g., community colleges and research universities) were not aware of efforts on other campuses, within or beyond their sector or geographic region.	◆ Many regional/national consortia and collaboratives include institutions from the different sectors, resulting in dissemination and adaptations of innovations that work.
◆ Disciplinary societies focused their ‘educational’ attention to issues at the graduate level.	◆ Disciplinary societies include undergraduate educational issues at meetings and in peer-reviewed journals.
◆ Only one professional association (the Council for Undergraduate Research) brought together SME&T faculty across disciplinary lines to consider their scholarly roles and responsibilities.	◆ National discussions, leveraged by support from the NSF and private foundations, have led to a broad range of partnerships relating to faculty development.
◆ Poor performance in math and science by K-12 students caused grave concerns about the preparation of K-12 teachers.	◆ K-12 teacher preparation has become a focus for improvement throughout the country. Early results of the NSF Collaboratives for Excellence in Teacher Preparation program—linking schools, institutions of higher education and community groups—are promising.

IN THE NEXT DECADE

Education should be seen as a seamless web from kindergarten to graduate school; then the quality of preparation of K-12 teachers, as well as the quality of preparation of graduate students for academic careers, can be addressed. Building networks at the local (K-16), regional and national levels is needed to give greater credibility, visibility, and support to faculty and teachers pursuing the revitalization of education. The quality of the human infrastructure needed for the success of current national efforts to sustain global leadership, and the cost to build and maintain this infrastructure, must be a concern of legislative bodies, business and industry, funding agencies, and disciplinary societies. Special attention should be given to bringing greater numbers from groups currently underrepresented in SME&T fields into these scholarly networks.

A Faculty Story

The newly arrived student at Mesa Community College (MCC) in Mesa, Arizona looks up her assigned biology professor's web page and finds, " *Welcome to Brad Kincaid's BIO 100— Biology Concepts. A variety of teaching methods will be employed in this course. The methods may be different from those you are most familiar with, but they have been selected to facilitate learning in a variety of ways. No one approach is best for all students, so hopefully one of my approaches will work for you.... As with most of life, you will get out of this course what you put into it. You must take some responsibility for your learning. Work to get the most out of each lecture, discussion, and assignment and think about the applicability and consequences of the concepts we study....To understand our world, you not only need to understand biology.. You also need to know how to ask questions and determine the most reasonable answers to those questions. In short, you need to learn how to learn."*

After receiving an A.A. degree from Big Bend Community College, Moses Lake, WA and a B.S. in Environmental Science from Western Washington University, Kincaid completed his Ph.D. in biology at the University of Houston in 1982. For the next seven years he carried out ecological research as a Faculty Associate at Arizona State University. Then in 1990, something new and different appeared in his list of publications. Following "Tree-ring environment interactions and their assessment," one finds "Using the learning cycle to teach biology concepts and learning skills." Influenced by the biology educator Anton Lawson at Arizona State University, and working with his MCC colleague Peggy Johnson, Kincaid had begun to apply the results of cognitive research to teaching introductory biology. By 1989 Kincaid had decided on emphasizing teaching and educational research at MCC for the next phase of his career.

A unique aspect of Kincaid's BIO 100, supported by the NSF Course and Curriculum Development program, is that it employs a specific learning theory to promote the goals of the course. The learning cycle method used is inquiry-based, consisting of three instructional phases: exploration, introduction of terms, and application of concepts. Students in the MCC course exhibited more positive attitudes toward science, greater comprehension of biology concepts, and greater gains in scientific reasoning skills when compared to students taught with traditional methods (Johnson and Lawson, 1998).

Kincaid and Johnson have also investigated enhancing student learning with computer simulations that will complement the hands-on laboratory. This modification has resulted in improvement in biology achievement, attitudes regarding the collaborative aspects of science, scientific prediction skills, and the reasoning levels of students' discussions.

Kincaid finds that the dynamic nature in his classroom makes teaching especially exciting and enjoyable. He credits Project Kaleidoscope, where he is a member of the Faculty for the 21st Century network, with providing an important national support group and a valuable set of workshops about leadership in effecting change.

Not all of the Life Sciences faculty at Mesa have adopted his teaching approaches, but he is optimistic that new approaches are becoming credible. As Department Chair, he notes that many of the candidates he interviews for adjunct faculty positions are knowledgeable about the new pedagogies that are emerging in teaching SME&T. He has led the design of a new facility for Life Science at Mesa, which supports inquiry-based learning and collaborations and invites participation in science by all. The spaces in this building, shaped today, will shape Life Science education at this community college well into the 21st century.

Faculty Careers

Strong faculty are indispensable to strong undergraduate SME&T programs. Faculty come to this profession with training as scientists, passionate about using the scientific process to understand and add to the body of knowledge. It takes experience and support to be able to share those passions and understandings with students, to know how to shape and reshape courses and curricula, how to plan new facilities and orchestrate the use of emerging technologies, and how to transfer that knowledge.

One of the most important attributes of undergraduate programs that attract and sustain student interest in mathematics and the various fields of science is a cadre of faculty who are as committed to student learning as to their own intellectual endeavors. Another attribute required is institutional support for faculty who are as creative in the classroom as in the research laboratory.

The cultures and reward systems on many university and four-year college campuses, however, value research over teaching. On other campuses, including most two-year colleges, the primary emphasis is on teaching. What is missing in each case is the realization that faculty who remain vital as scientists also prove to be the best educators. The two roles are at best inclusive, not exclusive, and career patterns on all campuses should provide continuing opportunities for renewal in both roles.

Because Ph.D. candidates receive little or no formal instruction in their departments on what it means to teach, or how to profess, many SME&T faculty come to this work woefully unprepared. They teach the way they were taught, without any of the insightful questioning and collaborative efforts that characterize their research. Effective programs that socialize new faculty into the scholarly community are crucial, and many new efforts are emerging to address this need. But faculty need support also as their careers evolve: as they undertake new challenges, teach different subjects, assume leadership roles, and engage in varied types of scholarly endeavors.

The Scholarship of Teaching. How to teach mathematics and science has traditionally been taught in schools and departments of education. Yet, instructors need to have a deep understanding not only of general instructional strategies, but also of special ones which address common difficulties encountered by many students in these subjects. Such strategies are best learned in math or science departments from faculty who have made the teaching of their discipline the area of their own research.

The Physics Education Group at the University of Washington, founded by Arnold Arons and directed by Lillian McDermott, pioneered science education in a disciplinary department by offering the Ph.D. in Physics Education in 1973. Today the group conducts research, curriculum development, and instruction on student learning in introductory college physics, and on the preparation of faculty and pre-college teachers to teach physics as a process of inquiry. Ph.D.s in education in the discipline are now offered

For an activity to be designated as scholarship, it should manifest at least three key characteristics: it should be public, susceptible to critical review and evaluation, and accessible for exchange and use by other members of one' s scholarly community.

These three characteristics are generally absent with respect to teaching. Teaching tends to be a private act (limited to a teacher and the particular students with whom the teacher is engaged). Teaching is rarely evaluated by professional peers. And those who engage in innovative acts of teaching rarely build upon the work of others as they would in their more conventional scholarly work. Through the scholarship of teaching, therefore, we seek to render teaching public, subject to critical evaluation, and usable by others in the community.

Like any other form of investigation, teaching has outcomes. The outcomes of teaching are acts and products of the students' learning. ..An account of teaching without reference to learning is like a research report with no results. It lacks its most essential ingredient.

— Lee Shulman, President,
The Carnegie Foundation for
the Advancement of Teaching.

in at least eight physics departments as well as several biology, chemistry, and math departments throughout the country.

Faculty Networks. One of the most striking steps forward in the past decade is that institutions and national organizations are taking a different look at faculty careers; considerable thought is going into policies and practices in regard to tenure, promotion, and reward criteria in ways that value and encourage participation in educational innovation, including integrating research into the teaching of undergraduates. Some research universities are offering formal programs to prepare graduate students to teach, both as teaching assistants and in future faculty positions. At institutions of all kinds, centers for teaching and learning encourage faculty attention to technologies and to nontraditional pedagogies, stimulate interdisciplinary collaborations, and support efforts focused on student learning.

These local efforts are facilitated by national discussions leveraged by support from NSF and a wide range of other groups. For example, the Pew Charitable Trusts is supporting two efforts: one, by the American Association for Higher Education and the Carnegie Foundation for the Advancement of Teaching, to develop a scholarship of teaching and learning; another, 'Preparing Future Faculty,' is coordinated by the Association of American Colleges and Universities and the Council of Graduate Schools. The focus of the Council of Undergraduate Research is to enhance the careers of faculty actively engaged in research with students. The National

Faculty and Networks

The Leadership Alliance, founded in 1992, is the largest coalition of its kind addressing the shortage of underrepresented minorities in graduate school and the professions. The twenty-seven member coalition includes HCBUs, predominantly Hispanic institutions, and major research universities, including all of the Ivy League. The Alliance also has an affiliation with Tribal Colleges in Montana. The Alliance's Summer Research Early Identification Program (EIP) supports undergraduate minority students in summer programs at the research universities under the guidance of a faculty or research mentor. The program has recently expanded from SME&T to all academic areas, and has added international research sites. In a recent survey of former EIP participants, 101 of the 243 responders (42%) were currently in graduate school.

The BioQUEST Curriculum Consortium, now in its fourteenth year develops and disseminates innovative software designed to help students learn long-term strategies of research within a philosophical framework of problem posing, problem solving, and peer persuasion. The development phase (1986-1993) culminated in the publication of the first edition of *The BioQUEST Library*, which included seventeen modules designed by faculty "innovators." In the second phase (1993-2000), BioQUEST has been very successful in reaching out to and engaging "early adopters," who have adapted materials from *The BioQUEST Library* for their classroom, laboratory, and field curricula. *The BioQUEST Library* grew to 65 modules in Volume V, issued by Academic Press. Over 120 colleges and universities purchased campus site licenses for use of the modules. In addition, *BioQUEST* distributes the free newsletter *BioQUEST Notes* to over 5,000 subscribers, and, with Howard Hughes Medical Institute (HHMI) and NSF funding runs numerous workshops for faculty. Their next goal is the difficult one of crossing the wide "chasm" between "early adopters" and an "early majority" who subscribe to their pedagogical goals.

Faculty for Undergraduate Neuroscience (FUN) was founded in 1991 to provide an opportunity for faculty to engage in dialogue. Because of the explosive growth of undergraduate programs in neuroscience, FUN has been committed to nurturing the growth of undergraduate neuroscience programs in institutions from small liberal arts colleges to large research universities. FUN has worked with Project Kaleidoscope to create blueprints for undergraduate curricula in neuroscience and to offer workshops promoting discovery-based learning at all curricular levels. FUN, with a membership of over 300 faculty, holds annual meetings promoting interaction among faculty who teach undergraduates, gives Undergraduate Travel Awards to attend the Society for Neuroscience Annual Meeting, where it hosts Poster Sessions for undergraduate neuroscience students.

Research Council is undertaking a study on evaluating and rewarding excellence in undergraduate SME&T teaching.

The evolution of activities within the disciplinary society community must be noted. In some cases, efforts bring agents of change together to shape public documents (*e.g.*, the standards for introductory college mathematics published by the American Mathematical Association of Two-Year Colleges, the report on *Shaping the Future of Undergraduate Earth Science Education* from the American Geophysical Union in cooperation with the Keck Geology Consortium, and the *Chemistry in Context* materials from the American Chemical Society). Most major disciplinary societies provide opportunity for faculty to present innovations and materials about their experiences in classroom and lab at disciplinary meetings and through print and electronic journals, such as those found on the web pages of the American Institute of Physics and the American Society for Microbiology.

Some networks emerging from these efforts, such as Project NeXT sponsored by the Mathematical Association of America and the Engineering Education Scholars Program supported by NSF, are focused on the early career development of faculty. Project Kaleidoscope (PKAL), begun in 1989, has become a major informal national alliance addressing faculty career development at all stages. The involvement of administrators in PKAL networks has fostered greater attention at the campus level on the investments needed to build faculty careers that are productive over the long-term.

In all of this, what is important is that boundaries are being dissolved as young faculty join with pioneers of reform, and as faculty in one discipline draw on the experience, expertise and support of like-minded colleagues across mathematics, engingeering, and the various fields of science. The pervasiveness of electronic conversations and the growing awareness of archives of appropriate materials will continue to shape networks and faculty development programs.

K-12 Teachers

In the United States today, improving public school education in mathematics and science is a major concern of government, the press, and citizens in general. In 1999, the Governor of almost every state highlighted concerns about the quality of teachers and the preparation of teachers in his or her *State of the State* address.

During the past decade, scrutiny and criticism of teacher preparation has increased, particularly in mathematics and science. Questions have been raised about teachers' mastery of the disciplines they teach, in some of which, like biology, new knowledge appears at a rapid pace. However at many colleges and universities, there is little collaboration between the mathematics and science departments and the education faculties that have primary responsibility for teacher preparation. The scrutiny has led to improvement at some institutions: Apparently it is better to be complained about than ignored.

The NSF Collaboratives for Excellence in Teacher Preparation. This program was launched as a major nationwide program in 1993 in order to help build bridges among all stakeholders in teacher preparation. The program is geared to "pre-service" students, i.e., students preparing to teach for the first time. NSF and other agencies also sponsor programs for "in-service" teachers to continue their professional development.

As of 1998, the seventeen Collaboratives involved 175 institutions, of which 69 were two year colleges. Implementation was carried out by over 1200 faculty and nearly 1300 K-12 teachers and administrators. Of the 76,000 plus undergraduate students, 42.5% were minorities. The inclusion of two-year community colleges in the Collaboratives is of great importance, not only because many future teachers begin their education there, but because these colleges tend to take a more pragmatic approach to dealing with regional problems than do more "ivory tower-like" universities.

Teacher Evaluation. In recent years, each State has adopted standards for K-12 student performance, informed by national standards. In Tennessee, which has a state-wide data base capable of generating robust statistics, studies have clearly shown that the single largest factor affecting academic growth of student populations is the effectiveness of individual classroom teachers (Haycock, 1998). In the future, data of this type will help to further identify the qualities that make teachers effective in promoting student learning.

Teacher Preparation

In California's Silicon Valley, as in the rest of the country, teaching science and mathematics in K-12 schools is not highly ranked as a career choice. The cost of living is high and the expanding computer and biotechnology industries offer attractive jobs at substantially greater salaries. Not surprisingly, there is a shortage of mathematics and science teachers. Indicators predict the situation to worsen as the population increases due to the baby-boom echo, and as experienced teachers retire.

Now entering its fourth year, The San Francisco Bay Collaborative for Excellence in Teacher Preparation is beginning to turn the situation around. Funded by a five year, $5.5 million grant from NSF, the Collaborative, known as MASTEP (Mathematics and Science Teacher Education Program) involves San Jose State and San Francisco State Universities, four community colleges (San Jose City, Evergreen Valley, City College of San Francisco, and College of San Mateo), local industry and government laboratories (e.g., Genentech, Intel, the NASA Ames Space Center) and informal institutions of education. MASTEP's goals are to improve the preparation of science and mathematics teachers, attract an increased number of talented students into the teaching profession, and provide a support system for new teachers who are prone to "burn out." Approximately 40 selected elementary, middle and high schools are involved. Non-academic MASTEP partners contribute guest speakers, field-trip sites, training personnel, and summer jobs.

In its first three years, MASTEP has made significant strides. In California, prospective teachers first complete a bachelor's degree, majoring in an academic discipline, and then must take a year of education courses. This system provides little visibility for teaching as a career during the undergraduate years. In what is probably MASTEP's most successful program to date, "Future Teacher Clubs" were initiated on each college and university campus. The clubs meet every other week for educational activities. This network of "pre-ed" students has attracted a strong cadre who wish to consider teaching as a career, but were previously reluctant to declare such an interest because of low peer esteem of the choice. The clubs are now fully chartered, and like other student organizations, receive a budget from the institution. A great deal of social "bonding" takes place. At San Jose State University, the number of students who have declared their interest in going into teaching has increased from about a dozen to 200; in MASTEP as a whole, there are now about 400 students interested in a teaching career. Outstanding K-12 teachers have participated in recruiting more students into teaching.

MASTEP has also set up a New Teacher Support network, in which new and veteran teachers are electronically linked. This site contains sample lesson plans, links to web resources, and multimedia classroom exercises. New teachers can obtain budgetary support for innovations in the classroom. The annual number of science teachers being certified at the participating universities has more than doubled since formation of MASTEP; retention rate of new hires has also increased substantially.

However, there is still a long way to go. A panel of new teachers reported that the most frustrating part of their work has been to have their efforts at improving the curriculum discouraged by some veteran teachers. At the colleges and universities, efforts to change faculty thinking to be more accepting of teaching innovation as a major disciplinary activity are achieving positive results very slowly.

The success of the Collaboratives will depend on whether good practices introduced under the NSF grant will be maintained when the grant terminates after five years. Professor Daniel Walker, Principal Investigator of the MASTEP grant, is optimistic. The Future Teachers Clubs will be funded from institutional funds, and there is a possibility for obtaining State funding for the new teacher networks. The industrial partners are expected to continue their generous support for what is clearly a very beneficial activity for the local community, a model for state-wide and national efforts.

That significant internal and external resources have been expended over the past decade to maintain strong undergraduate SME&T programs is clear from stories presented here. Studying many institutions with demonstrable success in serving all students, we see clear evidence of institutional priorities and careful leveraging of external grants.

Reform is a costly undertaking. Keeping the physical infrastructure up-to-date and safe is just one aspect. Keeping SME&T faculty current with scientific, technological, and pedagogical advances; developing up-to-date curricular materials; and building networks of faculty and administrators to support these key common goals—faculty professional development—are other costs.

Federal Agencies. Many federal agencies, including the National Science Foundation and National Institutes of Health, support SME&T faculty and programs at the undergraduate level. The Fund for the Improvement of Postsecondary Education (U.S. Department of Education) has made a major contribution by providing seed grants for approaches to systemic problems, as well as risk-taking efforts to address new opportunities.

*The National Science Foundation***.** A mid-1980s National Science Board report set forth a national agenda to strengthen undergraduate SME&T and called for NSF to take the lead in this effort. From a modest $5 million for a college laboratory improvement program in 1985, the Division of Undergraduate Education (DUE) [Directorate for Education and Human Resources] now has a budget of about $100 million. These funds support developing and adapting exemplary curricula and programs, leading to institution-wide implementation of quality instruction. DUE programs are designed to increase the level of achievement of all students in SME&T, with a special emphasis on teacher preparation. The DUE National Digital Library effort is now contributing to developing the platform, protocols, and resource content for this virtual facility. In the 1990s, attention to undergraduate programs has been visible in all NSF directorates, with support totaling over $200 million (1997). Research directorates support faculty and student research, and join with DUE in funding grants for the integration of research and education and institution-wide reforms.

State Governments. With the vast majority of undergraduates enrolled in public (state) institutions, funding decisions by state legislators and governors play a crucial role in the health of SME&T education. While there has been great variability among the states in the priority given to public higher education, a broader groundswell of interest, and in some cases support, is becoming visible.

Private/Corporate Foundations. Major private /corporate foundations have also had a significant impact. A quick analysis of available data suggests such support has increased at least sixfold during this period. These foundations, reflecting priorities of founder or sponsor, have supported the development of partnerships across disciplinary, geographic, and sector boundaries (*e.g.,* the Keck Geology Consortium funded by the W.M. Keck Foundation; the Pew Science Clusters funded by The Pew Charitable Trusts; the regional affiliates of the M.J. Murdock Charitable Trust).

A major Howard Hughes Medical Institute program enables a select group of institutions to enhance the quality of undergraduate biology/biomedical education by supporting faculty and curricular development, facilities renewal, and student/faculty research. Faculty research has been a focus of grant programs at The Camille and Henry Dreyfus Foundation, Inc. and the Research Corporation. The Kresge Foundation is now the only national supporter of facilities projects.

Corporate programs, such as the Boeing Outstanding Educator Award, and grants from the Exxon Education Foundation (now ExxonMobil Foundation) for the PKAL Faculty for the 21st Century network and Project NeXT for new mathematics faculty, offer additional evidence of the value of external support.

In the Next Decade. The increased investment in undergraduate SME&T is encouraging, particularly as we consider the cost of not making such an investment. The continuing support of federal agencies and state governments, together with long-time private supporters such as the Arnold and Mabel Beckman Foundation, Sherman Fairchild Foundation, the Shell Oil Company and those named above, is critical at this time. The emergence of new foundations, such as The David and Lucile Packard Foundation and the Bill and Melinda Gates Foundation, and the attention of mainstay foundations such as the Carnegie Corporation of New York and the Alfred P. Sloan Foundation, will also play a significant role in the national effort in the next decade.

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ABOUT PROJECT KALEIDOSCOPE

1989: With support from the Directorate for Education and Human Resources/Division of Undergraduate Education–National Science Foundation, a group of academics meets to outline an agenda for reform of science and mathematics in liberal arts institutions; organize as Project Kaleidoscope (PKAL).

1991: The PKAL vision of *what works* is presented at a Colloquium at the National Academy of Sciences and in PKAL *Volume I– What Works: Building Natural Science Communities*.

1992-1998: Phase II begins with workshops on planning undergraduate facilities for SME&T programs. PKAL's *Volume II– What Works: Resources for Reform* is published. With support from the Fund for the Improvement of Postsecondary Education, U.S. Department of Education and continuing support from DUE/EHR-NSF, the workshop series expands to address reforming introductory courses, developing a research-rich environment, and establishing supportive institutional practices. PKAL sponsors national events bringing together major stakeholders in undergraduate SME&T. The work of PKAL now connects to institutions of higher education in all sectors of the community: two- and four-year colleges, comprehensive, doctoral, and research universities.

- PKAL begins to build a network of SME&T faculty with potential to play a leadership role at the local and national levels into the next decade. This network, **PKAL Faculty for the 21st Century**, is supported by the Exxon Education Foundation.
- Ensuring the persistence of local efforts toward reform is a goal of the **Keck/PKAL Consultant Program**, supported by the W.M. Keck Foundation.
- Realizing the relationship of good spaces and strong programs, PKAL mounts a major effort to assist colleges and universities in planning new **spaces for science**. PKAL *Volume III– Structures for Science: A Handbook for Planning Facilities for Undergraduate Natural Science Communities* is published, and workshops are sponsored that bring academics and design professionals into dialogue.
- With an increasing focus on assessing institutional efforts toward reform, PKAL convenes a group of **Core Institutions**, with support from the Fund for the Improvement of Postsecondary Education (U.S. Department of Education).
- The **PKAL Web Site (http://www.pkal.org)** serves as a means to connect and communicate with faculty and their administrative colleagues.

1999-2000 & Beyond: PKAL is part of the larger and growing effort to build an undergraduate SME&T community that serves the interests of students and science most effectively. Over the past decade, nearly 4000 academics, representing over 700 colleges and universities—large and small, public and private, from all geographic regions—have participated in PKAL-sponsored events and activities. Of special note is that the PKAL Faculty for the 21st Century network now includes 945 members. In the coming years, PKAL's focus will continue to be on developing informed teams for renewal at the campus level, as well as on increasing public understanding of how a strong undergraduate SME&T community serves the national interest.