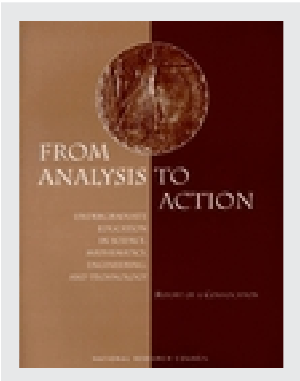

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FROM ANALYSIS TO ACTION

UNDERGRADUATE EDUCATION IN SCIENCE, MATHEMATICS, ENGINEERING, AND TECHNOLOGY

Report of a Convocation

Center for Science, Mathematics, and Engineering Education
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FROM ANALYSIS TO ACTION

UNDERGRADUATE EDUCATION IN SCIENCE, MATHEMATICS, ENGINEERING, AND TECHNOLOGY

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 train many of the technical support personnel who will keep our technological society functioning smoothly in the years to come.

Today, a quiet revolution is under way in the teaching of undergraduate science, mathematics, engineering, and technology. Courses that have resembled nothing so much as their 19th century precursors are beginning to change, as students and instructors realize that employment and citizenship in the 21st century will require radically different kinds of skills and knowledge. A new generation of faculty is questioning the contemporary constraints of academic life and looking at new ways to balance the teaching of students with other priorities. Departments and institutions are acknowledging that their responsibilities extend beyond producing the next generation of scientists, engineers, mathematicians, and technicians; they are recognizing that the challenge also is to equip students with the scientific and technical literacy and numeracy required to play meaningful roles in society.

How did this revolution get started? Undergraduate education in science, mathematics, engineering, and technology has been a collage of successes and disappointments. On the success side, the diversity of institutions and courses of study in these subjects gives students a lengthy menu of options and opportunities. Many students emerge from these courses with valuable skills that have immediate application in their lives and their jobs. Undergraduate education continues to produce highly motivated and capable students who will go on to graduate school and become the scientists, engineers, and mathematicians upon whom our society so heavily depends.

But in addition to these strengths are some emerging weaknesses.

– *Many undergraduates do not receive enough education in these subjects. From some of the most prestigious institutions in the country, it is possible for students to graduate with not more than six percent of their work in the sciences and technology.*

– *Many classes rely on textbooks heavy on "coverage" but weak on example, so that students are exposed to encyclopedias of fact without ever engaging in the process that is science.*

– *Drop-out rates from science major programs are alarmingly high.*

– *Faculty members who teach in the sciences, mathematics, and engineering often are occupied with exciting programs of investigation, but their students only rarely get to experience these programs.*

– *Future science teachers for elementary and secondary school programs, who are essential if there is to be overall improvement in the system, are not being encouraged and are not graduating in adequate numbers.*

– *Leaders in research intensive, high-technology industries increasingly complain that the graduates they recruit lack vital knowledge and skills they will need in the workplace.*

THE CONVOCATION

Administrators, faculty members, and students involved in undergraduate science, mathematics, engineering, and technology education are now engaged in a Year of National Dialogue that is meant to consolidate and extend areas of strength and efforts to remedy weaknesses. The Exxon Education Foundation is sponsoring four major regional symposia and a number of smaller forums through 1996 to focus attention on important issues and build consensus on promising approaches. The National Research Council and National Science Foundation have initiated a number of other activities that will examine all facets of undergraduate education in science, mathematics, engineering, and technology. The aim is to establish a common vision of what undergraduate preparation in these vital subjects should be, and how higher education can achieve that vision.

The Year of National Dialogue was inaugurated by a national convocation held at the National Academy of Sciences in Washington, D.C., on April 9-11, 1995. Co-sponsored by the National Research Council and the National Science Foundation, the convocation brought together representatives of all the major segments of higher education for the first time under the auspices of the nation's most august scientific, engineering, and medical academies. Participants represented two-year colleges, technical schools, liberal arts colleges, comprehensive institutions, research universities, professional societies, foundations, and government. The gathering embodied both the diversity and the unity of higher education.

Before the convocation, all participants received a 44-page "challenge paper" that laid out the central issues and posed a number of questions for discussion. The paper was divided into three broad sections. The first focused on the goals of undergraduate education in science, mathematical engineering, and technology; the second on how faculty could contribute to achieving those goals; and the third on the role of institutions in meeting the goals of undergraduate education. Each section of the paper, in turn, considered four or five specific issues, which formed the basis for discussions during small-group workshops at the convocation.

The conclusions and recommendations that emerged from the workshops, which are summarized in the appendix to this report, underwent several subsequent levels of refinement and consolidation. First, workshop representatives from each of the three broad categories came together to compare and combine their findings. Then the workshop representatives and convocation leaders sorted themselves by professional roles—college presidents and deans, tenured faculty, foundation representatives, and so on—to do a cross-cutting analysis of the recommendations. The result was a set of findings that commanded widespread agreement among the almost 300 convocation participants.

This report, which is a product of the steering committee for the convocation, summarizes the main conclusions of the event. Given that the convocation involved several hundred participants with diverse backgrounds and points of view, finding common ground was not an easy task. Science education, unlike the doing of science itself, is an activity for which outcome measures are difficult to obtain and in which "evidence" in the usual sense is often unavailable. Judgment, experience, and opinion often have to substitute for data. Given these limitations, a remarkable degree of consensus emerged from the convocation with regard to the basic directions of prospective change.

MAIN RECOMMENDATIONS

The phrase "science literacy" occurred repeatedly during the discussions, perhaps more often than any other term. Its prominence reflected two convictions: that science *training* is good preparation for a wide variety of societal roles; and that the nation will depend increasingly on a citizenry with a solid base of scientific and technical understanding. If Americans are not "literate" in this sense, they will be unable to participate meaningfully in resolving the large proportion of national issues that have heavy scientific and technical content.

Science literacy means the capacity to understand, at least at an elementary and inquisitive level, the phenomena of nature and the products of human technological endeavor. How do wetlands "filter" water supplies? How do our muscles work? How is it that a boat can sail at a speed faster than that of the wind propelling it? The "outside" world—our environment—and the "inside" world—our bodies—constantly raise such questions for us. The answers not only give us understanding and an enhanced joy in both worlds; they ultimately equip us to make wise and humane decisions about the problems our society faces—from ozone holes to health care policy, from risk assessment to family planning.

Thus one recommendation emerged from all the others as conveying a fundamental conviction of the assembled group:

– *All students should have access to supportive, excellent programs in science, mathematics, engineering, and technology, and all students should acquire literacy in these subjects by direct experience with the methods and processes of inquiry.*

This conclusion, though simply stated, is audacious in its implications. It looks to a future in which science, mathematics, engineering, and technology education incorporates open-ended investigations in which students are fully engaged with the ideas and methodologies of the disciplines they are studying. It looks to a future in which many undergraduates get degrees in science, mathematics, or engineering not because they necessarily want to work in those fields but because those subjects are superb training for whatever it is they want to do. It looks to a future in which English majors, for example, emerge from college not fearful and distrustful of science and technology but familiar with their basic principles and outlooks—and in which science majors can express themselves fluently, both orally and in writing, as a result of the experiences they have in college.

Three other broad conclusions emerged from the convocation—one from each section of the challenge paper—that provide means for achieving this overarching goal. First, convocation participants concluded that:

– *Departments and programs should define their missions and establish explicit educational goals; they should be evaluated against those goals by fair assessments that are as rigorous as those applied for research; and they should be rewarded both as groups and as individuals for success in reaching these goals.*

This conclusion calls for major changes in the culture that presently surrounds undergraduate teaching. It requires that departments and institutions come together to establish common objectives that actually have an effect on what transpires in classrooms, laboratories, and seminar rooms. It requires that assessments of teaching and learning be devised and implemented that can drive progress toward agreed-upon goals. And it implies a collective responsibility for instruction, as opposed to the current laissez-faire tradition that leaves the instruction students receive entirely in the hands of individual faculty members.

The second conclusion focuses more explicitly on the responsibility of faculty. It states that:

– *Institutions must promote a new balance and a new linkage between teaching and research, so that teaching is enlivened by investigation and research is defined more broadly, and so that faculty may be rewarded for educational scholarship as well as for other kinds of scholarship.*

Considerable uncertainty surrounds the vital matter of what institutional value is attached to the different kinds of professional work. Faced with this uncertainty, faculty members are apt to stress the one activity for which relatively clear objectives and rewards exist: research that results in peer-reviewed publications. Yet the distortions that result from a single-minded attention to research divorced from teaching are evident: buy outs of teaching time in favor of research; a haunting sensation that time spent preparing a lecture is time taken away from research; admonitions of elders to forget about teaching until one has tenure; funds available for travel to research meetings but not to develop teaching skills; and most of all a virtual absence in many institutions of informed discussion about what makes for good teaching.

Universities need to be more inclusive in their definition of what constitutes both scholarship and teaching. Within the formal curricula there is room for a greatly revised and expanded view of teaching—one that brings it closer to real scholarship and demonstrates the real (though often neglected) linkages between teaching and research. In addition, "scholarship" can and should encompass a much broader range of activities than those now defined as essential for academic success. Examples might include software designed for teaching but unusual in the way it deals with what is known; critical or synthetic analyses of a field; textbooks that take a novel or especially effective approach; case materials or studies that present a policy issue in new light; or even videos aimed at increasing popular understanding of an issue. These might be assembled by the candidate or a committee of colleagues into a special section of achievement devoted to "forms of scholarship related to teaching"—or, perhaps better, scholarship beyond that reported in peer-reviewed scientific or technical journals.

The third conclusion that emerged from the convocation relates to the role of institutions and departments as administrative units in academic life:

– *Institutions and departments should promote educational innovation both through broad cultural change and through providing the resources and support needed for effective teaching.*

Undergraduate education will not change in a permanent way through the efforts of "Lone Rangers." Change requires ongoing interaction among communities of people and institutions that will reinforce and drive reform. And replication is essential: innovations and successes in education need to spread with the speed and efficiency of new research results. With the support of institutions, foundations, and federal agencies, educators need to form "invisible colleges" resembling the national and international research communities.

The convocation noted that the weaknesses of undergraduate science, mathematics, engineering, and technology education are not inherent in the enterprise. There is under way an explosion of new ideas, new technologies, and new methods for improving the quality of undergraduate education in science, mathematics, engineering, and technology. Faculty members are developing classroom techniques and laboratories that engage students more actively in learning. Departments and institutions are creating communities of learners that generate much higher levels of interest in science, mathematics, engineering, and technology. New information technologies are personalizing electronic instruction and are creating groups of learners who, although widely separated physically, are closely linked intellectually. Colleges and universities have established partnerships with businesses, schools, nonprofit organizations, and government agencies that support the missions of all.

The overall picture emerging from the convocation is one of striking contrasts. Twentieth-century science, mathematics, and engineering have become major forces of human progress and social change. They have not only created the technologies on which modern life is based; they have forged an entirely new view of the world, one based on close observation and creative insight. Yet undergraduate education in these subjects—where one would expect to find large and enthusiastic communities of students and faculty—often is hampered by outmoded instructional techniques, discipline fragmentation, and curricular inertia.

ADDITIONAL ISSUES

Beyond the broad conclusions stated above, the steering committee noted the frequent appearance of a number of other issues at the convocation.

There was a strong consensus that the professional training and development of future faculty members places too little emphasis on teaching and teaching improvement. As noted above, this has much to do with faculty rewards and incentives. But organization and the effective deployment of resources also can do much to provide a climate of improvement and the motivation to accomplish it. Institutional centers for teaching and learning, the creation of appropriate physical environments, and support for educational infrastructure can all contribute to the quality of science teaching.

Convocation participants noted that new technologies offer large potential opportunities for enhancing the quality of science teaching. However, “virtual” experiences may not be equivalent substitutes for direct laboratory exercises in many fields. Each form of activity offers different, and in many ways complementary, experiences.

The development and evaluation of new materials (whether courseware, new exercises, or texts) is often haphazard, and new products are frequently not examined systematically or centrally. *Review and evaluation mechanisms*, in other words, are important and often missing components of this kind of improvement.

The *problem of articulation* between educational institutions and between education and the workplace surfaced repeatedly. Clearly, a significant shaping of the possibilities for undergraduate education in the sciences takes place at the precollege level. States and institutions have not done all they might to ensure that some reciprocal attention is given to these transition points. Deeper college and university engagement with science teaching at the K-12 level—for example, through attention to the recently released *National Science Education Standards* and through careful articulation of admissions policies and requirements—would be productive. And a more thorough mutual interaction with science-based industry about transitions between university and workplace could help both participating institutions.

The *needs of K-12 science education* are especially strongly linked to undergraduate education. Not only does a sound precollege program depend on a flow of well-trained science teachers; sound curricula in the college years cannot be developed unless students are given a solid elementary and secondary science background on which to build. John A. Moore, a distinguished scientist and educator who has taught at Columbia University and the University of California at Riverside, puts the problem well:

> *"When the projected reorganization of the K-12 curriculum has been accomplished, students will receive a good grounding in all the sciences and have considerable understanding of the interrelations of the sciences with societal problems. With such a level of understanding the undergraduate curriculum can become far different from what it is today. There will be opportunities for detailed considerations of the individual disciplines, more effective analysis of human problems with a scientific component, and the historical and philosophical aspects of the sciences. There will also be the opportunity for courses devoted to broad interdisciplinary topics that will draw from the sciences, humanities, and social sciences. Undergraduate education can achieve a level far greater and more useful than is now the case—and it should become far more rewarding not only for the students but also for their professors."*

An especially controversial area, already referred to in connection with the balance between research, involves the possible use of institutions and mechanisms primarily associated with the research venture in the interest of improving science education. There is a natural reluctance to "mix missions," and the success of the scientific enterprise makes one hesitant to modify it. Yet its confined success depends both on the recruitment of new practitioners and on the scientific understanding of the polity that supports it. The convocation examined, perhaps cautiously, a range of mechanisms through which the research system might be modified to emphasize the teaching function. These are some of the proposals considered:

– *Professional societies should increase their efforts to incorporate educational research and ideas into disciplinary journals and at annual meetings.*

– *Federal funding agencies, including the mission agencies, should require explicit statements of undergraduate research objectives in all research proposals associated with undergraduate institutions.*

– *Postdoctoral fellows should be given opportunities to integrate teaching and research interests.*

– *Doctoral dissertations should be required to contain material relevant to the candidate's teaching accomplishments.*

CONCLUSION

The synopsis of the convocation that follows contains a number of more specific observations, recommendations, and justifications, some directed at students, some at faculty, and some at educational institutions. But there are, as the synopsis makes clear, roles for many other actors. States have significant responsibilities for public education planning, articulation, and support. The federal government, through innovative educational development and through its huge role in the support of university research, can be a vital force for improvement. Industry is both an important consumer of the human product of educational programs and, increasingly, a source of educational innovation.

Despite the importance of these entities, the protagonists in changing undergraduate education in science, mathematics, engineering, and technology will be those who learn and those who teach. Students now reach college with vastly disparate academic and socio-economic backgrounds, and they often encounter faculty members who have had little experience with such circumstances. The challenge is to make this encounter more productive and rewarding for both groups. The quality of K-12 education for all students needs to be improved by providing the resources, technology, and infrastructure that could enrich the experience. And a faculty "culture" needs to be established in which teaching and advising undergraduates are esteemed activities.

These changes will not come easily. Improvement in K-12 science education is under way and will be accelerated if the *National Science Education Standards* are widely adopted and implemented. But the teachers who will meet those standards must be prepared in our undergraduate institutions to a level more exacting than is usually reached now, and they must be ready to respond to the special needs of minority students and others who, a generation ago, never had a chance at college. We also need to provide an "open" system that can update these teachers as progress in the sciences accelerates.

With respect to the faculty, the academic culture that sets expectations and rewards is changing, but slowly. Most faculty members in our 3,000 or so colleges and universities are trained in a hundred or so research institutions whose values are quite different from those in which many of their graduates will teach. Academic departments often find it difficult to come together on such vital matters as curriculum design and collective responsibility for teaching quality. It is even more difficult for them to collaborate across disciplines to achieve the desired "folding in" of science, mathematics, engineering, and technology with courses in, for example, the humanities.

Despite the daunting character of these difficulties, the convocation left most of its participants with a sense of optimism. Exciting new approaches abound and offer real prospects for enriching undergraduate education. Imaginative initiatives in teaching improvement are widespread and are by no means limited to the most visible institutions. Outreach from universities to K-12 is growing, minority access programs are succeeding, and more graduate students are receiving serious training in how to teach science. The convocation atmosphere was one of excitement and hope—despite the well-advertised resource limitations that bear on nearly every one of the institutions represented there.

This nation has prospered because of its leadership in science, mathematics, engineering, and technology. If our educational system cannot produce the accomplished professionals, technologically skilled workers, and well-educated citizens who can make sound political decisions about issues with high technical content (and today that means most decisions), our leadership in the world will be jeopardized. The developing revolution in undergraduate education is good news for a nation whose future will depend on its ultimate success.

SYNOPSIS OF THE CONVOCATION

UNDERGRADUATE EDUCATION IN SCIENCE, MATHEMATICS, ENGINEERING, AND TECHNOLOGY

The April 9-11, 1995, convocation "From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology" sought to capture, on a small scale, the full diversity of undergraduate education. Its almost 300 participants included people from industry, government, and education; two-year colleges and four-year colleges; liberal arts, comprehensive, and research institutions; all regions of the country; and all levels of the professoriate. The result was three days of provocative conversation that ranged widely across issues affecting higher education.

The convocation was structured in parallel with a 44-page challenge paper sent to participants before the meeting. Following brief plenary sessions, participants broke into small groups to discuss issues raised in the paper. Each group had a chair and rapporteur that synthesized the group's conclusions and recommendations. These findings were then synthesized by three larger groups organized thematically according to issues affecting students, faculty, and institutions. A final round of breakout groups consisting of college presidents, government officials, tenured faculty, non-tenured faculty, etc., discussed issues directly affecting that group before a concluding plenary session announced the major conclusions and recommendations of the convocation, which in turn formed the basis for the preceding report of the convocation steering committee.

This synposis combines material from the challenge paper and from the workshop rapporteurs to provide a more thorough accounting of the convocation proceedings than could be provided in the preceding report. It is organized in the same way as the challenge paper and the convocation, with three broad areas that are each divided into four or five more specific topics. Lists of questions that appeared in the challenge paper are reproduced here in full, though participants did not necessarily address each question. References are from the challenge paper or were mentioned by convocation participants.

This synopsis should not be seen as the consensus recommendations of the group as a whole. But convocation participants raised many important issues and generated a number of intriguing ideas. They are presented here to foster dialogue and promote change of the undergraduate experience in science, mathematics, engineering, and technology.

STUDENTS

What should be the goals of undergraduate education in science, mathematics, engineering, and technology?

Students who enroll in America's two-year and four-year colleges and universities bring with them a wide array of talents, aptitudes, backgrounds, and deficiencies (National Science Foundation, Division of Research, Evaluation, and Dissemination, 1991). Some arrive at college with virtually no scientific or mathematical skills; a few have already done sophisticated research in high school. Some have clear-cut professional ambitions; others have little idea what they want to study or what they want to do after they graduate. Today about 40 percent of all undergraduates are over 25 years old. More of them live off campus than on. More of them are women than are men, and the proportion of minorities is growing steadily (U.S. Bureau of the Census, 1994).

The tremendous diversity of students and of the institutions they attend would seem to defy the setting of widely applicable goals for what all undergraduates should learn and be able to do in science, mathematics, engineering, and technology. Yet the current system, which rarely establishes specific goals beyond those associated with individual classes and courses of study, seems entirely unsatisfactory. Too many students fall through the cracks, either because they are exposed to these subjects very little in college, or because their experience in such courses is so unpleasant that their last formal academic experience with these disciplines is one of disillusionment and frustration (Seymour and Hewitt, 1994).

All stakeholders in undergraduate education need to give more thought to the goals of the enterprise. This examination needs to encompass different educational levels, including individual classes, courses of study, and the undergraduate experience as a whole. It needs to involve different groups within an institution, including individual faculty members, departments, schools, and entire institutions, and different kinds of institutions, including two-year colleges, four-year colleges, business, industry, and government. The goals that are set should be both ambitious and attainable. They also must be measurable, because meaningful assessments are needed to provide incentives and accountability.

General statements of academic mission are usually too vague to drive meaningful change. These mission statements may speak of integrating knowledge or of achieving rigor, but they rarely have any discernible impact on what goes on in the classroom. What is needed are specific objectives, along with means of implementation and evaluation, that reflect both institutional and national perspectives.

This part of the convocation summary considers the educational goals of undergraduate instruction in five categories: providing access to science, mathematics, engineering, and technology for all students; ensuring that all undergraduates become literate in these subjects; educating future precollege teachers; preparing students for technical occupations; and educating majors in science, engineering, and mathematics.

ACCESS

Giving all students the opportunity to pursue careers in science, mathematics, engineering, and technology

Programs to increase access to undergraduate education in science, mathematics, engineering, and technology traditionally have focused on groups that are underrepresented in these fields, and many of these programs have met with considerable success. Among the approaches that have been taken are outreach to surrounding schools, summer and weekend institutes, research apprenticeships, curriculum improvement, financial support, the development of study groups, and increased faculty involvement with students (American Association for the Advancement of Science, 1993a,b; Howard Hughes Medical Institute, 1993, 1994, 1995; Massey, 1989; Matyas and Malcom, 1991; National Science Foundation, Task Force on Women, Minorities, and the Handicapped in Science and Technology, 1989; Project Kaleidoscope, 1991, 1993; U.S. Congress, Office of Technology Assessment, 1988, 1989). In general, the most effective approaches are both comprehensive, in that they touch upon many aspects of a student's life, and extended over time. From elementary school through college and beyond, students need multiple sources of support to remain motivated and prepared for the next level of achievement.

QUESTIONS DISCUSSED AT THE CONVOCATION: ACCESS

- *What are the best ways to increase the recruitment and retention of underrepresented groups in science, mathematics, and engineering at different institutions?*
- *How can all faculty be prepared to support students with different needs, preparations, and backgrounds?*
- *How can higher education ensure that more members of underrepresented groups earn doctorates and become faculty members, so that they can serve as teachers, mentors, and role models for future generations of students?*
- *How can successful models in recruiting and retaining underrepresented groups in science, mathematics, engineering, and technology education be extended to all students?*

Despite steady improvement in many areas, women and minorities remain underrepresented in all but a handful of fields, which argues for a continued effort to recruit and retain members of these groups in science, mathematics, engineering, and technology. But issues of access also need to be interpreted in a broader context. In a country where school-aged ethnic minorities have become majorities in many areas, the rationale for programs focused on particular groups is shifting. Special programs and efforts must be effective for *all* students, not just for certain categories of students.

The need for access extends throughout a student's educational experience. At the K-12 level, all students need access to educational experiences that create high levels of scientific, mathematical, and technological literacy (National Council of Teachers of Mathematics, 1989; National Research Council, National Committee on Science Education Standards and Assessment, 1995). Requirements for entry to college should be at a high level, so that students do not think that expectations are unimportant. Students should not come to college so deficient in science and mathematics that their entire undergraduate education in these subjects consists essentially of remedial courses.

Two-year colleges are an important factor in issues of access, since they enroll over half of the first-time freshmen in the country. These institutions have valuable experience in teaching a diverse student body, and this experience can be a valuable resource for four-year institutions. For example, two-year faculty should be included in development activities with four-year faculty, since each group can learn from the other.

The cost of education is a major issue for today's students, as of course are sources of financial assistance. Considerations of access therefore involve the provision of adequate financial resources for all students, especially the underrepresented. The benefits and costs of providing adequate resources to various groups—for example, through a national scholarship program focused on recruitment and retention—needs to be documented to build public support for such initiatives.

Evaluation plays an important role in programs designed to increase access. To determine the effectiveness of a program, criteria and measurable goals must be established—preferably early in the program to permit midcourse corrections. Studies of different student populations that are structured to permit comparisons can provide data on the effects of programs. A program's success in meeting stated goals should be evaluated before, during, and after intervention.

LITERACY

Science, mathematics, engineering, and technology for all undergraduates

Above all others, one goal has emerged as most important in considering undergraduate education in science, mathematics, engineering, and technology: the need for all students at all institutions of higher education to achieve a basic level of knowledge in these domains.

At the K-12 level, the national standards developed for science and mathematics define what students should know and be able to do in these subjects (National Council of Teachers of Mathematics, 1989; National Research Council, Mathematical Sciences Education Board, 1989; National Research Council, National Committee on Science Education Standards and Assessment, 1995). At the level of two-year and four-year colleges, the great diversity of student needs and institutional objectives makes defining desired levels of literacy more difficult (National Research Council, Committee on the Federal Role in College Science Education of Non-Specialists, 1982; Sigma Xi, 1990). No matter what the institution, however, undergraduates should acquire substantive knowledge in science, mathematics, engineering, and technology. They should understand the basic principles used to explain natural phenomena, and they should be able to connect science, mathematics, engineering, and technology to real-world problems and issues, including personal and social needs. They should understand the processes by which scientists, mathematicians, and engineers investigate and solve problems. They should be exposed to information that is broad and current, and they should acquire the ability to remain life-long learners about these subjects.

QUESTIONS DISCUSSED AT THE CONVOCATION: LITERACY

- *As national standards for science and mathematics are implemented in K-12 education, should institutions of higher education—individually or collectively—develop similar standards for scientific, mathematical, and technological literacy that specify the expected outcomes of undergraduate education?*
- *What responsibility should colleges and universities assume for making up deficiencies in K-12 education?*
- *How could college entrance requirements be changed to produce better preparation among entering students?*
- *How should scientific, mathematical, and technological literacy be defined, and how is it best acquired?*
- *How much attention should technological literacy receive in addition to scientific and mathematical literacy?*
- *Should the same introductory courses serve both future majors in science, mathematics, engineering, and technology as well as arts and humanities students?*
- *Should students be expected to have a breadth of understanding in science, mathematics, and technology or should their experiences allow them to encounter subjects in depth, or both?*
- *Should hands-on laboratories be required for all students?*
- *Is there a simple statement of value added against which the success of science, mathematics, engineering, and technology education can be measured for any type of undergraduate program?*
- *How can faculty in different departments be encouraged to work together so that students see the connections among subjects that are an inherent part of those subjects?*
- *How can faculty in the sciences, mathematics, and engineering become engaged in contributing to courses outside those subjects?*

A variety of educational experiences can achieve these goals, and all that do would be appropriate.

In curricula often crowded with distribution requirements, why should colleges and universities demand literacy in science, mathematics, engineering, and technology? There are several key reasons: Gainful employment in the 21st century often will require a basic level of scientific, technological, and mathematical understanding. All people should be able to make intelligent and informed decisions not only about legislative and public policy issues but also about choices involving science and technology that affect them and their families. And science literacy is a powerful antidote to anti-science beliefs that periodically threaten the rationalistic underpinnings of society (Holton, 1993).

Helping students achieve literacy in science, mathematics, engineering, and technology places demands on faculty members throughout an institution. Faculty members will need to adopt new curricula, teaching styles, and means of assessment. Arts and humanities classes will need to incorporate perspectives based on science, mathematics, and engineering, just as the latter courses will need to teach the historical and cultural dimensions of their subjects. Faculty in all departments will need to work together—overcoming current obstacles to such cooperation—along with individuals from organizations outside academia.

Incoming students have different needs and different levels of preparation in science, mathematics, and engineering, and different courses may be required for different kinds of students. Options range from separate courses rooted in individual departments to interdisciplinary courses that range across science, mathematics, engineering, and technology. Research on the most effective ways of teaching these subjects to students and on the optimum organization of content within such courses could have great practical benefits.

TEACHING

Educating future elementary and secondary teachers

Through the education they provide to future K-12 teachers, colleges and universities have a heavily leveraged influence on American education. An elementary school teacher will influence hundreds of students over the course of a career; a secondary school teacher, thousands. Providing K-12 teachers with the training, resources, and support they need to master these subjects is a powerful means by which to improve the scientific and technical literacy and numeracy of the American public (National Science Foundation, Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers, 1993).

A lack of interaction among science, mathematics, and engineering faculty, faculty in other academic disciplines, and faculty in schools of education is a serious flaw in much precollege teacher preparation. There are many ways to foster such interaction, including formal centers devoted to the preparation of future teachers, standing faculty committees, and department-based programs. Greater interaction could help realize the potential that schools of education have to improve science, mathematics, engineering, and technology education.

Content should not be separated from methods in preparing future teachers. The two should be embodied in the same course or run in parallel. For example, laboratory courses could include special sections for future teachers in which consideration is given to how best to teach the material being covered. Neither should "teacher prep" be a special watered-down version of the regular curriculum.

Practicing teachers have too few options to upgrade their skills and establish meaningful relationships with other professionals. In efforts to address these needs, college and universities can play a central role. One model, based on the agriculture extension stations, would have college-based specialists in science, mathematics, engineering, and technology education charged with developing outreach activities for schools, establishing teacher networks through the college or university, and arranging for internships in institutions of higher education and in business.

These partnerships need to be two-way exchanges. Faculty might work in K-12 settings both to convey their expertise to teachers and to learn from

QUESTIONS DISCUSSED AT THE CONVOCATION: TEACHING

- *What are the best ways for faculty and administrators of science, mathematics, and engineering departments and education departments to work together to integrate the education they provide future teachers?*
- *How can future elementary school teachers acquire the scientific, mathematical, and technological background that will make them effective teachers of those subjects?*
- *How should degree programs that prepare future teachers of science and mathematics be structured?*
- *How can teachers continue to update their knowledge of science, technology, and mathematics as well as their familiarity with new methods of teaching (including the uses of technology in the classroom)?*

skilled teaching professionals. Similarly, master teachers at the K-12 level can help college faculty design undergraduate courses and outreach activities.

Teacher preparation in science, mathematics, engineering, and technology is an area in which much valuable research could be done. An important priority is identifying existing elements of teacher preparation that are effective so that these elements can be incorporated into new courses and curricula.

COMPETENCY

Preparing students for technical occupations

As was emphasized throughout the convocation, education in science, mathematics, engineering, and technology is for more than just future scientists, mathematicians, and engineers. All undergraduates need exposure to these subjects, and one group needs both a thorough grounding in them along with an emphasis on their practical applications—namely, students who will go on to take jobs as technical support personnel. Such students attend both two-year and four-year institutions, and some complete graduate work. Many earn degrees in science, mathematics, engineering, or technology, but some graduate with nontechnical degrees and others enter the workplace directly from high school. The occupations they will enter vary widely, from computer service technician to science laboratory technician to automobile repair technician. These jobs are vital to the functioning of the economy and, in the aggregate, to the nation's international competitiveness (National Science Foundation, Workshop on Science, Engineering, and Mathematics Education in Two-Year Colleges, 1991; National Science Foundation, Workshop on Critical Issues in Science and Engineering Technician Education, 1993).

These students suffer from a lack of public recognition and attention. Sometimes the educational programs directed at them are derided as "voc ed" and assigned a second-class status, despite their growing importance. The first need is therefore for a better definition of technician, one that would enable these individuals to be identified and recognized both professionally and publicly. One possible definition is that a technician is someone who specializes in applying and using technology, has a core credential (often involving two years of higher education and usually no more than four years), and possesses a balance of specialization and breadth. Institutions of higher education, professional societies, and industry can all act to further the recognition of who technicians are, what they do, and why their work is so valuable.

QUESTIONS DISCUSSED AT THE CONVOCATION: COMPETENCY

- *What role should colleges and universities, professional societies, and industry play, individually and collectively, in the ongoing development of standards for the technical work force?*
- *How can the programs of different institutions be linked so that future technicians can move smoothly through educational transitions?*
- *What are the best avenues for professional development for faculty who are involved with educating future members of the technical work force?*

Colleges and universities, industry, and government should continue to collaborate on the preparation of standards and competencies for technician education. In the past, efforts to set standards and competencies in technician education have not always been well coordinated—a problem that requires the sustained attention of those involved in these efforts.

Advisory councils from industry can help shape educational programs in colleges and universities. In addition, state and national oversight bodies can be supportive as well as critical in their monitoring of technician education.

The education of future technicians highlights a major challenge facing higher education: placing content in context. Student and faculty internships in industry, industrial involvement in designing and teaching college courses, and cooperative projects in undergraduate education all promote continuous interaction between educational and industrial partners. An emphasis on flexibility and core competencies would help ensure that institutions of higher education balance broad education with specific training. Hands-on learning, project-oriented courses, distance learning, and the delivery of courses at industrial sites would tie learning to the application of knowledge. Inquiry capabilities, including problem solving, critical thinking, communication, and teamwork are all basic to lifelong technical careers.

DEPTH

Educating the next generation of science, mathematics, and engineering professionals

Two major themes characterize discussions of the education received by students majoring in science, mathematics, and engineering. The first is that, in a society characterized by rapid scientific and technological change, degrees in science, mathematics, and engineering can be gateways to a vast array of careers. In this respect, these subjects should properly be seen as an integral part of a liberal arts education, both for those who major in these subjects and for those who take science, mathematics, or engineering as part of other undergraduate programs (American Association for the Advancement of Science, 1990).

At the same time, the needs of the work force are changing (American Society for Engineering Education, 1994; Committee on Science, Engineering, and Public Policy, 1995). Rapid shifts in the labor market are creating a paucity of jobs in some areas and exciting new opportunities in other areas. This dynamism in the labor market is putting a premium on students who have a broad knowledge of different subjects, skills in synthesizing and communicating information, and the ability to work in teams. Students educated with a narrow disciplinary focus and in solitary learning styles can have difficulties adjusting to such an environment. Indeed, such difficulties are a dominant theme in the complaints voiced by business leaders about contemporary undergraduate education.

Faculty members and departments are responding to the new needs of the workplace with a variety of innovations (National Science Foundation, Division of Undergraduate Education, 1995). Close links between the offerings of different departments are enhancing understanding of the connections among subjects. Some departments are trying to move away from covering as much material as possible while emphasizing the basic concepts and practices on which students can build throughout life. Majors in some departments are doing senior projects grounded in real-world problems that instill skills they will need in their careers. Internships and summer work experiences are adding new dimensions to the undergraduate experience.

To contribute to the breadth required of science, mathematics, and engineering majors, every course should foster "orthogonal skills" that all such majors need, such as communication skills, team participation, and preparation for lifelong learning. Notions of rigor and depth should be expanded to include exposure to these activities, and new forms

QUESTIONS DISCUSSED AT THE CONVOCATION: DEPTH

– *How can majors in science, mathematics, and engineering best combine breadth of exposure with the disciplinary rigor required for an undergraduate degree?*

– *What are the best ways for science, mathematics, and engineering faculty to incorporate historical, social, and ethical issues into courses for undergraduate majors?*

– *How can science, mathematics, and engineering departments accommodate students who arrive at majors through unconventional routes, such as beginning course sequences later in a college career or after a period away from academic study?*

of assessment will be needed to measure success in achieving these outcomes. In addition, departments must emphasize the interdisciplinary links among subjects, which encourages students to develop the foundational knowledge that will be widely applicable during their careers. Each department also must ask whether students who major in science, mathematics, or engineering have too many required courses, leaving too little time for other courses.

Students majoring in science, mathematics, or engineering should have a close interaction with a faculty member on a topic of mutual interest, and not necessarily at the very end of a college career. Investigative laboratory experiences are one option, but there are many others, such as field work or cooperative programs between a college or university and industry.

Many majors receive less than adequate advising. Students need much more information about possible careers, job opportunities, and options for graduate education. Faculty members tend to have a lack of experience and knowledge about career counseling. Both they and their institutions need to provide students with more and better information about educational and career options. In addition, professional societies and businesses can help both faculty members and students learn more about the careers available within and outside a given field.

Finally, colleges and universities should not let the focus on raising standards for all students detract from the continued need to discover and nurture gifted students. This is a valuable group that needs special attention.

FACULTY

How can faculty and their departments contribute to the goals of undergraduate education in science, mathematics, engineering, and technology?

At any given time, a professor may be called upon to be a scholar, teacher, advisor, mentor, administrator, or surrogate parent. It is hardly surprising that so many feel pulled in so many directions at once.

In the face of these competing demands, the rewards associated with various activities can affect behaviors in ways that are both obvious and subtle (Boyer, 1987, 1990; Joint Policy Board for Mathematics, Committee on Professional Recognition and Rewards, 1994; University of California, Task Force on Faculty Rewards, 1991). The faculty member who minimizes teaching obligations to conduct research can be seen as responding to one set of rewards. So is the one who attends a session on research rather than teaching at a professional meeting, or the one who designs introductory courses predominantly to meet the needs of future scientists, engineers, and mathematicians rather than students headed for different careers.

In addition to overt rewards, the broader culture of a department, an institution, and a profession inevitably influences the education offered to undergraduates. In considering this culture, questions such as the following arise: Are faculty members encouraged to reexamine curricula and the effectiveness of their teaching? Are graduate students and adjunct professors given the support they need to be good teachers? Are means of assessment available that can guide teaching improvements? Do departments take collective responsibility for the quality of teaching? Are students given the support they need to succeed, or are they encouraged to switch majors if problems arise?

This section of the convocation summary looks at those issues most directly under the control of faculty and their departments. It begins by examining the curriculum, shifts from “what” and “why” to “how” by discussing new pedagogical techniques and educational technologies, and concludes by looking at the education and professional development of college faculty.

CURRICULUM

The organization and structure of courses in science, mathematics, engineering, and technology

To ensure the integrity of the curriculum it offers, each science, engineering, and mathematics department needs to engage in a dialogue based on the question: "What should students know and be able to do as a result of the courses they take in our department?" This statement of scholarly mission should include an explicit statement of educational goals. The dialog should extend to individual courses and to courses of study and should embrace both majors and nonmajors. It should consider issues of content and pedagogy, and it must lead to assessments that can measure whether established goals are being met.

Departments have traditionally distinguished between courses that serve majors and nonmajors (Alliance for Undergraduate Education, 1990; National Advisory Group, 1989). But the distinction between the two groups is far from clear. Only about half of the first-year students in a four-year college who express an interest in majoring in science, mathematics, or engineering eventually major in those subjects—often because of difficulties they encounter in an introductory course (Seymour and Hewitt, 1994). On the other hand, according to one survey, about 20 percent of eventual science and engineering majors consist of students who did not plan in high school to major in those subjects (U.S. Congress, Office of Technology Assessment, 1988). Even more students might transfer into these fields if not for the early commitment typically required of majors.

To reflect the interpenetration of these two groups, colleges and universities should consider the question of how all courses can serve as gateways to degrees in science, mathematics, engineering, and technology. Introductory courses still can be offered on many levels to accommodate a diversity in backgrounds, abilities, and interests of different students. But introductory courses designed to be the final course in a particular subject can be counterproductive in developing student skills and interests in these areas.

Introductory courses for all students should offer a serious encounter with both the processes and essential concepts of mathematics, science, engineering, and technology. The courses should be problem-driven, emphasize critical thinking, have hands-on experiences, and be taught in the context of topics that students confront in their own lives. Interdisciplinary courses can be particularly valuable in helping students see the links among disciplines and in placing subjects in broader personal, historical, cultural, social, and political contexts.

For majors, undergraduate programs should seek to balance broad exposure to important contemporary topics with significant opportunities for in-depth mastery through direct investigation. Curricular changes that could contribute to these objectives include a reduction in the number of courses required in a major, greater expectations for mastery of cognate courses outside a

QUESTIONS DISCUSSED AT THE CONVOCATION: CURRICULUM

- *What should be the structure and organization of undergraduate curricula in science, mathematics, and engineering?*
- *How can curricula be developed to provide students with a broad and integrated view of science?*
- *What new curricular tools can be developed to enhance scientific, mathematical, and technological literacy?*
- *What kind of faculty rewards and development are needed to drive curricular reform?*
- *How can science, mathematics, and engineering departments be encouraged to create introductory courses that act as pumps rather than filters, especially for women and minorities?*
- *To what extent should curricula be based on case studies versus the coherent presentation of principles?*

discipline (e.g., physicists taking biology), courses that emphasize interdisciplinary links, a greater emphasis on writing (including revision and writing for different audiences), and the development of communication and collaborative skills.

At some point, questions of what is taught must give way to considerations of why something is being taught. With the explosion of knowledge in all disciplines, equating quality with the coverage of as much material as possible is fundamentally misguided. Students need the intellectual tools to explore new areas and topics throughout their lives so that they can respond to change rather than trying to anticipate it by increasing the bulk of acquired "knowledge" (Alliance for Undergraduate Education, 1990).

To gain widespread acceptance, curricular reform needs nucleating faculty members who are both interested in curricula and respected for their contributions within their disciplines. Tenured faculty must take a large share of the responsibility for leadership in reforming educational practices.

PEDAGOGY

New approaches to teaching

As the goals of undergraduate education in science, mathematics, engineering, and technology expand to include such skills as the ability to define and solve problems and facility in oral and written communication, the forms of pedagogy that predominate today seem increasingly incomplete (National Research Council, Committee on Undergraduate Science Education, Draft). Large lectures, an emphasis on demonstration rather than investigation, and content disengaged from context can impart information, but they also can make students passive learners who absorb concepts and facts only long enough to get through the next test.

Many different approaches offer alternatives to straightforward lectures and tightly structured labs (Bonwell and Eison, 1991; McKeachie, 1994). Possibilities include cooperative learning, project-centered classes, investigation-oriented laboratories, courses centered on case studies, self-paced instruction, techniques that solicit immediate feedback on teaching and course content, and so on. These approaches allow students to analyze, criticize, and communicate, even in large classes. They help students take responsibility for their own learning. They also allow students to learn from each other, building communities of learners and teachers that extend beyond the classroom.

A particularly important challenge is to develop opportunities for all students to have direct experience with the processes of scientific investigation. These experiences need not be centered on the laboratory. For example, interdisciplinary courses such as environmental science can provide an effective vehicle for investigative learning.

Cognitive research has much to offer undergraduate education, both in its past results and its potential for further insights (Bok, 1986). Research on differences in learning styles among students, for example, can help instructors engage larger groups of students in learning. Studies of how extensive exposure to television, computers, and video games

QUESTIONS DISCUSSED AT THE CONVOCATION: PEDAGOGY

- *How can faculty create active learning experiences for all students?*
- *How should science, mathematics, and engineering be set in the appropriate contexts?*
- *Which students can benefit from research experiences?*
- *How best can students not involved in research be exposed to the methods and processes of science?*
- *How and to what extent should students be involved in developing new pedagogical approaches?*

has modified the ways in which young people learn can help faculty take advantage of the particular skills undergraduates bring to the classroom.

Departments need to create an environment in which teaching is viewed as an activity worthy of study and improvement. Departments should have available a body of literature on effective teaching. Visiting lecturers could speak on pedagogy as well as research. Journal clubs can periodically be devoted to discussions of teaching. Students themselves should be encouraged to contribute to teaching innovations in the same way that they are encouraged to participate in scientific, mathematical, and engineering research.

The questions that surround pedagogical issues are central to the undergraduate experience. How quantitative should evaluation be? Can rules of evidence be developed for evaluating educational strategies? Research also can shed light on broader issues that relate to the culture of departments and institutions. How do faculty learn about new teaching techniques? How can they be encouraged to adapt and use them?

EDUCATIONAL TECHNOLOGIES

The potential for incremental and radical change in instruction

Although still in their infancy, computer-based information technologies already are bringing powerful educational experiences within the reach of every undergraduate (Jenson, 1993). Electronic networks are creating new forms of interaction among students and faculty, both locally and across great distances. An ever-increasing supply of easily accessible multimedia learning modules are allowing students to supplement or replace regular coursework. Electronic simulations are supplementing traditional laboratories, allowing students to experience science, mathematics, and engineering in new and often more accessible ways. And students are becoming involved in computer-based forms of research as faculties themselves increase their use of these technologies.

So far the changes wrought by educational technologies have been largely incremental. But these technologies also create the possibility of radical change in higher education. Communication technologies can dissociate learning from location. "Virtual universities" are taking shape that link students and faculty electronically, and the potential growth of such institutions is unlimited. Already, undergraduates are participating in interactive discussions from their homes, from offices, from satellite campuses, or from other learning centers. These technologies also can extend research experiences to many more people in many more places. Faculty and students alike would have access to the frontiers of science, mathematics, engineering, and technology both as observers and participants.

These more radical uses of educational technologies raise a number of difficult issues. Some question whether the dynamism of the teacher-student link will be lost if this link occurs electronically. Students value the human element in their education and will not willingly relinquish that element. Educational technologies also may not support all types of learning styles, and centrally dispersed learning may sacrifice the local adaptations that capture student attention.

Yet many insist that these drawbacks can be overcome. If properly structured, they contend, electronically mediated education can not only retain but strengthen person-to-person ties. Furthermore, technology can help reduce the repetitiveness of much teaching, freeing faculty members and students for more productive exchanges.

Software development often is a large-scale enterprise. Development teams need to include experts in pedagogy, content matter, hardware, and software. Such teams also benefit from including representatives of all educational levels—two-year and four-year schools, doctoral and nondoctoral institutions, and graduate schools.

Innovations are of limited value unless they are disseminated, both within a campus and among campuses. A useful model may be a nationwide center that can evaluate prototypes, examine past and current successes, and provide information on useful products.

Faculty members who want to increase their use of information technologies need equipment, training, and incentives if they are to take advantage of these powerful tools. Education of the administration is often equally necessary to develop the necessary infrastructure. The delivery, sup-

QUESTIONS DISCUSSED AT THE CONVOCATION:
EDUCATIONAL TECHNOLOGIES

- *To what extent should the electronic simulation of laboratory experiences be encouraged?*
- *How can equitable access to educational technology be ensured?*
- *Is new and inexpensive technology adequately exploited for real laboratory experiences?*
- *What is the potential of technology to improve classroom presentations?*
- *What is the potential of technology to expand access to continuing education for people already in the work force, including teachers?*
- *How can excellent instructional software be recognized and widely distributed?*
- *How can the creation of a truly global college system be realized?*
- *To what extent might information technologies result in faculties becoming less directly involved with undergraduate students and their teaching responsibilities?*
- *How will information technologies affect class size and the structural design of facilities to house classrooms of the future?*
- *What impact will computing and communications technology have on remote learning, and how will this technology affect pedagogy, faculty activity, and college and university facilities?*
- *What are the implications of information technologies for the development of communities of learners?*
- *To what extent can and should electronic media replace textbooks?*

port, and incentives associated with educational technologies need to be an integrated system.

Despite rapidly falling prices, educational technologies inevitably raise questions of financing and equity. Hardware and software can be expensive both to buy and maintain. Though an increasing number of students own their own computers, some cannot afford them and some have very little familiarity with them.

In considering questions of access to computers, institutions and departments need to establish goals for computer literacy. What should all students know and be able to do with computers as a result of their experiences in college?

PREPARATION AND DEVELOPMENT

Fostering teaching skills

The vast majority of doctorate recipients get their degrees from somewhat more than 100 research-intensive universities, but most of those who enter academia will not be employed in those institutions. They will work instead in the more than 3,000 other institutions of higher education, often focused much more on teaching than on the research they did in graduate school.

Most of these students have little or no preparation for the range of professional challenges they will face in academia. Professional schools generally offer some variant of "professional responsibility" courses for law, business, and medical students, but graduate schools do little for the students they are training to assume positions of responsibility in higher education (Kennedy, 1995; National Research Council, Committee on High School Biology Education, 1990; National Research Council, Committee on Undergraduate Science Education, Draft). Such students arrive on the job with little guidance about how to make the transition from expert learner to novice teacher, or even about what is expected of them as professionals.

To train their students for the full range of responsibilities that many of them will face, graduate schools need to place more emphasis on teaching. To earn a Ph.D., all graduate students should be required to demonstrate their ability and promise as scholars who can represent their field to others. To achieve this goal, departments should consider assigning a teaching mentor as well as a research mentor to students, and dissertations could include a chapter on instructional innovations or scholarship undertaken by the candidate.

Graduate students aspiring to faculty positions should have opportunities for meaningful teaching experiences. Teaching assistants, for example, could redesign junior-level courses and teach upper division courses. Graduate teaching assistants need to receive both careful preparation and continuous evaluation from their departments. Institutions should emphasize, both inside and outside the institution, that having classes taught by teaching assistants is a necessary part of their training.

Departments should inventory and share the steps they are taking to train graduate students for teaching. Departments also could routinely survey their alumni to determine whether the training they provided is adequate for the responsibilities their alumni are assuming.

One change that would alter the dynamics of graduate education would be for graduate students to be supported to a greater extent through education/training grants to departments and to a lesser extent through research grants to individuals (Committee on Science, Engineering, and Public Policy, 1995). This change would help ensure that the education of students remains paramount during their graduate years. Federal agencies also should consider giving postdoctoral awards for scholarship on pedagogy and for teaching residencies.

The transition from graduate school or a postdoc to a first academic job is a critical juncture, both for its effects on training and practice. Candidates for faculty positions could teach a class, which has the effect of both screening candidates and sending a clear signal of what is valued. Candidates might be asked, for example, to develop a draft syllabus for a course they might be teaching, or they might be asked in an interview about how they would teach a difficult concept in the field. The number of papers reviewed for evidence of scholarship should be limited to emphasize the need for a balanced relationship between research and teaching.

Once a new faculty member has been hired, departments should ask that person what is needed in terms of instructional set-up money. Departments also should provide new faculty members with a start-up package of exemplary materials, syllabi, examinations, and other materials pertaining to the courses they will be teaching.

Faculty need opportunities to augment their skills as they progress through a teaching career. Many institutions have taken steps to offer instructional training to graduate teaching assistants and young faculty, including workshops, resource materials, centers for teaching and learning, and evaluations of teaching effectiveness. Such assistance needs to be available for all faculty members, and it needs to draw upon both local and national sources of expertise and experience.

Faculty need much greater access to information and new ideas about teaching and learning. Each discipline should have an archival literature on teaching and instruction that can be used by new and established faculty. Faculty should have internship opportunities available to them that are focused on instruction. Senior faculty could give talks on campus about their approach to teaching; for example, perhaps federal agencies could fund "distinguished teacher" lectureships. Workshops on promotion and tenure could clarify the reward structure for faculty, so that they do not mistakenly assume that only research is a consideration.

Questions discussed at the convocation: PREPARATION AND DEVELOPMENT

- *What training should be provided to graduate students who intend to pursue teaching careers at colleges and universities?*
- *Who should provide this training? Who should determine its content?*
- *What development opportunities should be provided to faculty at colleges and universities to enhance their teaching and advising skills?*
- *Who should provide this training? Who should determine its content?*
- *How should faculty development efforts be promoted, recognized, and rewarded at the departmental and institutional levels?*

INSTITUTIONS

How can institutional reforms contribute to the goals of undergraduate education in science, mathematics, engineering, and technology?

A wide array of constituents are demanding changes in undergraduate education (Wingspread Group on Higher Education, 1993). Businesses want students who are prepared to take jobs available today yet who are flexible enough to adapt to changing circumstances. Parents and students want a high-quality education at a price that does not require them to assume huge debts. State and federal legislators call for more emphasis on undergraduate education, even as budget cuts further increase the pressures on faculty.

Many colleges have been responding to these forces through changes in programs and procedures. But change in higher education—where decision making is collegial and widely distributed—rarely happens quickly. Furthermore, much of the change is likely to be disruptive, in that it will alter expectations for students, faculty, and administrators.

This section of the summary examines undergraduate education in science, mathematics, engineering, and technology largely from the perspective of institutions. It looks at the reward system for faculty and at issues surrounding the resources institutions devote to undergraduate instruction in these subjects. It then looks at the transitions among educational institutions and between educational institutions and the workplace. It examines partnerships between higher education and schools, businesses, professional societies, and other organizations. Finally it discusses the role of federal agencies, foundations, and other organizations in catalyzing reform.

ACCOUNTABILITY

Recognition and rewards

One of the most pressing issues in undergraduate education is how to generate a sense of community, and therefore collective responsibility, for teaching (Massy et al., 1994). This sense of community must be rooted at the department level. It does not imply that everyone in a department does the same thing, but it does mean that the department as a whole does many things well. Institutions can act to further this attribute by rewarding departments rather than individuals with such benefits as office space, laboratory facilities, travel funds, and other things of real value to faculty.

In addition, a sense of collective responsibility needs to extend beyond the faculty. It should encompass graduate programs, professional societies, and federal funding agencies. For example, the National Academies of Sciences and Engineering could make consideration of teaching issues a more integral part of their activities.

QUESTIONS DISCUSSED AT THE CONVOCATION: ACCOUNTABILITY

- *How can an institution clarify its vision of the relationship between education and research?*
- *How can we cultivate institutional environments in which educational issues are viewed as a professional responsibility and as a prominent cross-disciplinary area of intellectual and philosophical inquiry?*
- *What range of activities properly constitutes scholarship?*
- *How can we develop strategies and instruments for evaluating the quality and effectiveness of scholarship, broadly defined, that command the same levels of confidence that we confer upon peer review of research scholarship, based mainly on archival publication?*

Questions discussed at the convocation: RESOURCES

- *To create active learning environments, what is required in terms of class size, instructional lines, classroom space, office space, and study environments?*
- *Is an institution-wide center of teaching and learning needed to provide support and resources for faculty, beyond what can be effectively supplied within departments?*
- *How should the acquisition of instructional technology be planned and financed, and how can provisions be made for professional system managers to keep systems functional?*
- *How can the needs for new and renovated facilities be met given today's financial constraints?*
- *Given likely future constraints on resources, how can all faculty and departments be encouraged to develop ways of doing more with less?*
- *What new models of teaching, facilities, and technology are needed to plan for education in the 21st century?*

The federal government also should consider ways to have teaching accomplishments and priorities reflected in research awards. Reviewers could be asked to take teaching activities into account where appropriate. Grant recipients should emphasize and publicize the substantive outcomes of their educational products, which would help legislators and the public to associate educational value with dollars spent.

Collective responsibility for teaching does not necessarily imply reducing the autonomy of individuals, but it does imply a closer evaluation of teaching. Self-assessments, student evaluations (from both current and former students), and—most especially—careful peer evaluations of teaching can combine to create a composite measure of teaching effectiveness. Change, risk taking, and teaching improvements should all be assessed and rewarded.

In general, institutions must move toward a broad and continuing series of rewards and recognition for teaching that parallel what is given to recognize research. They must empower a group of individuals who can spearhead change among larger groups. Educational change will rarely endure if it arises through the "lone ranger" model, where one faculty member works virtually alone on educational issues.

Good teaching occurs in many different ways. The professor who inspires individual students by involving them in research can be as important to a department's education offerings as someone who can make science, mathematics, or engineering come alive for hundreds of students in a lecture hall. Monolithic adherence to a single style of teaching is dangerous no matter what the style.

By the same token, American science, engineering, and mathematics will continue to prosper in a system in which active researchers are faculty at colleges and universities. The challenge is to improve undergraduate education while maintaining the research excellence that nourishes education.

RESOURCES

Institutional support for undergraduate education in science, mathematics, engineering, and technology

Changes in undergraduate science, mathematics, engineering, and technology education need not be expensive, but they can call for additional resources. Smaller and more interactive classes can cost more, in both materials and personnel, than lectures to large groups of students three times a week. Curriculum development—for example, the writing of new textbooks or educational software—also can require extra resources, as can the development of new teaching skills in faculty members or the provision of additional computer centers and software.

As has been the case throughout higher education, departments of science, mathematics, and engineering have had to deal with constrained resources in recent years (Government-University-Industry Research Roundtable, 1992, 1994; National Science Board, Task Committee on Undergraduate Science and Engineering Education, 1986). Faculty numbers have not kept pace with enrollment increases, forcing larger classes and greater use of adjunct faculty, teaching assistants, and other non-tenured instructors. Laboratory experiences remain constrained, in both quantity and quality, because resources are inadequate.

Changes in the broader culture of teaching also face funding obstacles. For example, travel support, though available for research, is generally absent for education. In addition, funding agencies and other sources need to consider whether institutions should be able to recover the full costs of educational programs they undertake with outside support, rather than assuming that administrative costs and other forms of overhead will be covered essentially as matching grants.

Each stakeholder in undergraduate education has a unique role to play in providing support. Colleges and universities have to prioritize their needs and balance short-term and long-term objectives. State and local governments can recognize the needs of science, mathematics, engineering, and technology education, develop partnerships to supplement resources, and implement other incentives to encourage support. Industry can support colleges and universities in ways that meet their own long-term goals. Foundations can target their support to areas that leverage other resources and that would not be funded otherwise. And the federal government can look beyond the straightforward provision of research support to the broader set of policies needed to build the human resources needed for the 21st century.

Facilities and equipment need special attention. Instructional equipment, instrumentation, and facilities need to be upgraded to reflect the professional environments students will be entering upon graduation. This responsibility is shared by institutions, business and industry, and government.

Accountability is related to resources. One innovation that might generate additional resources is a national ranking for educational quality that would confer prestige upon the institutions that are especially successful in this respect.

Finally, instructional technologies—which are already being used to stretch available resources—could dramatically affect costs through the restructuring of higher education.

TRANSITIONS

Articulation among educational institutions and with the workplace

Education, like learning, needs to be a seamless process, with new knowledge and skills extending and consolidating what has been learned in the past. But the educational system today contains marked discontinuities among educational institutions and between those institutions and the workplace. The result is a substantial loss of human resources. About half of the students who enter four-year colleges and universities do not earn their bachelor's degrees within five years. An even greater proportion of the students who enter Ph.D. programs fail to earn their doctorates (though many earn master's degrees). Many students who transfer from two-year to four-year colleges drop out before receiving their bachelors degrees. And the transition from any of these institutions to the workplace often is marked by an extended period of underemployment and uncertainty.

Considerations of articulation begin in the precollege years. Today, the preparation many students receive in high school is inadequate for college courses in science, mathematics, engineering, and technology. Many students quit taking science and mathematics courses early in their high school years. Because of a lack of agreement on what constitutes proper college preparation, students enter college with widely varying expertise in these subjects. Colleges and universities often fail to communicate their expectations to entering students, or they set those expectations too low to spur better student preparation.

Transitions between two-year and four-year institutions present another source of difficulty. Smooth articulation does not mean conformity, since identical curricula can hamper innovation and change. But obstacles to smooth articulation need to be identified and studied, preferably by teams that have representatives from all the institutions involved. A study of the states in which formal articulation structures are in place could provide much valuable information. How many students desire to transfer from two-year to four-year institutions? How many make that transition successfully? Where did the graduates of four-year institutions begin their college careers?

When students leave college and enter the workplace, their education should have prepared them for many of the challenges they will face. Yet many employers claim that graduates lack certain key skills, such as working in teams, dealing with ambiguity, solving ill-defined problems, and communicating with others. Access to workplace experiences as undergraduates can help impart these skills. Internships and cooperative programs, for example, give students a sense of professionalism, purpose, and community in the workplace. Similarly, students can work on real problems from industry, with the solutions being delivered to an industrial client. Faculty sabbaticals or summer work in industry can foster a greater appreciation for the needs of the workplace, though such programs can be expensive. Industrial employees also can work for a time in colleges and universities to reach students. Faculty development programs can support the teaching of competencies that are needed in the workplace. These experiences should be reflected in the reward structure for faculty and in credit arrangements for students.

Transitions among educational institutions and between those institutions and the workplace are becoming more varied and more complex. Many students return to college after a period of work to learn additional skills or earn a different degree. Modern workplaces require employees who can learn new skills and information continually, whether informally as part of their job or formally in training and development programs. To encourage the lifelong education a rapidly changing society requires, the expenses of education required for changing careers could be made tax exempt.

QUESTIONS DISCUSSED AT THE CONVOCATION: TRANSITIONS

- *What can be done to make college curricula and admissions policies recognize and embrace the standards-based reform of science and mathematics education in the schools?*
- *How can two-year and four-year colleges develop stronger ties so as to support successful transitions for students from the former to the latter?*
- *What role should college-industry collaborations, such as internship programs, play in preparing students for the work force?*
- *In what ways should programs for majors be broadened or enhanced to prepare students for graduate or professional school, particularly for women and minorities?*
- *What is the appropriate design of lifelong education programs, and what should be the relation of these programs to the undergraduate curriculum?*

PARTNERSHIPS

Schools, businesses, professional societies, and higher education organizations

What makes for a successful partnership? Each partnership is unique, but the ones that work best are those where all partners have a stake in the outcome. All partners should be equal and treat the other partners with respect, should participate actively in planning the partnership and setting its missions and goals, and should receive a share of the benefits.

Many different kinds of partnerships between institutions of higher education and other organizations meet these criteria (American Association for Higher Education, 1994). For example, just as colleges and universities can be extremely valuable resources for precollege teachers—providing them with classes, seminars, laboratory experiences, field trips, workshops, summer institutes, technology (including Internet access), and technology training—so, too, can that part of the education community concerned with K-12 education offer much to college and university faculty. Immersed in the challenges of teaching, secondary and elementary teachers possess pedagogical expertise and experience that can have great value at the collegiate level.

Business and colleges also have much to gain from each other. By supporting good teachers, offering internships and technical support, contributing equipment and facilities, and supporting local efforts to secure funds for education, business and industry can strengthen undergraduate education. In return, they gain better access to prepared candidates for work, to faculty members, and to information that can create an advantage in the marketplace. In developing partnerships with industry, colleges and universities need to be aware of both the changes going on in industry (e.g., downsizing), and of concerns within their own faculties that close ties with industry could affect academic freedom. Tax provisions, cooperative programs, and degrees custom tailored to industrial needs can all encourage ties between colleges and businesses. Industrial advisory boards also can help colleges and universities keep up with the rapidly changing needs of the workplace (such as the need for flexibility in job assignments or the need for employees to be more entrepreneurial).

Because many faculty have a closer affinity to their disciplines than they do to their own institutions or departments, professional societies can act as powerful forces for change within the academic disciplines. They can involve broad constituencies in discussions of important issues. They can develop programs to recruit and retain women and underrepresented minorities. They can recognize and reward important innovations in education and extend public understanding and communications. They can develop guidelines for partnerships among institutions, provide opportunities for networking between institutions interested in starting partnerships, encourage institutions to provide appropriate awards for faculty and administrators who establish and run partnerships, and assist in breaking down institutional barriers. Societies themselves can form partnerships, as between science and engineering societies, to pursue issues of common interest, including education.

QUESTIONS DISCUSSED AT THE CONVOCATION: PARTNERSHIPS

- *What are good models of productive collaboration between college and university faculty and precollege teachers?*
- *How can industry usefully support educational improvement in colleges and universities?*
- *What kinds of educational collaborations between businesses and higher education are appropriate?*
- *What is the best role of professional societies in fostering the improvement of education and the valuing a broader definition of scholarship?*
- *How can the educational and outreach activities of professional societies be better coordinated and disseminated across disciplines?*
- *Should federal funds be used directly and indirectly to support disciplinary meetings that create obvious conflicts with teaching?*

Professional societies also can erect barriers to educational improvements. For example, by holding major research meetings in the middle of the school year, professional societies ignore the plight of faculty who have to cancel classes or persuade colleagues to fill in for them if they are to attend. By ignoring educational issues, professional societies send powerful messages about what is valued in a profession.

Partnerships among different types of institutions in higher education deserve encouragement. Higher education organizations offer natural linkages that can help make education reform cumulative and self-sustaining.

FUNDERS

Federal agencies, foundations, and other organizations as catalysts for reform

Many organizations have an interest in helping to improve undergraduate education in science, mathematics, engineering, and technology. But the isolation that plagues efforts to improve teaching afflicts these organizations as well: rarely are their efforts jointly planned or well coordinated. For example, eight different federal agencies spend approximately a half billion dollars each year solely to support undergraduate education, but there is very little joint planning or overall evaluation among these agencies (Expert Panel for the Review of Federal Education Programs in Science, Mathematics, Engineering, and Technology, 1993).

Making educational objectives an integral part of research proposals would help different agencies develop explicit policies and coordination on this issue. It would also provide for more sustained financial support of undergraduate education. Funders need to identify and support leadership by creative individuals, thus helping faculty gain a reputation for teaching activities, and should work to institutionalize isolated innovations. This kind of outside funding can have a significant catalytic role in shaping how institutions spend and use money and which programs they decide to support.

Educational programs need to be evaluated as rigorously as are research programs. Without such evaluation, it is difficult or impossible to improve programs, decide whether to retain or expand them, or provide for accountability. Evaluations also make it possible to publicize the results of educational programs to demonstrate the links between financial support and educational outcomes.

Over the years, foundations also have contributed significant funds and energy to improve undergraduate instruction, and their efforts have had a major impact. When federal funding has flagged, foundations have continued to be a valuable source of support. But the impact of foundation support can be attenuated if programs are of limited duration or if foundations support solutions that do not mesh with institutional needs. Unless reforms are built into the institutional structure, they may wither when funding disappears, individuals leave, or initial enthusiasms fades.

QUESTIONS DISCUSSED AT THE CONVOCATION: FUNDERS

- *What should be the role of different federal agencies in supporting educational quality and improvement?*
- *How can federal efforts be better coordinated?*
- *How can higher education work to ensure that federal programs are appreciated and adequately funded in the future?*
- *How can communication between higher education and governors and state legislatures be strengthened to support educational goals?*
- *Have the contributions of corporations and foundations to undergraduate education been effectively structured and implemented?*
- *Are there useful new mechanisms for the involvement of these institutions?*

CONCLUSION

Making the whole greater than the sum of the parts

Undergraduate education in science, mathematics, engineering, and technology has seen many successful reforms in recent years (Howard Hughes Medical Institute, 1993, 1994, 1995; National Research Council, Board on Engineering Education, 1995; National Research Council, Committee on Mathematical Sciences in the Year 2000, 1991; National Science Foundation, Division of Undergraduate Education, 1995; Project Kaleidoscope, 1991, 1993; Tobias, 1990, 1992). Yet these successes also highlight the difficulties associated with broader change. Innovations are rarely coordinated, so as to build on each other to produce a self-sustaining and expanding community of innovators. Individual programs are continually at risk from a loss of key personnel or funding. Innovations that could make a difference in other settings remain confined to a single institution, department, or instructor. The contrast with scientific innovation is particularly striking. Scientific knowledge is quickly shared and extended, whereas knowledge about teaching and learning is often neglected or lost.

Large-scale reform can be considered along several dimensions. Within individual institutions, such reform can be thought of as engaging and coordinating different departments and many different aspects of undergraduate education, including curriculum, facilities, instruction, student research, faculty development, and support services. This does not, however, necessarily mean that institutions will be successful in their efforts to achieve comprehensive reform by doing a little bit of everything. Experience with systemic reform in K-12 education has shown that some changes are more significant than others. A few major problems within the system may need to be attacked before other changes can be made.

Across institutions, large-scale reform requires coherent efforts at many different sites to build self-sustaining communities of reformers and to combat the "not-invented-here" syndrome.

QUESTIONS DISCUSSED AT THE CONVOCATION: CONCLUSION

- *What institutional changes are needed to make science, mathematics, engineering, and technology learning and teaching more central and important in postsecondary education?*
- *How can needs that cut across traditional structure and disciplines within institutions be met?*
- *Are there indicators of quality in science, mathematics, engineering, and technology education that transcend the great diversity of our undergraduate institutions, populations, and student aspirations?*
- *How can personal knowledge and teaching skill best be combined to increase the effectiveness of teaching?*
- *What responsibilities must colleges and universities assume to achieve and sustain undergraduate instruction in science, mathematics, engineering, and technology that is personal, active, hands-on, enmeshed in communities of learners, and strongly connected to contexts?*
- *How can the disciplinary and institutional isolation that leads to complacency be overcome?*
- *How can the quality of learning be improved in an era of seriously constrained resources?*

These linkages might be among institutions of the same kind (as in the colleges joined in Project Kaleidoscope), among institutions in the same region (as in the clusters of colleges and universities supported by the Pew Science Program in Undergraduate Education), or among university programs in the same discipline (as in NSF's Engineering Education Coalitions or in the Howard Hughes Medical Institute's support for undergraduate biology education).

Change also needs to be sustained over time. Many promising past reforms have foundered when funding expired or interests changed and the inertia of the system reasserted itself. Reformers need to find some way of institutionalizing the process of change, so that the system itself is changed. Regular feedback on a national level—for example, an annual report card on institutional change, or ratings of undergraduate educational programs—could contribute greatly to the momentum of change.

Colleges and universities have been presented with a unique opportunity to remake undergraduate education in science, mathematics, engineering, and technology (Presidential Young Investigator Colloquium on U.S. Engineering, Mathematics, and Science Education for the Year 2010 and Beyond, 1992; President's Council of Advisors on Science and Technology, 1992). The reassessment of national goals set in motion by the end of the Cold War, the demographic changes occurring in the country, the financial constraints affecting many institutions, and the rapidly growing influence of new technologies have contributed to an environment in which fundamental principles are being reexamined. This reexamination will inevitably change higher education. Toward what end depends on the decisions that colleges and universities make today and on the support they get to carry out those decisions in the future.

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